FOP2

April 8-12th, 2012
Chengdu, China

The 2nd International Conference on Frontiers of Plasmonics

Program & Abstract Book

Organizers

Nanoscale Physics & Devices Lab., IOP, Chinese Academy of Sciences
College of Physical Science and Technology, Sichuan University

Organizations

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Nanoscale Physics & Devices Lab., IOP, Chinese Academy of Sciences
College of Physical Science and Technology, Sichuan University

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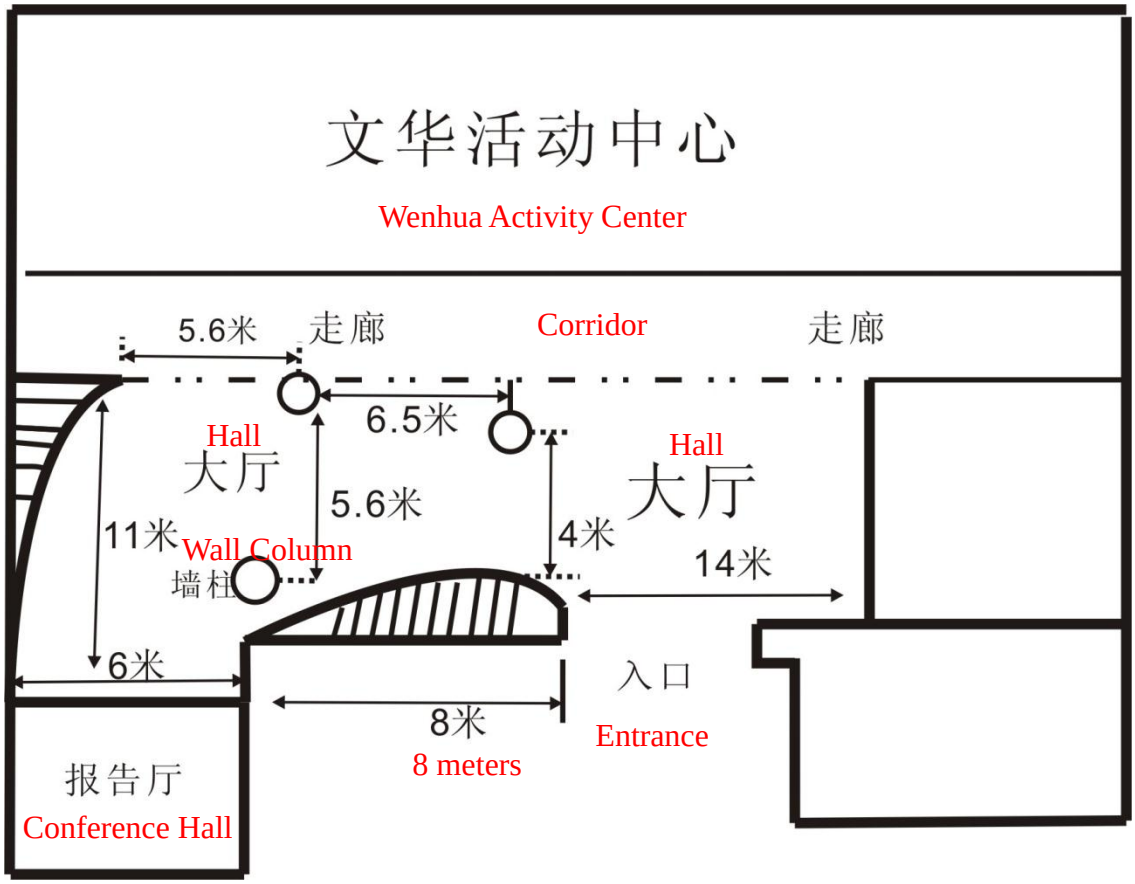
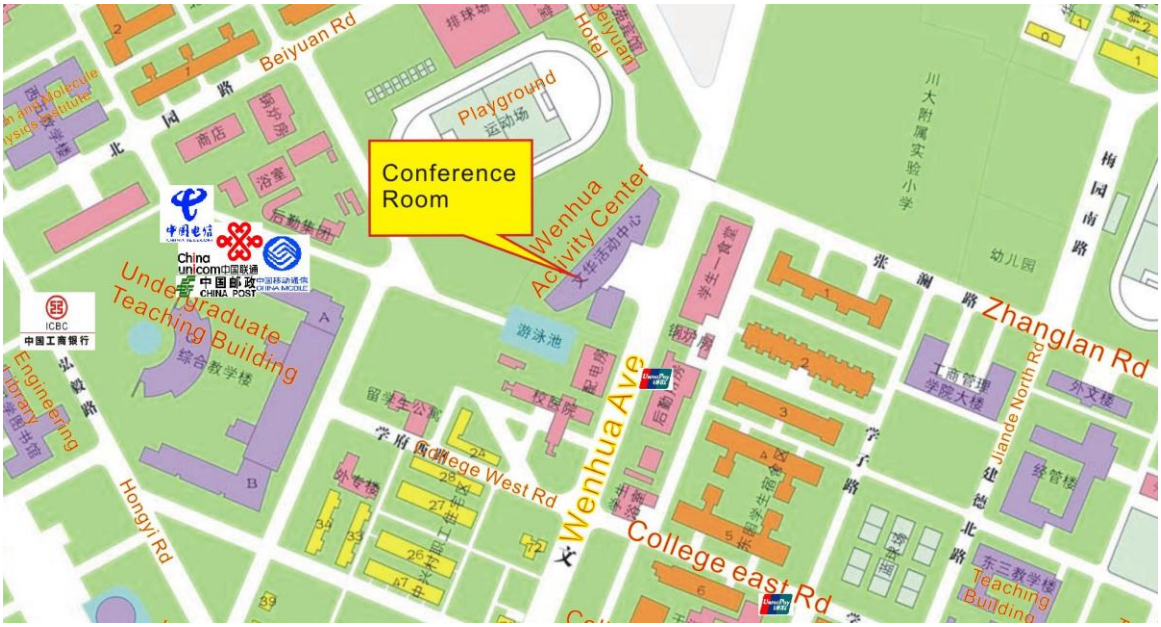
FOP2 Conference Center





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Contents

Program

Abstract book

About FOP

The International Conference on Frontiers of Plasmonics (*FOP*) aims to build a platform for scientists in the field of plasmonics to present and discuss their latest research results, exchange ideas and inspire new thoughts. It is open worldwide to professors, young researchers and students. Inspired by the Nanophotonics workshop of the International Centre for Quantum Structures (ICQS), Chinese Academy of Sciences, in 2009 (which could be regarded as *FOP0*), the First International Conference on Frontiers of Plasmonics (*FOP1*) was successfully held in Xi'an, China, in September 2010. It was co-organized by Nanoscale Physics & Devices Lab., IOP, Chinese Academy of Sciences and Shaanxi Normal University, China, and had 25 invited talks and over 100 participants.

The 2^{nd} International Conference on Frontiers of Plasmonics (*FOP2*) is co-organized by Nanoscale Physics & Devices Lab., IOP, Chinese Academy of Sciences and College of Physical Science and Technology, Sichuan University, China, and it will be held in Chengdu, China, from Apr. 8^{th} to Apr. 12^{th}, 2012. It will cover all aspects of plasmonics, including near-field optics, surface-enhanced spectroscopy, chemical and biological sensing, waveguiding, metamaterials, etc. We anticipate about 35 invited talks and more than 150 participants. The academic activities will include invited talks, contributed talks, poster presentations and tutorial sessions.

Program at a glance

Apr 7, Sat.	Day 1, Apr 8, Sun.		Day 2, Apr 9, Mon.		Day 3, Apr 10, Tue.		Day 4, Apr 11, Wed.	
	8:00-8:30	*Opening ceremony*						
Registration	8:30-9:00	Joachim KRENN	8:30-9:00	Zhongqun TIAN	8:30-9:00	Peter NORDLANDER	8:30-9:00	Katherine WILLETS
	9:00-9:30	Tao LI	9:00-9:30	Stefan MAIER	9:00-9:30	Minghui HONG	9:00-9:30	Che Ting CHAN
	9:30-9:55	Zee Hwan KIM	9:30-9:55	Lei ZHOU	9:30-9:55	Zhenlin WANG	9:30-9:55	Xuanming DUAN
	9:55-10:20	Laura LIU	9:55-10:20	Ruwen PENG	9:55-10:20	Zhiyuan LI	9:55-10:20	Bin REN
	10:20-10:40	*Coffee Break*	*10:20-10:40*	*Coffee Break*	*10:20-10:40*	*Coffee Break*	*10:20-10:40*	*Coffee Break*
	10:40-11:10	Javier AIZPURUA	10:40-11:10	Mikael KÄLL	10:40-11:10	Rainer HILLENBRAND	10:40-11:10	Yoram SELZER
	11:10-11:40	Jennifer DIONNE	11:10-11:40	Q-Han PARK	11:10-11:35	Xiaoguang Li	11:10-11:40	Yiping ZHAO
	11:40-12:00	Xifeng REN	11:40-12:00	Mengtao SUN	11:35-11:55	Zhipeng LI	11:40-12:00	Hui LIU
	12:00-12:15	Junxue FU	12:00-12:15	Wei ZHANG	11:55-12:10	Chongjun JIN	12:00-12:15	Yuan Hsing FU
	12:15-12:30	Thaís Lira Tavares Dos Santos	12:15-12:30	Benfeng BAI	12:10-12:25	Zhiqiang GUAN	12:15-12:30	Yun LAI
	12:30-14:00	*Lunch*	*12:30-14:00*	*Lunch*	*12:30-14:00*	*Lunch*	*12:30-14:00*	*Lunch*
	14:00-14:30	Naomi HALAS	14:00-14:30	Stephan LINK	14:00-14:30	Mu WANG	14:00-14:30	Björn REINHARD
	14:30-15:00	Din Ping TSAI	14:30-14:55	Hongxing XU	14:30-15:00	Jim SCHUCK	14:30-15:00	Gilad HARAN
	15:00-15:25	Zhenchao DONG	14:55-15:20	Hairong Zheng	15:00-15:25	Min QIU	15:00-15:25	Jinglei DU
	15:25-15:45	Deyin WU	15:20-15:45	Tamitake ITOH	15:25-15:45	Xianggang QIU	15:25-15:40	Qiluan Cheng
	15:45-16:00	Huigao DUAN	15:45-16:00	Gao LEI	15:45-16:00	Raymond OOI	15:40-15:55	Thomas SIEGFRIED
	16:00-16:20	*Coffee Break*	*16:00-16:20*	*Coffee Break*	*16:00-16:20*	*Coffee Break*	*15:55-16:20*	*Coffee Break*
	16:20-16:50	Frank KOPPENS	16:20-16:50	Javier GARCIA DE ABAJO	16:20-16:50	Ququan WANG	16:20-16:50	Christy LANDES
	16:50-17:20	Hui WANG	16:50-17:20	Wolfgang FRITZSCHE	16:50-17:20	Shijie XU	16:50-17:05	Paerhatijiang TUERSUN
	17:20-17:40	Jixiang FANG	17:20-17:45	Tahsin AKALIN	17:20-17:45	Chunlei DU	17:05-17:20	Peijie WANG
17:30-19:00 Reception	17:40-17:55	Rongyao WANG	17:45-18:10	Atsushi ONO	17:45-18:00	Pavel DOROZHKIN	*17:20-18:00*	*Closing ceremony*
	17:55-18:10	Zhenghua AN	*18:10-18:50*	*Buffet*	*18:00-19:30*	*Dinner*	18:00-20:30	Banquet
19:30-21:00 Tutorial session	*18:10-20:30*	*Dinner & Dinner for speakers*	*18:50-20:50*	*Poster Session & Snacks + Drink*	*19:30-21:00*	*Tutorial session*		

Conference Program

Venue: Wenhua Activity Center, Sichuan University

Apr. 7, Saturday

Registration	
17:30-19:00	*Reception*
19:30-21:00	*Tutorial Session (by Stefan Maier)*

Apr. 8, Sunday

8:00-8:30	*Opening Ceremony, Chairperson: Hong ZHANG*		
Session Chairpersons: Frank KOPPENS, Zhenchao DONG			
8:30-9:00	Joachim KRENN	Plasmonic Nanowires	University of Graz, Austria
9:00-9:30	Tao LI	Steering Plasmons on Metal Surface	Nanjing University, China
9:30-9:55	Zee Hwan KIM	Driving and Monitoring Photo-Reactions with Gap-Plasmons	Korea University, Korea
9:55-10:20	Laura LIU	Smart Nanoplasmonics for Chemistry and Biology	Rice University, USA
10:20-10:40	*Coffee Break*		
Session Chairpersons: Frank KOPPENS, Zhenchao DONG			
10:40-11:10	Javier AIZPURUA	Close Encounters Between Nanoantennas: Quantum Plasmonics	DIPC, San Sebastian, Spain
11:10-11:40	Jennifer DIONNE	Quantum Plasmon Resonances of Individual and Coupled Metallic Nanoparticles	Stanford University, USA
11:40-12:00	Xifeng REN	Integrated surface plasmon based polarizer and polarization beam splitter	University of Science and Technology of China, China
12:00-12:15	Junxue FU	Ag Nanorods Prepared by Localized Oblique Angle Deposition as SERS-active Substrate	Hong Kong Baptist University, China
12:15-12:30	Thaís LIRA TAVARES DOS SANTOS	Effects of Geometry, Substrate and Angles of Incidence on Resonant Properties of Gold Nanoparticles	Federal University of Pará, Brazil
12:30-14:00	*Lunch Break*		
Session Chairpersons: Zee Hwan KIM, Tahsin AKALIN			
14:00-14:30	Naomi HALAS	Plasmonic Nanosystems: Realizing the Alzar Model and Exploiting Optical Frequency Magnetism	Rice University, USA
14:30-15:00	Din Ping TSAI	Active Surface Plasmon And Toroidal Resonance In Three Dimensional Magnetic Metamaterials	National Taiwan Univeristy, Taiwan, China

15:00-15:25	Zhenchao DONG	Plasmon Mediated Single Molecular Electroluminescence	University of Science and Technology of China, China
15:25-15:45	Deyin WU	SERS and Molecular Plasmonics of Adsorbed Molecules in Metal Nanogaps	Xiamen University, China
15:45-16:00	Huigao DUAN	Charge Transfer Plasmons Across A Few-atoms-wide Bridge	A*STAR, Singapore
16:00-16:20	*Coffee Break*		
Session Chairpersons: Zee Hwan KIM, Tahsin AKALIN			
16:20-16:50	Frank KOPPENS	Graphene: a new platform for capturing and manipulating light at the nanoscale	Institut de Ci ències Fot òniques (ICFO), Spain
16:50-17:20	Hui WANG	Geometry Control and Optical Tunability of Metal-Semiconductor Core-shell Hybrid Nanoparticles	University of South Carolina, USA
17:20-17:40	Jixiang FANG	Mesostructures for enhanced light/matter coupling: synthesis and applications	Xi'an Jiaotong University, China
17:40-17:55	Rongyao WANG	Chiral plasmonic nanosors and its circular dichroism probe for cysteine	Beijing Institute of Technology, China
17:55-18:10	Zhenghua AN	Plasmonic photocoupler design for multicolor infrared photodetectors	Fudan University, China
18:10-20:30	*Dinner & Invited Dinner for Speakers*		

Apr 9, Monday

Session Chairpersons: Wolfgang FRITZSCHE, Tamitake ITOH			
8:30-9:00	Zhongqun TIAN	Plasmon-enhanced Raman spectroscopy	Xiamen University, China
9:00-9:30	Stefan MAIER	Plasmonic Nanoantennas: New design principles and new applications	Imperial College London,UK
9:30-9:55	Lei ZHOU	Gradient meta-surfaces to bridge propagating waves and surface waves	Fudan University, China
9:55-10:20	Ruwen PENG	Transparent Metals for Ultrabroadband Electromagnetic Waves	Nanjing University, China
10:20-10:40	*Coffee Break*		
Session Chairpersons: Wolfgang FRITZSCHE, Tamitake ITOH			
10:40-11:10	Mikael KÄLL	Directional plasmonic nanoantennas for spectroscopy and sensing	Chalmers University of Technology, Sweden
11:10-11:40	Q-Han PARK	Effective medium theory for resonant plasmonic particles	Korea Univeristy, Korea
11:40-12:00	Mengtao SUN	Plasmon-driven chemical reaction in HV-TERS	Institute of Physics, CAS, China
12:00-12:15	Wei ZHANG	Optical properties of super-nanostructures: Hybrid exciton, nonlinear Fano effect, and size-dependent circular dichroism absorption	Institute of Applied Physics and Computational Mathematics, Beijing

12:15-12:30	Benfeng BAI	Novel-concept refractometric nanosensors based on plasmonic nanostructures	Tsinghua University, China
12:30-14:00	*Lunch Break*		
Session Chairpersons: Lei ZHOU, Ruwen PENG			
14:00-14:30	Stephan LINK	Collective Plasmon Modes in Nanoparticle Assemblies: Role of Disorder, Energy Transport, and Active Modulation	Rice University, USA
14:30-14:55	Hongxing XU	On-chip integrated nanoplasmonic circuits and devices for optical computing	Institute of Physics, CAS, China
14:55-15:20	Hairong ZHENG	Substrate Configuration and Surface Enhanced Spectroscopy	Shaanxi Normal University, China
15:20-15:45	Tamitake ITOH	Experimental evaluation of electromagnetic enhancement and blinking in surface-enhanced Raman scattering	National Institute of Advanced Industrial Science and Technology (AIST), Japan
15:45-16:00	Gao LEI	Transparency through a metallic film and non-Reyleigh scattering with anisotropy particles	Soochow University, China
16:00-16:20	*Coffee Break*		
Session Chairpersons: Lei ZHOU, Ruwen PENG			
16:20-16:50	Javier Garc á de Abajo	Graphene plasmonics	IQFR-CSIC, Spain
16:50-17:20	Wolfgang FRITZSCHE	Noble metal nanoparticles as window into the nanoworld	Institute of Photonic Technology (IPHT) Jena, Germany
17:20-17:45	Tahsin AKALIN	State of the Art and Applications of THz Plasmonics and Metamaterials	IEMN-CNRS, Lille 1 University, France
17:45-18:10	Atsushi ONO	Applied plasmonics based on Kretschmann configuration	Shizuoka University, Japan
18:10-18:50	*Buffet*		
18:50-20:50	*Poster session & Snacks + Drink*		

Apr 10, Tuesday

Session Chairpersons: Atsushi ONO, Min QIU			
8:30-9:00	Peter NORDLANDER	Fano resonances in plasmonic nanostructures	Rice University, USA
9:00-9:30	Minghui HONG	Realization of Variable Three-dimensional Terahertz Metamaterials Tubes for Passive Resonance Tunability	National University of Singapore, Singapore
9:30-9:55	Zhenlin WANG	Ultra-Thin Dielectric Coating on Metal Nanoparticles for Surface-Enhanced Fluorescence and Raman Spectroscopy	Nanjing University, China
9:55-10:20	Zhiyuan LI	Trapping, Manipulation, and Patterning of Gold Nanoparticles by Optical Tweezers	Institute of Physics, CAS, China

10:20-10:40	*Coffee Break*		
Session Chairpersons: Atsushi ONO, Min QIU			
10:40-11:10	Rainer HILLENBRAND	Real-space mapping of infrared plasmons on antennas, transmission lines and graphene	CIC nanoGUNE Consolider, San Sebastian, Spain
11:10-11:35	Xiaoguang Li	Quantum Plasmonics: Dynamical Interactions Between Plasmons and Other Excitations	Fudan University, China
11:35-11:55	Zhipeng LI	Propagating surface plasmons on silver nanowires	Capital Normal University, China
11:55-12:10	Chongjun JIN	Non-planar nano-arc-gap arrays fabricated via colloidal lithography	Sun Yat-Sen University, China
12:10-12:25	Zhiqiang GUAN	Excitations of surface plasmon polaritons in double layer metal grating structures	Institute of Physics, CAS, China
12:30-14:00	*Lunch Break*		
Session Chairpersons: Zhenlin WANG, Wei ZHANG			
14:00-14:30	Mu WANG	New Approaches to Tune the Polarization State of Electromagnetic Waves	Nanjing University, China
14:30-15:00	Jim SCHUCK	Putting Plasmonic Probes in Perspective: The Case for the Campanile Tip	Lawrence Berkeley National Laboratory, USA
15:00-15:25	Min QIU	Plasmonic photothermal effects and their applications	Zhejiang University, China
15:25-15:45	Xianggang QIU	Tuning asymmetry parameter of Fano resonance of spoof surface plasmons by modes coupling	Institute of Physics, CAS, China
15:45-16:00	Raymond OOI	Surface Polariton Resonances with Magnetic Materials	University of Malaya, Malaysia
16:00-16:20	*Coffee Break*		
Session Chairpersons: Zhenlin WANG, Wei ZHANG			
16:20-16:50	Ququan WANG	Enhanced Transmission and Emission in Active Plasmonic Hybrids	Wuhan University, China
16:50-17:20	Shijie XU	Enhanced Raman scattering from self-assembled Si nanoclusters grown on siC: Spectrum and Imaging	University of Hong Kong, China
17:20-17:45	Chunlei DU	Recent Progress on super-focusing Plasmonic lenses	Institute of Optics and Electronics, CAS, China
17:55-18:10	Pavel DOROZHKIN	Recent instrumental advances in scanning near-field optical microscopy and tip enhanced Raman scattering	NT-MDT, Russia
18:10-19:30	*Dinner*		
19:30-21:00	*Tutorial Session (by Rainer Hillenbrand)*		

Apr 11, Wednesday

Session Chairpersons: Bjoern REINHARD, Christy LANDES			
8:30-9:00	Katherine WILLETS	Super-resolution imaging of plasmonic nanoparticle hot spots	The University of Texas at Austin, USA
9:00-9:30	Che Ting CHAN	Strong light induced forces in plasmonic resonating systems	Hong Kong University of Science and Technology, China
9:30-9:55	Xuanming DUAN	Plasmonic Metamaterials Fabricated by Multiphoton Photoreduction	Technical Institute of Physics and Chemistry, China
9:55-10:20	Bin REN	From Single Nanoparticles to Tip-enhanced Raman Spectroscopy	Xiamen University, China
10:20-10:40	*Coffee Break*		
Session Chairpersons: Bjoern REINHARD, Christy LANDES			
10:40-11:10	Yoram SELZER	Plasmonic Controlled Molecular Junctions	Tel Aviv University, Israel
11:10-11:40	Yiping ZHAO	Designing Three-Dimensional Silver Nanorod Arrays for Surface Enhanced Raman Scattering Applications	University of Georgia, USA
11:40-12:00	Hui LIU	Manipulating microparticles by laser-induced vapor bubble on metal film	Nanjing University, China
12:00-12:15	Yuan Hsing FU	Generating and Manipulating Higher Order Fano Resonances in Dual-Disk Ring Plasmonic Nanostructures	A-STAR, Singapore
12:15-12:30	Yun LAI	Bending waveguides made of anisotropic epsilon-near-zero metamaterials	Soochow University, China
12:30-14:00	*Lunch Break*		
Session Chairpersons: Bin REN, Yoram SELZER			
14:00-14:30	Björn REINHARD	Optoplasmonic Molecules and Superlenses	Boston University, USA
14:30-15:00	Gilad HARAN	Symmetry and the plasmonic molecule	Weizmann Institute of Science, Israel
15:00-15:25	Jinglei DU	Surface-plasmon-polaritons-assisted nanolithography with high exposure depth	Sichuan university, China
15:25-15:40	Qiluan Cheng	Fourier optics theory for invisibility cloaks and optical illusions	Wuhan University, China
15:40-15:55	Thomas SIEGFRIED	Hidden Fano resonances enable crescent type SERS enhancement	Paul Scherrer Institute, Switzerland
15:55-16:20	*Coffee Break*		
Session Chairpersons: Bin REN, Yoram SELZER			
16:20-16:50	Christy LANDES	3D Transport in Charged and Crowded Environments	Rice University, USA

16:50-17:05	Paerhatijiang TUERSUN	LSPR Biosensing Properties of Metal Nanoparticle Arrays	Xidian University, China
17:05-17:20	Peijie WANG	The study of electron charging of Ag/Au core shell nanorode by SERS	Capital Normal University, China
17:20-18:00	*Closing Ceremony*		
18:00-20:30	*Banquet*		

Poster Session

18:50-20:50, Apr 9, Monday

P-01	Anomalous reflection based on gradient metamaterial *Kuang-Yu Yang[1], Shulin Sun [2,3], Chih-Ming Wang[4], Ta-Ko Juan[4], Wei Ting Chen[3], Guang-Yu Guo[1,3], Lei Zhou[5], Din Ping Tsai[1,3,6,7*]*
P-02	Engineered substrate for metallic nanowires toward high performance plasmonic waveguiding *Shunping Zhang[1] and Hongxing Xu[1,2*]*
P-03	Ultrasensitive Stokes and Anti-Stokes Raman Spectroscopy of benzenedithiol in HV-TERS system *Zhenglong Zhang[1,2], Xiaorui Tian[1], Mengtao Sun[1], Hairong Zheng[2], and Hongxing Xu[1,3]*
P-04	Coupling between semiconductor quantum dots and surface plasmon polaritons *Jinjin Xie[1],Feilong Mao[1], and Zhenghua An[1,*]*
P-05	An exploration of photo detection in restrahlen band with plasmonic cavity *Feilong Mao[1], Jin Xie[1], Qingyan Fan[1] , Lijian Zhang[1], Susumu Komiyama[2] and* Zhenghua An[1,*]
P-06	Electromagnetic field enhancement and the potential application in microwave spin rectification *Fuchun Xi[1], Lei Zhou[2], Zhenghua An[3*]*
P-07	Enhancement UV Emissions from the Ag/graphene/SiO2/ZnO Hybrid Structure via Ag doping graphene *Hong Xiao[1] and Zhenghua An[2,*]*
P-08	Enhancement of Magneto-Optical Effect in Multilayer Heterostructures *Victor Dmitriev, Fernando da S. Paixão, Marcelo N. Kawakatsu, Thais L. T. dos Santos[*]*
P-09	The amplification effect of the anisotropic shape of the plasmonic core by the shell material with high refractive index *Song-Yuan Ding[1], Liang Chen[1], Song-Bo Li[1], De-Yu Liu[1], Hai-Xin Lin[1], Bin Ren [1], and Zhong-Qun Tian[1*]*
P-10	Watching outside while under a carpet cloak of invisibility *De-Lin Wang, J. Z. Zhao, Ye-Qing Dong, Wei Zhang, Qing Hu, Ru-Wen Peng*, and Mu Wang*
P-11	Tunable multimodes and narrowbands in a photonic quasicrystal waveguide *Di-Hu Xu, Qing Hu, Yu Zhou, Dong-Xiang Qi, Ren-Hao Fan,Ru-Wen Peng*, and Mu Wang*
P-12	Exchange of electric and magnetic resonances in multilayered metal/dielectric nanocavities *Ling Qin, Li-hao Zhu, Jia Li, Ming-rui Shao, Kun Zhang, De Li, Ru-wen Peng*, and Mu Wang*
P-13	Modeling of an optical slot antenna *Jong-Ho Choe[1] and Q-Han Park[1*]*
P-14	High-sensitivity nanosensor based on a sparse array of gold nanoparticle chains *Oubo You, Xiaowei Li, Dandan Zheng, Benfeng Bai[*]*
P-15	Plasmonic antenna array at optical frequency based on nanoapertures *Liu-yang Sun, Ren-hao Fan, Cheng Wang, Wu-qiong Sun, Ru-wen Peng*, and Mu Wang*
P-16	Extraordinary optical transmission studies in infrared regime on polycrystalline and epitaxial Ag films *Bo-Hong Li[1], Charlotte E. Sanders[2], James McIlhargey[2], Fei Cheng[1], Changzhi Gu[1], Guanhua Zhang[1,2], Kehui Wu[1], Jisun Kim[2], S. Hossein Mousavi[2], Alexander B. Khanikaev[2], Gennady Shvets[2*], Chih-Kang Shih[2*], and Xianggang Qiu[1*]*

P-17	Effects on enhanced transmission of middle-range rotational symmetry in 12-fold-quasicrystal-like hole arrays *Bo-Hong Li*, Houfang Liu, Fei Cheng, Jing Han, Hong Xiao, Xiufeng Han, Changzhi Gu, Xianggang Qiu**
P-18	Fabrication of high-aspect-ratio nanostructures by template stripping technique *Fei Cheng[1], Denitza Denkova[2], Yuhui Chen[1], Bohong Li[1], Changzhi Gu[1], Xianggang Qiu[1*]*
P-19	Enhancement variation of the gap electric field in gold bowtie nanoantenna arrays *Feng Lin, Chaojie Yang, Shan Huang, Meng Yang, Jie Li, Peipei Wang, Jiaming Li, Xing Zhu**
P-20	Separation of Absorption and Scattering of Metallic Nanoparticles and Its Relation with SERS *Bi-ju Liu, Xiang Wang, Hai-xin Lin, Bin Ren [*]*
P-21	Electrical Detection of Surface Plasmon Polaritons by Quantum Point Contacts of Noble Metals *Naomi Ittah[1], Yoram Selzer*[1]*
P-22	Encoding Photonic Angular Momentum Information onto Surface Plasmon Polaritons with Plasmonic Lens *Aiping Liu[1], Guanghao Rui[2, 3], Xifeng Ren[1,*], Qiwen Zhan[3], Guangcan Guo[1], Guoping Guo[1]*
P-23	Preparation of SiO2: (Tb3+, Ag) nanostructure for luminescent materials and fluorescence enhancement effect research *Zhang Dekai[1,2] Ji Ruonan[1] Yan Zhiyun[1] Zhang Guodong[1] Hu Xiaoyun[1,2*] Hou Xun[1,3]*
P-24	Far-field focusing behaviors of subwavelength planar metallic lenses based on non-uniform rings *Di Feng [1, 2*], Chunxi Zhang[1]*
P-25	A Facial Synthesis of Branched Silver Nanowire Structure *Xiaorui Tian, Fengzi Cong, Hong Wei, Hongxing Xu**
P-26	The localized near-field enhancement of metallic periodic bow-tie structure: an oscillating dipoles picture *Guanhai Li[1*], Lujun Huang[1], Xiaoshuang Chen[1], Weida Hu[1], Wei Lu[1]*
P-27	Quantum mechanical study on plasmon resonances in small sodium clusters with ring structure *Hai-feng Yin[1,2], Hong Zhang[1*]*
P-28	Localized Surface Plasmon Resonance Modes at Edges of Gold Film Patterns *Heh-Nan Lin[*], Sheng-Yung Lo, Jing-Hung Wang*
P-29	Plasmonic characteristics of hybrid Au/GaAs QW structure under electrical injection *Jing Li[1,2], Shunping Zhang[1], Hao Shen[1], Zhensheng Zhao[2], Xuanming Duan[1,2], Hongxing Xu[1]**
P-30	Photocatalytic Activity of TiO2 Nanotube Array Enhanced by Surface Plasmon Resonance *Feng Wu[1] , Xiaoyun Hu[2], Limin Kang[1], Enzhou Liu[1],Wenqian Hou[1],Qian Zhang[1],Jun Fan[1]**
P-31	Focusing light using spiral plasmonic lens *Junjie Miao[1,2,3], Yongsheng Wang[1,3], Zhiping Zhou[2] Qian Liu[1*]*
P-32	The Relationship between Scattering Spectra and SERS Effect in SHINERS *Lingyan Meng[a], Shu Chena, Zhilin Yang[*a], Jianfeng Lib, Bin Renb and Zhongqun Tian[*b]*
P-33	Sub-attomolar sensitivity through directed pre-concentration on super-hydrophobic surface using an SERS optrode *Fansheng Cheng[1], Jianming Hu[2],Changyu Tang[1], Leo Lau[1], Alexandre Brolo[3], Meikun Fan[1*]*

P-34	Fabrication of Ag nanostructure substrate using the femto-second laser for broadband and tunable plasmonic enhancements *Ming Lun Tseng[1*], Yao-Wei Huang[1], Min-Kai Hsiao[2], Hsin Wei Huang[3], Hao Ming Chen[3], Nien-Nan Chu[4], You Je He[3], Chia Min Chang[5], Ding-Wei Huang[5], Hai-Pang Chiang[2], Ru-Shi Liu[6], Din Ping Tsai[1,3,4,7], and Greg Sun[7]*
P-35	Tip-enhanced Raman spectroscopy: from monolayer to single molecules *Xiang Wang, Zheng Liu, Jin-Hui Zhong, Zhi-Cong Zeng, Mao-Hua Li, Teng-Xiang Huang, Bin Ren**
P-36	The Raman spectroscopy studies on the oxygen ion implanted ultrananocrsytalline diamond films *X.J. Hu*, X.H. Chen,H.Hu，S.S. Gu*
P-37	Giant enhancement of near-ultraviolet light absorption by TiO_2 nanoparticles via designed Al nanostructures *Xiao-Lan Zhong*, Zhi-Yuan Li*
P-38	Preparation of 3D network Na2Ti2O4(OH)2 nanotube film and study on light absorption properties *Hui Miao *Xiaoyun Hu Yibo Shang Ruonan Ji Qian Zang Yue Wang*
P-39	Study the effect of dielectric layer thicknesses on plasmonic resonance response of a multilayer (metal-dielectric-metal) nanostructure *Yi-Ping Chen[1*], Ding-Zheng Li[1], and Tsung-Dar Cheng[1]*
P-40	Au-ITO Multilayer Grating: One-way Absorber at 1550 nm *Yufei Wang[1,2], Feiya Fu[1,2], Wanhua Zheng[1,2*]*
P-41	Surface Wave Holography for Wave Manipulation *Yu-Hui Chen , Lu Huang, Jin-Xin Fu, and Zhi-Yuan Li**
P-42	Direct surface plasmon induced reduction of metal salts *Xiaojuan Chen ,Abhishek Lahiri, Rui Wen, Peijie Wang and Yan Fang**
P-43	Simple and Efficient Computational Method to Analyze Cylindrical Plasmonic Nanoantennas with Arbitrary Configuration *K. Q. da Costa[1*], V. Dmitriev[1], J. L. de Souza[1], G. L. Silvano[1]*
P-44	Gold nanorods doped single polymer nanofibers for optical sensing *Pan Wang, Lei Zhang, Limin Tong**
P-45	Reflectionless Ultra-thin Microwave wave-plate based on Metamaterial *Wujiong Sun, Qiong He*, Jiaming Hao, Lei Zhou***
P-46	Strong coupling in plasmonic cavity combined with QWs at THz wavelengths *Lijian Zhang[1],Feilong Mao[1], Jin Xie[2], Susumu Komiyama[2] and Zhenghua An[1,*]*
P-47	Plasmon Controlled Single-Molecule Junctions *Michal Vadai, Nirit Nachman and Yoram Selzer*
P-48	Fabrication of M-shaped Nanogratings Nanostructures as Single-Molecule SERS Active-Substrate by Nanoimprint Lithography *Zhendong Zhu[1,2], Benfeng Bai[1*], Qunqing Li[2],Shoushan Fan[2]*
P-49	Silver dendrites substrate for surface-enhanced fluorescence *Jun Dong, Hairong Zheng*, zhenglong Zhang, Shuai Min, Miao Dai and Junna Li*
P-50	Giant Raman enhancement on nanoporous gold by conjugating with nanoparticles for single-molecule detection *Lihua Qian*, Biswajit Das, Yan Li, Zhilin Yang*
P-51	Collective Excitations in Ultrathin Magnesium Films on Silicon *Xiaoguang Li[1,2,3], Ao Teng[2], Hanno Weitering[2,3], Zhenyu Zhang[4,5,6*]*

Excursions

- *April 12, 2012*- Excursion to **The Giant Panda Breeding Research Institute** (http://www.panda.org.cn/english/index.htm) and **Jinsha Site Musuem** (http://www.jinshasitemuseum.com/homee.asp)

Departure from Wangjiang Hotel and Philharmonic Hotel at 8:30.
Return to the hotels at ~17:00.

Located just 10 km (6 miles) away from downtown Chengdu, the Chengdu Panda Breeding Research Center has been created and imitated the pandas' natural habitat in order that they might have the best possible environment for rearing and breeding. The Center cares also for other rare and endangered wild animals. Giant pandas, lesser pandas, black-necked cranes, white storks as well as over 20 species of rare animals are fed and bred there throughout the year.

Jinsha Relics is the first major archaeological discovery in China in the new millennium and was rated the key reservation unit of the nation. As a theme park-style museum, Jinsha Site Musuem is for the protection of research into and display of Jinsha relics and archaeological finds. The museum covers 300,000 square meters with a total construction area of approximately 35,000 square meters. It is mainly made up of departments of Relics and Exhibitions and the conservation center.

- *April 13, 2012*- Excursion to **Leshan Buda**

Departure from Wangjiang Hotel and Philharmonic Hotel at 8:30.
Return to Chengdu at ~17:00.

The Leshan Giant Buddha is the largest Buddha in China, towering to 71 m, with his 14.7 m head, and 24 m shoulders. The Buddha's ears are 6.72 m long, insteps 8.5 m broad, and big toe 1.5 m long. This carving project was begun in AD 713 and led by a Buddhist monk called Haitong, who hoped that the Buddha's presence would subdue the swift currents and protect the boatmen.

General Information

Transportation

Several bus lines are available at the outside of the campus and it costs 2.0 Yuan RMB. Participants can get nearly everywhere in down town by bus such as No.335 to the Temple of Marquis (Jinli Street) and No.19 to the Du Fu Thatched Cottage. If need, please ask our staffs for your guidance. The taxies are available too and the taxi fee from the university to down town area is normally around 10 to 30 Yuan RMB.

Money Exchange

A branch office of Bank of China is located between the West Gate and the South Gate of Wangjiang Campus, Sichuan University.

Currency and Credit Cards

The unit of Chinese Currency is Yuan (RMB). One US dollar is equivalent to approximately RMB 6.3 yuan. Major credit cards, including VISA, Master Card are acceptable at some shopping centers or stores.

Electricity Supply

The power supply in China is 220 V, 50 Hz. There are two plugs available in each room, one two-hole/line and one three-hole/line. Participants are encouraged to bring the necessary adapter for their electronic devices.

Water

The tap water is not for direct drinking in China. The boiled water is available in every room in the hotel.

Business Hours

Typical business hours in government and private offices are from 8:00 to 18:00 (Beijing Time), and the offices are closed on Saturday and Sunday. Most stores or shopping centers are open from 9:00 to 21:00 or later, and open seven days a week.

Tipping

Tipping is usually not necessary in China. No tipping is expected unless you are provided with extra service.

Emergency Contact (Wangjiang Campus)

Campus Hospital: 86-028-85400120
Security Office: 86-028-85460110

About Chengdu

Chengdu is one of the most important economic, transportation, and communication centers in Western China. According to the 2007 Public Appraisal for Best Chinese Cities for Investment, Chengdu was chosen as one of the top ten cities to invest in out of a total of 280 urban centers in China. It was recently named China's 4th-most livable city by China Daily.

The fertile Chengdu Plain, on which Chengdu is located, is also known as the "Country of Heaven" (天府之国, Tiānfǔzhiguó), a phrase also often translated as "The Land of Abundance". The discovery of the Jinsha site suggests the area of Chengdu had become the center of the bronze age Sanxingdui culture around the time of the establishment of the state of Shu, prior to its annexation by Qin in 316 BC.

ORAL PRESENTATION

O-01

Plasmonic nanowires

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High field enhancements and mode densities make plasmonic excitations an appealing playground for the manipulation of the absorption and emission properties of elementary emitters as molecules, quantum dots or color centers. In this context metal nanowires [1] are a versatile platform, combining highly confined fields with quasi-1D waveguiding. I will discuss, first, plasmon propagation in silver and gold nanowires, emphasizing the role of wire geometry [2], metal crystal structure and roughness [3]. Second, I will discuss the coupling of (individual) quantum dots with nanowires, both for exciting the plasmon with the quantum dot emission and vice versa. In both cases lithographic methods enable the precise mutual positioning of dot and nanowire.

References:

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O-02

Steering Plasmons on Metal Surface

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Surface plasmon polariton (SPP), as a surface wave with subwavelength property, provides possibilities in routing the energy in a planar dimension of a metal surface. Many efforts have been dedicated to the manipulations of the SPP waves, and a variety of functional elements have been proposed and demonstrated (e.g., beam reflection, focusing, splitter, multiplexer, etc.). A newly developed Airy beam arrested many researchers attention due to its novel characteristics (such as non-dispersive, non-diffraction, self-accelerating, self-healing, etc.), which has been realized in the free space by a phase modulation on its Fourier plane [1]. Very recently, several approaches were reported to achieve this intriguing wave packet in the plasmonic system [2, 3].

Here, we developed a new non-perfectly matched in-plane diffract method to modulate the SPP beam phase, as well as the wave front. As a 3/2-type phase modulation is achieved by this method, we successfully generated the SPP Airy totally in a planar dimension [4] (see Fig. 1). The unique properties of SPP Airy beam, such as non-diffraction, non-dispersion, parabolic bending, self-healing, have been well demonstrated. Moreover, this method was further adopted to realize a broadband SPP focusing, based on which a good plasmonic demultiplexer was established, which exhibited a relative high wavelength resolution about ~13nm [5], as shown in Fig. 2. These two examples would indicate further explorations in steering SPP waves on the metal surface.

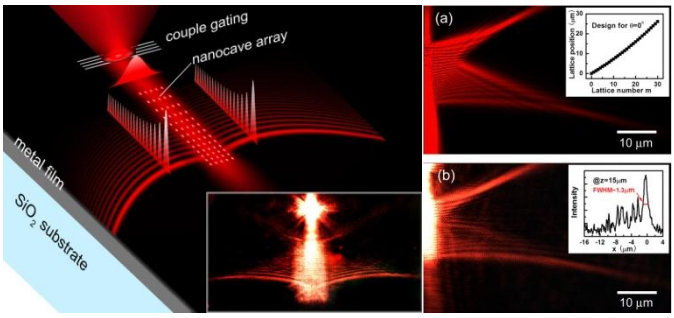

Fig. 1. Plamsonic Airy beam generated by diffraction

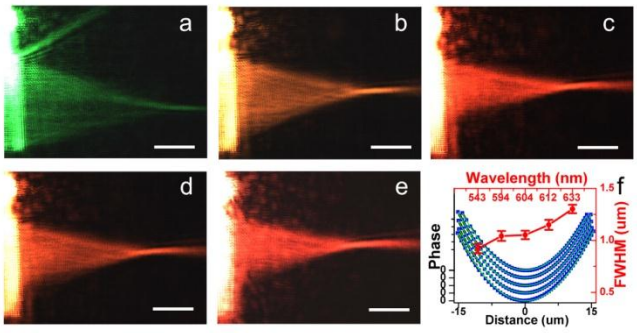

Fig. 2. Broadband SPP focusing and demultiplexing

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O-03

Driving and Monitoring Photo-Reactions with Gap-Plasmons

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We demonstrate the use of gap-plasmons to locally drive a photochemical reaction, and to monitor the kinetics using single-molecule SERS (sm-SERS). Visible light excitation of a self-assemble Ag nanoparticle (NP) – 4 nitrobenzenethiolate (NBT) monolayer – Au thin film (TF) junction generates locally enhanced field at the metallic gap, and also drives AgNP → NBT electron transfer, which ultimately leads to 4-aminobenzenethiolates (ABT) and/or dimercaptoazobenzene (DMAB) products. The sm-SERS trajectories not only reveal decay kinetics of ~200 number of NBT reactants, but it also shows the formation and decay of nitrobenzenethiol anion intermediates (NBT-). While the SERS peaks of reactants and intermediates show more or less continuous time evolution, those of DMAB products show discrete and regular steps of intensities which can be assigned to the formation of individual DMAB molecules. This drastic difference can be explained by assuming that the azo-coupling is only a minor product channel, whereas other major products are largely invisible in the SERS trajectory. Possible influences of molecular geometry, molecular electronic resonance, and the chemical potentials of the NPs on the photo-reaction kinetics are also explored.

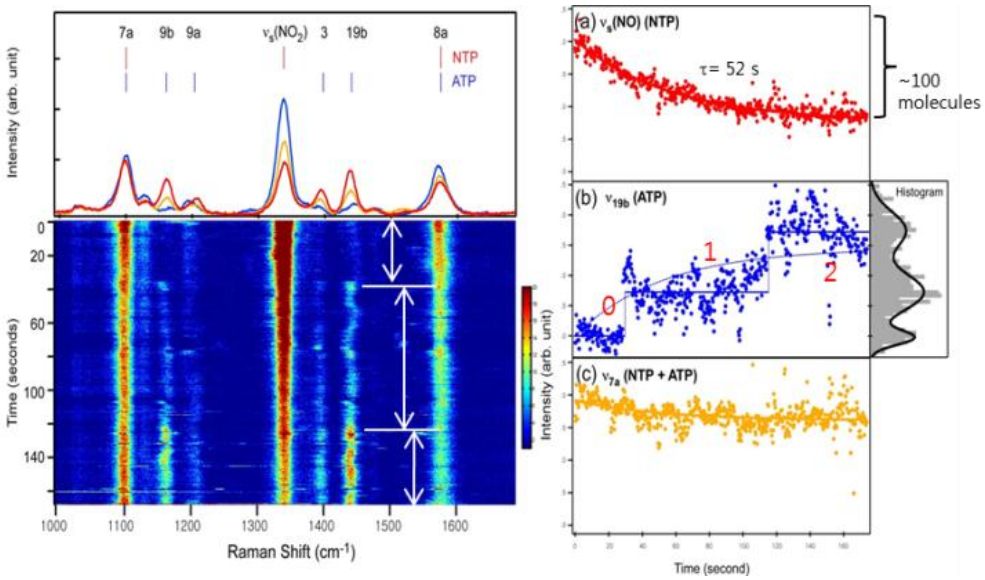

Figure 1: (left) A time-trajectory of SERS spectra obtained from a AgNP-4NBT-AuTF junction; (right) time-evolutions of vibrational peaks.

O-04

Smart Nanoplasmonics for Chemistry and Biology

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In this talk, I will present how to utilize smart nanoplasmonics for answering catalytic chemistry questions and constructing 3D nanostructures that exhibit intriguing plasmonic chirality.

I will first demonstrate antenna-enhanced hydrogen sensing at the single-particle level[1].

We place a single palladium nanoparticle near the tip region of a gold nanoantenna and detect the changing optical properties of the system upon hydrogen exposure. Antenna-enhanced single-particle sensing pushes the sensitivity of plasmonic gas sensors to an ultimate limit and opens up myriad possibilities for detecting optically inactive species in a controlled fashion. The single-particle sensing strategy will have profound significance for the optical observation of chemical reactions and catalytic activities on a single platform in nanoreactors, and has the potential to be extended to biochemical systems in the future. Moreover, antenna-enhanced sensing comprises a noninvasive and generalizable scheme that is applicable to a variety of physical and biochemical materials.

I will then present the construction of 3D plasmonic architectures using structural DNA nanotechnology[2].

Structural DNA nanotechnology is an emerging multidisciplinary area of research. This technology excels in controlling spatial addressability at a sub-10 nm resolution, which has thus far been beyond the reach of traditional top-down techniques. We demonstrate the realization of 3D plasmonic chiral nanostructures through programmable transformation of gold nanoparticle-dressed DNA origami. Gold nanoparticles are assembled along two linear chains on a two-dimensional rectangular DNA origami sheet with well-controlled positions and particle spacing. By rationally rolling of the 2D origami template, the gold nanoparticles can be automatically arranged in a helical geometry, suggesting the possibility to achieve engineerable chiral nanomaterials in the visible range.

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O-05

Close encounters between nanoantennas: Quantum plasmonics

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Plasmonic structures act as effective receivers, transmitters and receivers of visible light, acting as effective optical nanoantennas. These nanoatennas show the ability to focus electromagnetic radiation into tiny spots of nanometer-scale dimensions allowing for more effective field-enhanced visible and infrared spectroscopies such as in surface-enhanced Raman spectroscopy (SERS) or in surface-enhanced infrared absorption (SEIRA). When two metallic nanoparticles are closely located to each other, a strong Coulomb interaction between the surface charge densities induced at each particle is produced. This situation supports the existence of a highly localized Bonding Dimer Plasmon (BDP) that results in a huge field enhancement at the interacting gap between the particles. This structure can be used as a canonical building block for a variety of complex physical phenomena to happen such as non-linear effects, quantum tunneling or photoemission, to cite a few. We will present a number of examples where a conductive contact between the two arms (nanoparticles) of the gap-antenna is produced, giving rise to a new surface mode at lower energy characterized as a Charge-Transfer Plasmon (CTP). We will illustrate the use of this effect (i) to effectively control the near-field oscillations in a loaded antenna, (ii) to relate transport and optical spectroscopy based on the evolution of the BDP and CTP with the conductivity of a molecular gap linker, and (iii) to produce optical spectral switching based on the presence of a photoconductive material at the gap that can sustain a large free-carrier density that metalizes the gap.

As the control of sub-nanometer separation distances is technological feasible, a classical description of the metal surface, based on the assumption of an abrupt change of the electron density at the surface of the metallic material, fails to correctly describe the optical response of a gap antenna. To account for the effect of the spill-out of the electrons at the surface of the metal, full quantum mechanical calculations have been developed with use of techniques such as time-dependent density functional theory (TDDFT). Since plasmonic nanostructures are usually large, a full quantum description of the optical response of standard plasmonic systems is not possible due to the huge number of electrons involved in the response. We present a new method to calculate quantum effects in large plasmonic systems based on parametric inputs derived from simpler full mechanical calculations. Our results of the optical response in small systems agree perfectly with full quantum calculations and allow us for a complete description of the modal redistribution and collapse of the field enhancement in subnanometer gap-antennas formed by large structures. With this quantum effective model (QEM), we bridge a gap between classical and quantum plasmonics.

O-06

Quantum Plasmon Resonances of Individual and Coupled Metallic Nanoparticles

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The plasmon resonances of metallic nanoparticles have received considerable attention for their applications in nanophotonics, biology, sensing, spectroscopy, and solar energy harvesting. While thoroughly characterized for spheres larger than 10 nanometers in diameter, the plasmonic properties of particles entering the quantum size regime (~2-10 nm) have been historically difficult to describe. Quantum-sized plasmonic particles not only exhibit very low extinction cross-sections, but the observed plasmon resonances are also typically blurred by surface-ligand interactions and inhomogeneity in ensemble measurements. Such difficulties preclude plasmonic control of quantum-sized particles, which are arguably the most relevant to many natural and engineered processes, notably catalysis.

In this presentation, we investigate the plasmon resonances of individual ligand-free silver nanoparticles using aberration-corrected transmission electron microscope (TEM) imaging and monochromated scanning TEM electron energy-loss spectroscopy (STEM EELS). This technique allows direct correlation between a particle's geometry and its plasmon resonance. As the nanoparticle diameter decreases from 20 nm to less than 2 nm, the plasmon resonance exhibits a blue-shift from 3.3 eV to 3.8 eV, with particles smaller than 10 nm showing a substantial deviation from classical predictions. We present an analytical quantum-mechanical model that well describes the plasmon resonance shift due to a change in particle permittivity. Our results highlight the unique quantum plasmonic properties of small metallic nanospheres, with direct application to understanding and exploiting catalytically-active and biologically-relevant nanoparticles.

Furthermore, using TEM EELS, we can observe the plasmonic properties of multi-particle systems. Using excitation from the electron beam, ligand-free silver particles are capable of moving on silica substrates, allowing dynamic monitoring of plasmonic resonances as the particles approach each other and coalesce. This strategy provides a straightforward method for studying dimer interactions at variable separation distances, including quantum-sized separations. Because individual sets of particles can simultaneously imaged and spectrally analyzed, we can directly probe the crossover from classical to quantum plasmon resonances in particle dimers.

O-07

Integrated surface plasmon based polarizer and polarization beam splitter

Xifeng Ren[1*], *Changling Zou*[1], *Chunhua Dong*[1], *Fangwen Sun*[1] *and Guangcan Guo*[1]
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Integrated optical circuit, composed of multiple photonic functions in a single chip, has attracted more and more attention due to its small footprint, reduced power consumption, and enhanced processing stability. It is greatly expected that ultrafast classical and quantum information processing could be performed on these ultracompact chips. Polarization is one of the most important properties for light in the modern optics. However, the manipulation of polarization that is one of the most important properties for light is still a challenge in integrated optical systems, since the propagation of light in dielectric waveguides is insensitive to the polarization. Here we show theoretical design and experimental demonstration of a polarizer based on surface plasmon polariton, and a broadband integrated waveguide polarization beam splitter is also proposed.

An in-line high efficient polarizer, composed of tapered fiber on the Au thin film, is theoretically proposed and experimentally demonstrated. The protocol is based on the high efficient adiabatic conversion of transverse magnetic mode from tapered fiber into surface plasmon (SP) and attenuates quickly in metal film. On the contrary, the transverse electric polarized light is influenced hardly in the whole process. The polarization extinction ratio higher than 500:1 (~27 dB) is obtained in our experiment. Our demonstration offers a potential way to manipulate the polarization of light in integrated circuit and may inspirit more attention to surface plasmon based devices for polarization controlling[1-2].

A broadband integrated waveguide polarization beam splitter consisting of a metal nanoribbon and two dielectric waveguides is proposed and numerically investigated. This surface plasmon based device provides a unique approach for polarization sensitive manipulation of light in an integrated circuit and will be essential for futureclassical and quantum information processes[3].

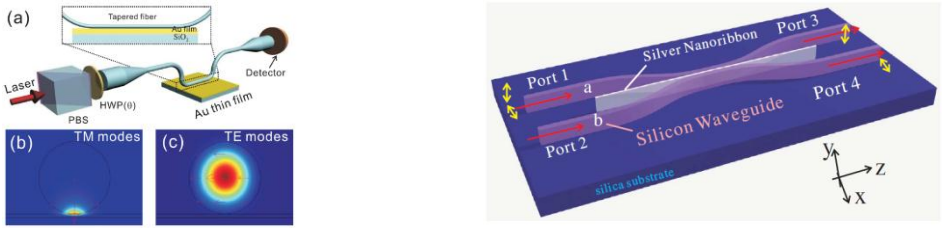

Figure (left part) Sketch of the experimental setup of in-line polarizer. (right prat) Schematic illustration of the integrated surface plasmon based polarization beam splitter.

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O-08

Ag Nanorods Prepared by Localized Oblique Angle Deposition as SERS-active Substrate

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Oblique angle deposition (OAD) is a physical vapor deposition process and mainly uses shadowing effect and adatom diffusibility to form nanorods.[1, 2] In this study, we demonstrate a simple and convenient method of depositing Ag nanorods on a pre-micro-structured substrate by using localized OAD. First, micro-cavity substrates are patterned via standard photolithography and silicon dry etching. As shown in Fig. 1a, the sidewall of the micro-cavity has a large angle (>80 °) between the vertical line and the local surface normal. During the localized OAD process, the substrate is mounted to a horizontally placed holder in a standard electron beam evaporator and the micro-cavity is facing down to the material vapor. Thus, the large deposition angle between the vapor incident direction and the local surface normal, which is essential to produce nanorods by the shadowing effect, is created on the steep sidewalls. Thereby, a layer of Ag nanorods is formed on the sidewalls of the micro-cavity, as shown in Fig. 1b. Furthermore, functionality of the Ag nanorods has been verified by unraveling their surface enhanced Raman spectroscopy (SERS) activity on the Raman probe molecule Rhodamine B. The representative SERS spectra are showing Fig. 1c and the enhancement factor is calculated as in the order of 10^5。
Our present work focuses on applying Localized OAD to decorate other micro-structured substrates with Ag nanostructures for more versatile plasmonic applications.

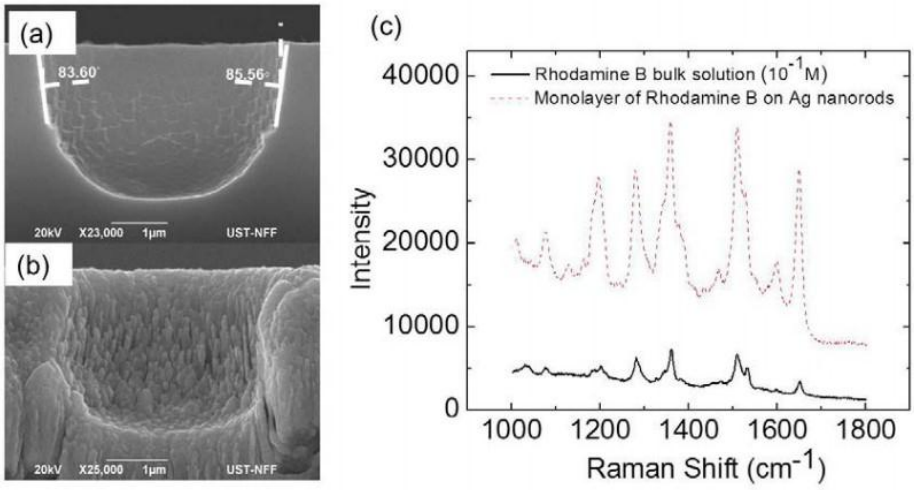

Figure 1

References:

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O-09

Effects of Geometry, Substrate and Angles of Incidence on Resonant Properties of Gold Nanoparticles

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The surface plasmon resonances in metals depend on the geometry, electrical properties and dimensions of the metal and also on the direction and polarization of the incident electromagnetic wave [1]. In our work, we investigate and compare the resonant properties and spatial distribution of electric near-field of gold nanoparticles of modified triangular geometries. Numerical analysis of optical scattering of the particles is fulfilled by the software CST MWS®. Complex permittivity of gold nanoparticles ($\varepsilon=\varepsilon_0\varepsilon_r$) is described by Lorentz-Drude model with an interband term [2]. The range of wavelengths in calculations is 400~1400 nm.

The particles are illuminated by E_x-polarized plane wave with normal incidence. The surrounding medium is the vacuum. The thickness of nanoparticles is equal to 20 nm. The analysed geometries are: conventional triangle (1 in Fig. 1a), concave triangle (2 in Fig. 1a), curved side triangle (3 in Fig. 1a) and curved side triangle with a corner formed by three tips (4 in Fig. 1a). The resonant responses were calculated at a point located at distance 5 nm from the corner of the nanoparticles (Fig. 1b). We have found that the curved side triangular geometries (3, 4 in Fig. 1a) possess higher near-field intensity compared to other analysed geometries.

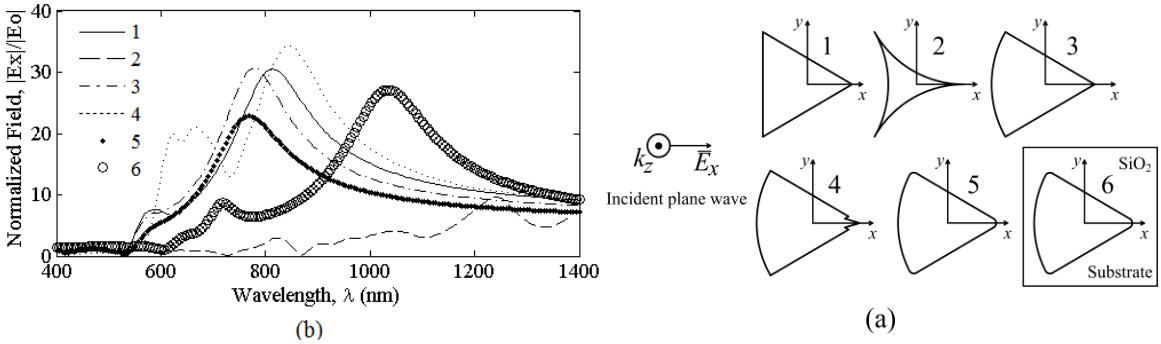

Figure 1. (a) Investigated geometries, (b) Resonant response of investigated nanoparticles

We also investigate and compared conventional triangle and curved side triangle (5 in Fig. 1a), both with rounded tips with radius of curvature equals to 10 nm. For curved side triangular nanoparticle, we investigate the influence of two parameters on its resonant properties: thickness of a silicon dioxide (SiO_2) substrate (6 in Fig. 1a) and the angle of incidence. The numerical results show that when nanoparticle is placed in a substrate, its electric near-field intensity and resonant wavelength are increased by 19% and 35%, respectively. Increasing the thickness of substrate, the near-field intensity increases too. According to the variation of the angle of incidence, the curve of near-field intensity is almost a cosinusoid.

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O-10

Plasmonic nanosystems: realizing the Alzar model and exploiting optical frequency magnetism

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Coupled systems of plasmonic nanostructures possess collective resonances, and in geometries with reduced symmetry, can support coherent effects due to coupling between the bright and dark modes of the system.[1] A straightforward coupled oscillator model describes many aspects of these systems quite well.[2] In particular, the excitation of collective modes of a plasmonic cluster by optical means, or alternatively, by an energetic electron beam, yield quite different resonant behavior that can be understood within this picture.[3] Plasmonic clusters also support magnetic plasmons at near-infrared frequencies, exhibiting an unusual type of antiferromagnetic behavior.[4] Semishells are yet another example of a plasmonic system where optical frequency magnetic modes can be excited;[5] in this system, they can be used to enhance a strong second-order nonlinear response that is a strong function of semishell orientation.[6]

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O-11

Active surface plasmon and toroidal resonance in three dimensional magnetic metamaterials

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Surface plasmon polaritons (SPPs) which are quantization from collective surface electrons resonance forms the surface plasma propagating wave. Surface plasmon wave can be modified by the artificial subwavelength structure on metal surface, such as plasomic lens with grating, SPPs focusing by the quarter-circle, and squeezing near-field light by metallic nanoparticles. In fact, there are three interactions processes between surface plasmon wave and nanostructure, including near-field reflection, transmission and far-field propagated light. The interactions in the far-field propagating light considered as a kind of loss are disscussed in most of papers. Here, we experimentally investigate the scattering of surface plasmon waves generated by the plasmonic nanostructures (see Fig. 1(a) and (b)). Both out of plane focusing and diverging plasmonic nanostructures are fabricated on the same surface of Au film to be imaged and studied simultaneously. In the field of metamaterials, the plasmonic interaction between sub-wavelength metallic structures results in many extraordinary properties and plasmonic modes. Split ring resonator (SRR) have attracted to a widen attention dut to the interacting resonant modes. Here, the off-plane U-shape SRR structures was fabricated by double e-beam lithography to excite the electric and magnetic resonances simultaneously and then investigate the plasmonic resonant modes. We find that the toroidal dipolar response can be observed in the metamolecules composed of four U-shape SRR structures at optical frequencies which is resulting from the magnetic interaction between the three dimensional metamolecules (see Fig. 1(c)). These research results have potential to be applied in the field of the integrated photonic circuit, three dimensional projection and plasmon rulers in optical frequency region.

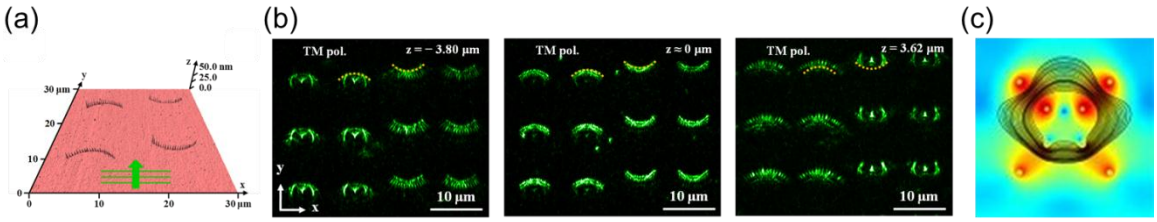

Figure 1. (a) AFM image of the quarter circles shows concave (left) and convex (right) structure composed of 21 nanobumps. (b) The TIRM images are observed at various focal planes. All the TIRM images are recorded under TM polarization illumination. (c) Simulated results of magnetic energy (color map), streamlines of magnetic field (black lines) at toroidal resonance.

O-12

Plasmon Mediated Single Molecular Electroluminescence

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Electrically driven single molecular light source is important for molecule-based optoelectronic integration and quantum information processing, but still demanding due to fluorescence quenching and the lack of in-depth understanding on the mechanism. In this talk, I shall demonstrate single molecular electroluminescence originating from intrinsic intramolecular optical transitions, i.e., the lowest unoccupied molecular orbital to highest occupied molecular orbital (LUMO–HOMO) transitions of a single porphyrin molecule that is inside the tunnel junction of a scanning tunneling microscope and well decoupled from the metal substrate. The generation of molecule-specific fluorescence is found to depend on two factors: one is the electronic decoupling that suppresses the fluorescence quenching effect; the other is the presence of nanocavity plasmonic fields that spectrally overlap with molecular vibronic transitions and thus enable resonant plasmon-exciton coupling for fluorescence enhancement. These findings help to substantially deepen our understanding on the coupling and decay of electronic excitations in single molecular optoelectronics and may open up new routes to generate electrically driven point-light sources.

O-13

SERS and Molecular Plasmonics of Adsorbed Molecules in Metal Nanogaps

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Collective oscillation of surface electrons under light irradiation leads to surface plasmon resonance on nanostructured metals. The surface plasmon resonance strongly depends on shape, size, and aggregation of nanoparticles. In general, the nanogap formed from metal nanoparticles has giant enhancement effect in absorption and scattering efficiency compared with general positions, like so-called 'hot spot' in surface-enhanced Raman spectroscopy (SERS). Here we report our results from the combining study of Mie theory and density functional theory (DFT) calculations on Raman spectra and SERS of 1,4-benzenedithiol(BDT), p-aminothiophenol (PATP), and p,p'-dimercaptoazobenzene (DMAB) in a silver nanogap. Their SERS spectra strongly depend on chemical property of probe molecules, the wavelengths and the polarization of excitation light. In this report, we further investigate the influence of the hybrid state between localized surface plasmon and adsorbed dye molecules on SERS signals in metal nanogapes. It has been found that the specific structure and chemical activity of probe molecules play important roles in its special Raman spectral features. Our results may provide a new insight to understand the SERS spectra of probe molecules adsorbed on nanostructures.

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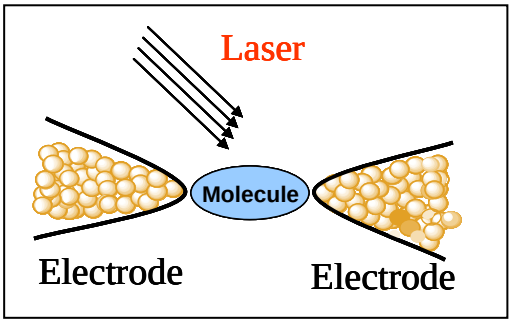

Figure 1. Model of probe molecules in metal nanogaps

O-14

Charge transfer plasmons across a few-atoms-wide bridge

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Charge.transfer plasmon (CTP) mode is theoretically predicted in two metal particles weakly connected either through tunneling or through physical conductive bridges [1, 2], which is very sensitive to the conductivity of connection junctions. With this unique property, CTP mode is expected to have promising applications in molecular electronics and high.sensitivity sensing [2]. However, due to both fabrication and characterization difficulties, a comprehensive experimental study of the CTP mode at the sub.10.nm scale is currently lacking.
In this talk, we present our recent work on pushing the experimental study of CTP mode to the atomic scale, with the smallest bridge width of 1.3 nm (8.atoms wide). [3] With gradually decreasing the bridge width, we have seen the systematic red shift and gradual disappearance of the charge transfer mode. Meanwhile, we have observed robust evidences to show that the 3λ/2 mode gradually transits into bright dipole mode when tiny gap forms between two particles. Figure 1 shows the spectrum taken from the particle with a 1.3 nm bridge, from which we can see that both charge transfer (λ/2) mode and 3λ/2 mode were supported by this particle pair.

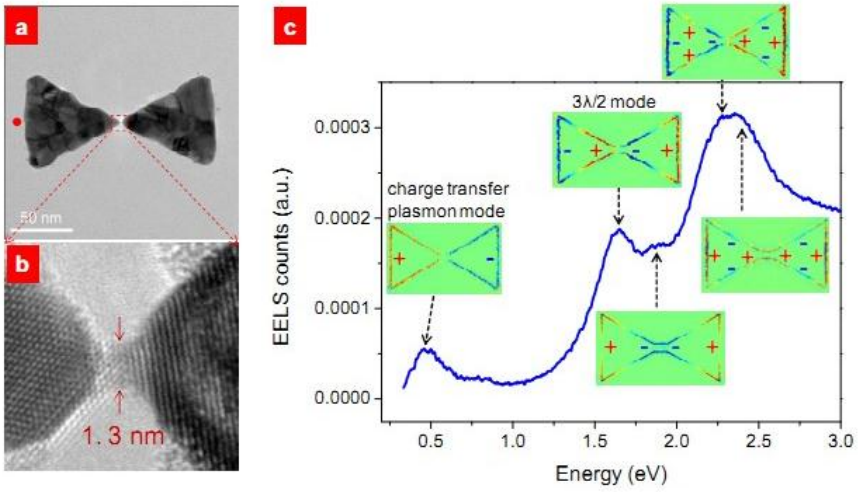

Figure 1. (a) TEM micrograph of the measured particle pair with 1.3 nm bridge. The red dot shows the electron.excitation position to obtain electron energy.loss (EEL) spectrum. (b) High.resolution TEM micrograph of the junction. (c) EEL spectrum of this particle pair. The nanoprism pair was fabricated on 30.nm.thick SiN membrane using electron.beam lithography and lift.off process. The bridge width was further decreased by in-situ electron.beam nanosculpting process in a high.resolution scanning transmission electron microscope. Numerical simulations were done to understand the origins of different plasmon modes, shown by the charge.distribution plots.

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O-15

Graphene: a new platform for capturing and manipulating light at the nanoscale

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In this talk, I will discuss recent experimental and theoretical work on exploiting graphene as a host for capturing, guiding, switching and manipulating light and at nanoscale dimensions. The first part of my talk will be devoted to the emerging and potentially far-reaching field of graphene plasmonics: surface waves coupled to the charge carrier excitations of the conducting sheet. Due to the unique characteristics of graphene, light can be squeezed into extremely small volumes and thus facilitate strongly enhanced light-matter interactions [1]. I will discuss recent observations of propagating and localized optical plasmons in graphene nano-structures [2] (Figure, right panel). By gating the graphene, in-situ control of the plasmon wavelength is demonstrated, which allows us to control the resonance frequency of graphene-based plasmonic cavities. In particular, we demonstrate the capability to completely switch on and off plasmon modes in a graphene ribbon, paving the way towards graphene-based optical transistors.

The second part of the talk is devoted to presenting a novel graphene-based phototransistor with extremely high photo-responsivity and gain [3] (Figure, left panel). The detection mechanism in these devices relies on the photo-gating effect caused by photo-generated charges trapped in quantum dots which decorate the graphene. Due to the combination of high absorption of light in the quantum dots, and the extremely high mobility in the graphene layer, a gain on the order of 10^8 is demonstrated. This highly sensitive photodetector can detect power in the fW regime while covering a broad spectral bandwidth, from the visible to the near infrared, and its responsivity can be tuned by electrostatic gates.

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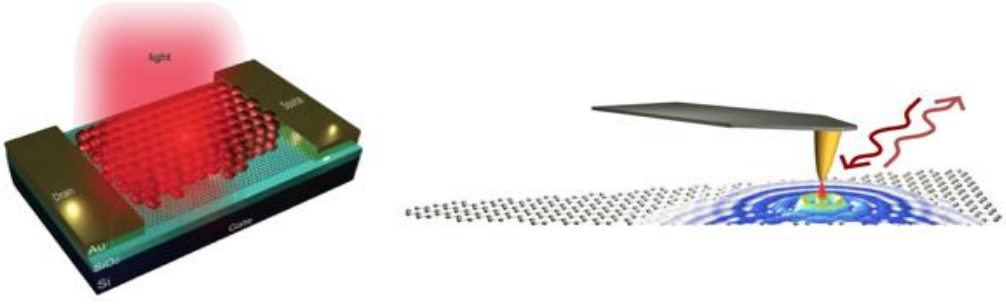

O-16

Geometry Control and Optical Tunability of Metal-Semiconductor Core-shell Hybrid Nanoparticles

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Metal-semiconductor hybrid heteronanostructures may exhibit not only a combination of properties from the disparate components but also new synergistic properties that arise from the interactions between the metal and semiconductor components. Noble metals and Cu2O represent an interesting combination of metal and semiconductor components for the construction of hybrid heteronanostructures. Metallic nanoparticles possess geometry-dependent localized surface plasmon resonances while Cu2O nanostructures may also exhibit geometrically tunable light absorption and scattering properties. We recently demonstrated that the Au-Cu2O hybrid core-shell nanoparticles not only combine the optical signatures of Cu2O nanoshells and the plasmonic properties of Au nanoparticles but also exhibit further enhanced and expanded plasmonic tunability due to the nanoscale interactions between the core and the shell.

In this presentation, I will be focusing on our latest progress on the quantitative understanding of the geometry-property relationship of metal-Cu2O core-shell nanoparticles developed through combined experimental and theoretical efforts, with a specific emphasis on how the structural tunability will enhance our capabilities to fine-tune the light absorption and scattering properties for specific applications. We have recently developed a robust wet chemistry approach through which we can fine-control a whole set of important geometrical parameters of metal-Cu2O core-shell nanoparticles, such as shell thickness, core dimensions, core compositions (Au, Ag, Pd, and bimetallic), spacing between core and shell, shell crystallinity, shell porosity, and surface texturing. The tight control over the core and shell geometries allows us to systematically and selectively fine-tune the synergistic light absorption and scattering properties of the hybrid nanoparticles over a broad spectral range across the visible and near-infrared regions. The geometrically tunable optical properties achieved in these core-shell hybrid nanoparticles are believed to be crucial and hold great promise to the optimization of a variety of important physical and chemical processes, such as biomedical imaging, photothermal therapy, photocatalysis, photovoltaics, and plasmon-enhanced spectroscopies.

O-17

Mesostructures for enhanced light/matter coupling: synthesis and applications

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Plasmonic resonances in nanoantennas overcome diffraction limit, allowing unprecedented control of light - matter interactions within subwavelength volumes, i.e., within the nanoscale at optical frequencies. Some applications such as the localized surface Plasmon resonance (LSPR) sensing, surface-enhanced Raman scattering (SERS), are highly relative to the sensitivity and repeatability of the signal detected. The lithography techniques seem difficult to achieve high sensitivity and repeatability simultaneously. Recently, a new type of namaterials, called mesocrystals or mesostructures, was figured out according to the nonclassical crystallization mechanism [1-2]. The mesostructures are ideally suitable for the enhancement of the light/matter coupling owing to the rough surface, small building blocks as well as notable internal porosity [3-5]. In this presentation, we summarized the latest progress to improve both sensitivity and reproducibility of the LSPR or SERS signals according to the mesoassembly protocol. Various mesostructures, such as Au "sea urchin", Ag corrugated nanowires, DNA-anchored nanobridged particles, et al. have been included. Importantly, these mesostructures, owing to uniform size and shape, demonstrate highly reproducible and homogenous single particle SERS effects. Thus they are promising candidates for LSPR based sensor substrates-combining high performance with simple preparation and low cost.

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O-18

Chiral plasmonic nanosors and its circular dichroism probe for cysteine

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Lipid/nanoparticles (NPs) hybrid superstructures have been paid growing attention in recent years, to exploit enormous possibilities of lipid-based, biocompatible nanocomposites for diverse nanobiotechnology applications. This work is to report a novel chiral hybrid superstructure created through self-assembly/self-organization of gold nanorods with bilayer-forming phospholipid amphiphilites. This chiral hybrid superstructure shows as a helical alignment of Au NRs like LC mesophase in organic nanostructure, and gives unique chiroptical responsiveness in the recognition of L- and D- cysteine molecules. In addition to a significant influence on the plasmonic CD response in the Vis/NIR region, the distinct interactions of the chiral hybrid superstructure with L- and D-isomer of cysteine molecules show mirror image of CD responses in the UV region of 200-350 nm. The origin of such special optical activity is substantially different from that of chiral metal nanoparticles/nanoclusters discussed in previous studies. We propose here a possibility that chiral plasmonic nanostructure of gold nanorods would lead to chirality amplification in the recognition of cysteine molecules. We believe that this study may open a new route for fabricating promising plasmonic nanosensor for a variety of bioscience and biomedicine applications.

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O-19

Plasmonic photocoupler design for multicolor infrared photodetectors

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Plasmonic resonances are favorable for trapping photons efficiently into optoelectronic devices and therefore boost their performance, as has been proposed or demonstrated by many groups.[1] So far, most of reported works have mainly concentrated on the visible light (or near-infrared) region partially due to the urgent demands from green energy industry. However, in the longer-wavelength region, i.e., infrared and terahertz regions, the surface electromagnetic waves, known as Sommerfeld or Zenneck waves are characterized by poor confinement to surfaces and are therefore ineffective in enhancing the coupling strength of light-semiconductor interaction. By patterning the metal surface with subwavelength periodic features can markedly reduce the asymptotic surface plasmon frequency, leading to 'spoof' surface plasmons with subwavelength confinement at infrared wavelengths and beyond, which mimic surface plasmons at much shorter wavelengths. The usefulness of spoof surface plasmons for infrared optoelectronic devices have been evidenced by reported smaller divergence (reduced from $\sim 180^0$ to $\sim 10^0$) and higher directivity (~10 decibels) in terahertz quantum cascade lasers[2] and larger photo-responsivity (~130%) of a photodetector at 8.8μm [3] . On the other hand, however, the spatial confinement of the spoof surface plasmons in the reported works was still weak if we compare their decay length with the thickness of photo-active semiconductor layers. It is therefore anticipated that further improvement to the performance of plasmonic infrared optoelectronics might be possible if additional confinement is introduced.

Here we demonstrate that a plasmonic cavity consisting of a perforated metal film and a flat metal sheet separated by a semiconductor spacer is particularly suitable for multicolor infared light detection, due to the excellent spectral tunability, spatially distinct field distributions and absorption enchancement. Three different types of optical modes are clearly identified --- the propagating and localized surface plasmons on the perforated metal film and the Fabry-Perot modes inside the cavity. Interactions among them lead to a series of hybridized eigenmodes exhibiting excellent spectral tunability and spatially distinct field distributions, which cannot be achieved by convential grating photo coupler. As an example, we design a two-color detector protocol with calculated photon absorption efficiencies enhanced by more than 20 times at both colors, reaching ~42.8% at 15μm (in wavelength) and ~46.2% at ~10.2 μm for a 1 μm total thickness of sandwiched quantum wells. The rich plasmonic-photonic hybridization effects discovered here provide plenty of opportunities to optimize light harvesting efficiencies for modern ultra-small infrared optoelectronic devices with subwavelength dimensions.

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O-20

Plasmon-enhanced Raman spectroscopy

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Surface-enhanced Raman scattering (SERS) may occur if the molecule is located in close proximity to a nanostructured materials with support of surface plasmons (SPs) or surface plasmon resonance (SPR), either localized surface plasmons or propagating surface plasmons [1,2]. The field enhancement can significantly increase the intensity of Raman scattering from a molecule adsorbed at or close to the nanostructures. Although SERS is comparable to the sensitivity of fluorescence, there are two significant drawbacks to the commonplace application of SERS: a lack of substrate/molecule generality and a lack of morphology generality. To bypass these obstacles, many groups have developed a "borrowing SP" strategy by utilizing different nanostructures. Tip-enhanced Raman spectroscopy (TERS)[3], shell-isolated nanoparticle-enhanced Raman spectroscopy (SHINERS)[4] and ATR-based Raman spectroscopy belong to the family of plasmon-enhanced Raman spectroscopy (PERS). With the advent of new family members with new nanostructures, PERS have significantly expanded the versatility of Raman spectroscopy in surface science and trace analysis on complex systems.

The SP properties of metallic nanoparticles placed on solid substrate or absorbed at air-liquid interface have been extensively investigated in the past years. However, just few works has been done to deal with the SP properties of nanoparticles at liquid-liquid interface. Recently we studied the optical properties, including extinction efficiency and near field distribution of gold nanosphere adsorbed at water/ dichloroethane at different penetration positions theoretically based on the three dimensional finite difference time domain (3D-FDTD) method. According to our calculations, the SPR properties at liquid-liquid interface show some distinct characteristics. It will be helpful for extending Raman spectroscopy to study liquid-liquid interfacial structures.

Finally, an outlook on further developments of PERS will be given with emphasis on the emerging methodology.

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O-21

Plasmonic Nanoantennas: New design principles and new applications

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We will show how transformation optics serves as a powerful tool for the design of nanoscale plasmonic light harvesting nanoantennas, revealing how structural singularities lead to a broadband response. A deep physical understanding of the effects of blunting out singu-larities and of non-local effects will be developed. Another important design paradigm are Fano resonances, and new results revealing the physics of the underlying interference process-es will be shown. Lastly, we will present new applications for nanoplasmonics, particularly plasmonic sinks and cw THz emitters.

Plasmonic nanoantennas have emerged as a major element in the control of light/matter interactions on the nanoscale [1]. Over the last two years, Fano resonances and transformation optics have emerged as powerful tools for the engineering of a desired spectral response. New insights into the underlying physics of plasmonic control over light localization will be presented, using a newly developed theory of Fano interferences, and via the use of transformation optics. Regarding the latter, we will focus on the effects of blunting out structural sin-gularities, and the concomitant change from a broadband light harvesting response to a quantized spectrum [2] (see figure 1). Additionally, transformation optics allows for an analytical examination of non-local effects in nm-scale plasmonic structures. Experimentally, electron energy loss spectroscopy will be shown to be an ade-quate tool for the investigation of localized plasmon resonances on the nanometer scale.

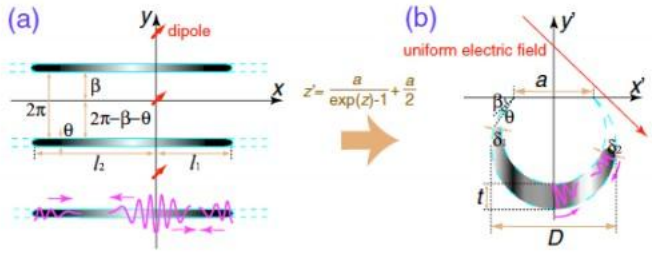

Figure 1. Transformation optics as a tool to examine the effects of blunting out struc-tural singularities[2]

Apart from enhancement of light emission [2], we show that plasmonic nanocavities can also be effectively utilized for the selective quenching of unwanted, long-lived states in emissive species [3]. This plasmonic sink concept will be applied to organic light emitters, and improvements in a decrease of photo-bleaching and achievable repetition rates in light-emitting devices quantified.

Lastly, we demonstrate the dramatic enhancement of an active THz device using a nanoantenna concept – the generation of cw-THz generation using a photoconductive photo mixer [4], where the traditional interdigi-tated electrode region is replaced with a tip-to-tip nanoantenna configuration. Field enhancement of both the optical pumping beam and the THz emission leads to a 1-2 order of magnitude enhancement of cw emission, tunable over a broadband frequency bandwidth.

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O-22

Gradient meta-surfaces to bridge propagating waves and surface waves

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The arbitrary control of electromagnetic waves is a key aim of photonic research. Although, for example, the control of freely propagating waves (PWs) and surface waves (SWs) has separately become possible using transformation optics and metamaterials, a bridge linking both propagation types has not yet been found. Such a device has particular relevance given the many schemes of controlling electromagnetic waves at surfaces and interfaces, leading to trapped rainbows, lensing, beam bending, deflection, and even anomalous reflection/refraction. Here, we demonstrate theoretically and experimentally that a specific gradient index meta-surface can convert a PW to a SW with nearly 100% efficiency. Distinct from conventional devices such as prism or grating couplers, the momentum mismatch between PW and SW is compensated by the reflection-phase gradient of the meta-surface, and a nearly perfect PW–SW conversion can happen for any incidence angle larger than a critical value. Experiments in the microwave region, including both far-field and near-field characterizations, are in excellent agreement with full-wave simulations. Furthermore, we show that the SWs generated on the meta-surfaces driven by incident PWs can be guided out to surface plasmon polaritons flowing on another system supporting such eigen surface modes. Our findings may pave the way for many applications, including high-efficiency surface plasmon couplers, anti-reflection surfaces, light absorbers, and so on.

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O-23

Transparent Metals for Ultrabroadband Electromagnetic Waves

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In this talk, I present that metallic gratings consisting of narrow slits have been demonstrated to become transparent for extremely broad bandwidths. This phenomenon can be explained by a concrete picture in which the incident wave drives free electrons on the conducting surfaces and part of the slit walls to form surface plasmons (SPs). The SPs then propagate on the slit walls but are abruptly discontinued by the bottom edges to form oscillating charges that emit the transmitted wave. This picture explicitly demonstrates the conversion between light and SPs and indicates clear guidelines for enhancing SP excitation and propagation. Meanwhile, the broadband optical transmission is verified for the structured metals with significant thickness in the range of half a wavelength, and the high transmission efficiency is insensitive to the metal thickness. Furthermore, this approach can implement transparent metals nearly over the entire spectrum ranging from the radio frequency to the visible. The investigations provide a guideline to develop many novel devices, including transparent conducting panels, white-beam polarizers, broadband metamaterials, and antireflective solar cells.

O-24

Directional plasmonic nanoantennas for spectroscopy and sensing

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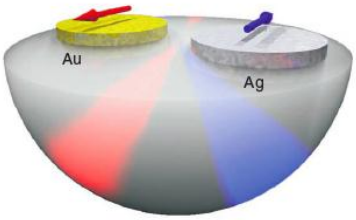
Plasmonic nanoantennas are well known for their ability to amplify signals from sub-wavelength sources. However, until recently, the directionality of the emission received comparatively little attention. In this presentation, three different examples of directional emission from plasmonic antennas composed of Au or Ag nanostructures will be discussed.

In the first example, it will be shown that single crystal silver nanowires act as broadband unidirectional antennas for visible light [1]. The degree of directionality can be controlled through the nanowire radius and its dielectric environment and the effect can be interpreted in terms of so-called leakage radiation from surface plasmons propagating in a single direction along the wire. We measure a forward-to-backward emission ratio exceeding 15 dB and an angular spread of 4 deg. for wires with radii of the order 150 nm on glass in air.

The second example concerns the angular distribution of surface enhanced Raman scattering (SERS) emitted by individual aggregates of gold nanoparticles [2]. The emission closely agrees with what can be calculated for a single point dipole oriented parallel to the dimer axis. In particular, we find that most of the radiation appears at angles exceeding the critical angle of the air-glass interface supporting the dimer. The results demonstrate that angle-resolved imaging can be used as a fast and facile method for determination of the three-dimensional orientation and symmetry of the SERS "transition dipole" and emphasize the importance of using optics with sufficiently high NA for collecting the "forbidden light" cone.

The final example concerns bimetallic nanoantennas able scatter red and blue light in opposite directions in spite of being as compact as ~$\lambda^3/100$ [3]. These spectral and spatial photon-sorting nanodevices can be fabricated on a wafer scale and offer a versatile platform for manipulating optical response through polarization, choice of materials and geometrical parameters, thereby opening possibilities for a wide range of practical applications.



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O-25

Effective medium theory for resonant plasmonic particles

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Subwavelength metallic structures are at the core of recent plasmonics and metamaterial researches. Effective medium theory is a fundamental tool to investigate the macroscopic optical properties of such structures where plasmonic resonance plays a key role. Maxwell-Garnet effective medium theory, valid for the dilute and small size nanoparticle systems, is not sufficient to account for the plasmonic resonance behavior of dense nanoparticle systems.

In this talk, a new notion of dressed polarizability will be introduced in terms of which a modification of the Maxwell-Garnet effective medium theory will be given. We explain the nature of local plasmon resonances of nanopaticles in the presence of nearby particles as well as dynamic depolarization effect and how the effective medium can be defined taking these effects into account. We also consider the complementary metallic hole structure and explain about the resonance features of a rectangular metal slot and the shift of resonances due to the nearby substrate.[1]

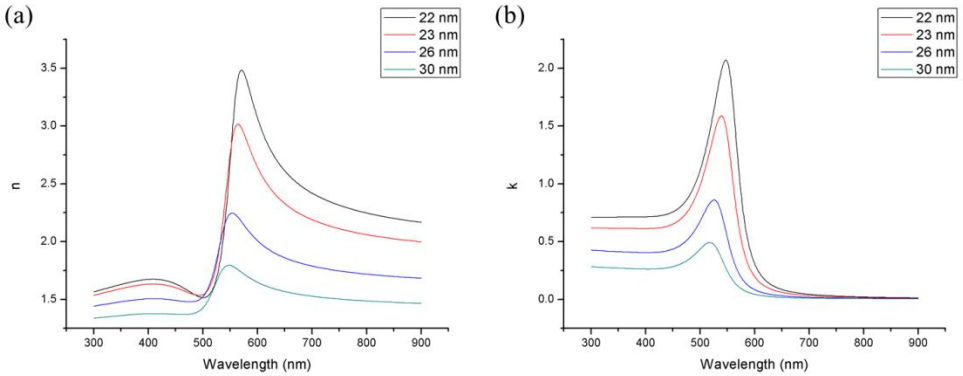

Fig.1 Plasmonic enhancement of effective refractive index of a single layer nanoparticles. (a) Real part, (b) imaginary part of refractive indices corresponding to lattice constant of 22 nm, 23 nm, 26 nm, 30 nm [2]

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O-26

Plasmon-driven chemical reaction in HV-TERS

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I will discuss the Plasmon driven chemical reaction in high vacuum tip-enhanced Raman spectroscopy (HV-TERS),[1] including how to control the rate and probability of surface catalyzed reaction. [2] To interpret these TER spectra, I will introduce the first order nonlinear effect on HV-TERS.[3]

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O-27

Optical properties of super-nanostructures: Hybrid exciton, nonlinear Fano effect, and size-dependent circular dichroism absorption

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Modern nanotechnology opens the possibility of combining nanocrystals of various materials with very different characteristics in one superstructure. Here we present our recent studies on the optical properties of hybrid molecules composed of semiconductor, molecules, and metal nanoparticles. The coupling between various elementary excitations in such a hybrid system leads to novel properties. For instance the interaction between the plasmon (semicontinuous collective intraband excitation) and the exciton (discrete single-particle interband excitation) leads to the formation of a new type of elementary excitation-the hybrid exciton. Moreover, we demonstrate the nonlinear Fano effect in the strong coupling regime based on our semiclassical and full quantum theories. In the quantum theory, the plasmons and excitons are treated on the same footing and the nonlinear Fano effect is described by a generalized complex field-tunable Fano factor for the systems with strong external field and dephasing. We also show that chiral biomolecule-stabilized CdTe or CdSe QDs present size-dependent circular dichroism (CD) characteristics in the visible light region. Theoretical studies based on discrete dipole approximation method reveal that the origin of CD in the visible region is the combination of the biomolecules' weak optical activity and the large enhancement effects from the strong absorption of QDs (in the visible region).

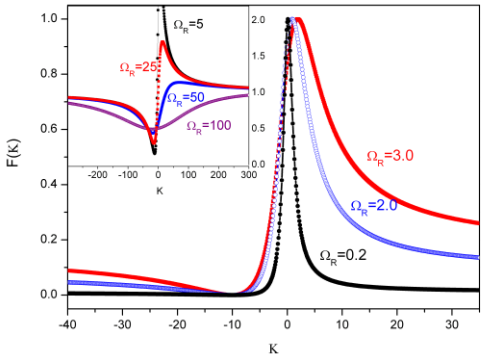

Figure 1. The generalized Fano function F(K).

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O-28

Novel-concept refractometric nanosensors based on plasmonic nanostructures

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Plasmonic nanosensors have shown great potential in biomedical applications due to the enhanced light-matter interaction in the vicinity of the surfaces of metallic nanostructures with the excitation of localized surface plasmons (LSPs) or surface plasmon polaritons (SPPs). In this talk, we review our recent research on three types of novel-concept nanosensors based on newly proposed plasmonic nanostructures.

We first demonstrate a *non-spectroscopic* refractometric nanosensor based on a plasmonic interferometer consisting of a metallic groove array and a tilted nanoslit (as shown in Fig. 1). By inspecting the spatial shift of the interference fringe under monochromatic illumination, the refractive index change of the cover analyte can be detected. In our experiment, the nanosensor shows a sensitivity up to 5×10^3 μm/RIU, a figure of merit as high as 250, and a footprint less than 0.01mm^2. It is potential for miniaturized, low-cost, and high-throughput chip-based biochemical sensing applications.

Recently, planar chiral metamaterials (PCMs) have been proposed as novel biosensors for the ultrasensitive detection and characterization of chiral biomolecules [1]. We performed a comparative study on the sensing performance of two complementary types of plasmonic PCMs. It is found that with hole-type PCMs, the refractive index sensitivity can be improved by 41%, the FWHM is reduced to 1/6, the FOM is enhanced by one order of magnitude, the chiral sensitivity can reach as high as 770 nm/RIU, and the peak amplitude of the CD spectra is enhanced by 30 times. Furthermore, we revealed that NO superchiral field can be generated in such PCMs, which corrects the previous conclusion [1] and clarifies the underlying physics.

Finally, we show a high-sensitivity nanosensor by utilizing an anomalous polarization-selective extinction effect in a sparse array of gold nanoparticle chains. Our theoretical estimation and preliminary experiments have shown that the sensitivity can reach as high as 1×10^3 nm/RIU in the wavelength range of 1.4-1.6 μm.

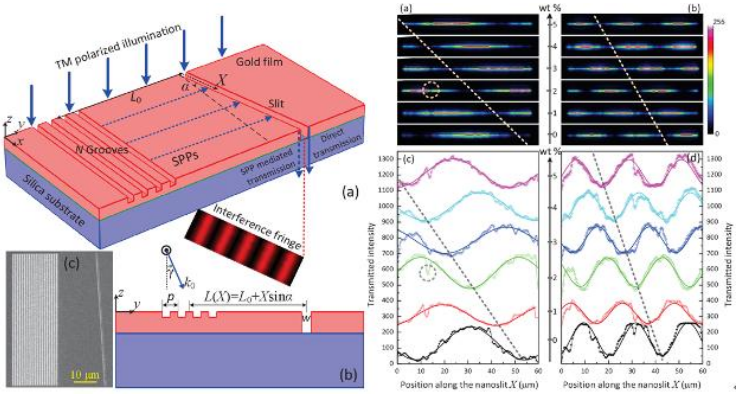

Figure 1. Non-spectroscopic nanosensor based on a monochromatic plasmonic interferometer

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O-29

Collective Plasmon Modes in Nanoparticle Assemblies: Role of Disorder, Energy Transport, and Active Modulation

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In order to incorporate plasmonic nanoparticle building blocks into functional devices such as optical antennas and waveguides it is necessary to understand how surface plasmons couple as particles are arranged into larger structures. Bottom-up assembly of chemically prepared nanoparticles yields small interparticle distances for strong near-field coupling, but also gives to rise to defects in particle size, shape, and ordering. Single particle spectroscopy of plasmonic nanoparticle assemblies, especially when correlated with structural characterization using scanning electron microscopy, allows one to gain a detailed understanding about collective plasmon modes and the role of disorder. We have investigated the collective plasmon resonances of close-packed linear nanoparticle chains with varying widths. We find that for these plasmonic polymers the optical properties depend on the repeat unit (single vs. dimer) when comparing one and two nanoparticle wide chains .For longer assembled chains we demonstrate long-range electromagnetic energy transport along this plasmonic waveguide. The small inter-particle distances enable strong electromagnetic coupling causing the formation of low-loss sub-radiant plasmons, which facilitate energy propagation over many micrometers, with an exponential decay distance exceeding 4 micrometers. Electrodynamic calculations furthermore show that disorder in the nanoparticle arrangement enhances energy transport, demonstrating the viability of using bottom-up nanoparticle assemblies for ultra-compact opto-electronic devices. Another important property for plasmonic devices is the active control of optical signals using external stimuli. We have used nematic liquid crystals to manipulate the polarization of light scattered by individual and coupled plasmonic nanostructures. An applied electric field induces a homogeneous to twisted nematic phase transition of the liquid crystal, which, because of its birefringence, causes a 90 degree rotation of the light and allows for 100% intensity modulation.

O-30

On-chip integrated nanoplasmonic circuits and devices for optical computing

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Modern electronics based on semiconductors is meeting the fundamental speed limit caused by the interconnect delay and large heat generation when the sizes of components reach nanometer scale. Photons as a carrier of the information are superior to electrons in bandwidth, density, speed, and dissipation. More over, photons could carry intensity, polarization, phase, and frequency information which could break through the limitation of binary system as in electronic devices. But due to the diffraction limitation, the photonic components and devices can not be fabricated small enough to be integrated densely. Surface plasmon polariton is quanta of collective oscillations of free electrons excited by photons in metal nanostrucrures, which offers a promising way to manipulate light at the nanoscale and to realize the miniaturization of photonic devices. Hence, plasmonic circuits and devices have been proposed for some time as a potential strategy for advancing semiconductor-based computing beyond the fundamental performance limitations of electronicdevices, as epitomized by Moore's law.

Here we investigate plasmon propagation on branched silver nanowires by using polarization dependent scattering spectroscopy. By controlling the polarization of the incident laser light, the wire plasmons can be routed into different wire branches and result in light emission from the corresponding wire ends. This routing behavior is found to be strongly dependent on the wavelength of light. Thus for certain incident polarizations, light of different wavelength will be routed into different branches. The branched nanowire can thus serve as a controllable router and multiplexer in integrated plasmonic circuits.

In branched NW structures composed of a primary NW and a branch NW, the plasmons on the NW can also be excited by laser illumination at the branch tip. If two plasmon beams are generated on the primary NW by excitation at the primary NW tip and the branch tip, these two beams will interfere on the NW and modulate the near field distribution and the output scattering intensity. Plasmonic OR, XOR or NOT gates can be obtained by tuning the intensity, the phase and the polarization of the incident lasers in a single branched silver nanowire structure. In a more complex nanowire network consisting of a primary wire with an additional input and an additional output, the interference of two plasmon beams by changing incident light polarizations and phases can result in controllable “ON” or “Off” light scattering behaviors in two outputs. By defining specific intensity thresholds for “ON” and “OFF”states of the outputs, additional logic operations can be realized, e.g. plasmonic AND gate and Half Adder.

We also demonstrate that a plasmonic binary NOR gate, one of the so-called “universal logic gates”, can be realized through cascaded OR and NOT gates in four-terminal plasmonic nanowire networks. We use quantum dot (QD) near-field imaging to trace the plasmon wave packets through the branched network and to demonstrate precise control of optical interferences at the nanoscale. This finding provides a path for the development of novel nanophotonic on-chip processor architectures for future optical computing technologies.

It is interesting to note that all the plasmonic devices demonstrated here are based on the same principle: how to excite different plasmon modes and control the interference of these modes to control plasmon propagations on nanowire networks and realize different routing and logic functions. We also explored how to control the fundamental plasmon modes and found that chiral surface plasmon polaritons (SPPs) can be generated by linearly polarized light incident at the end of a nanowire, exciting a coherent superposition of three specific nanowire waveguide modes. Images of chiral SPPs on individual nanowires obtained from quantum dot fluorescence excited by the SPP evanescent field reveal the chirality predicted in our theoretical model. Chirality is preserved in the free-space output wave, making a metallic nanowire a broad bandwidth subwavelength source of circular polarized photons. We also find an extremely large modulation of surface plasmons on Ag nanowires with a beat period of the near field distribution pattern increasing by 90 nm per nm of Al2O3 coating, or by 16 μm per refractive index unit change in the surrounding medium. Such giant modulation is crucial to directly control the optical signal distribution for various routing and demultiplexing functions in plasmonic circuits. These findings may pave way to the development of on-chip plasmonic integrated circuits for the next generation of sensing and information technologies.

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O-31

Substrate Configuration and Surface Enhanced Spectroscopy

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Surface enhanced fluorescence (SEF) is a fast growing branch of surface enhanced spectroscopy(SES) referring to the intensity increase of the optical signal through the interaction or coupling of light with molecules and properly selected substrate surface. Enhancement of the surface plasmon of a metal nanostructure is generally considered as the origin of the local EM field enhancement, which leads to the surface enhanced Raman and fluorescence. The morphology or configuration of the nanostructured substrate, distribution of the optical active molecules, and the excitation conditions to the system are important factors dominating the magnitude of the enhancement. In current talk, the influence of the substrate structures on the fluorescence enhancement effect will be discussed from the point of structure dimension and configuration. The nanostructures from zero to three dimensions, including the fractal structures, will be focused for SES investigation.

O-32

Experimental evaluation of electromagnetic enhancement and blinking in surface-enhanced Raman scattering

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Nanostructures of Ag and Au generate large enhancement in the optical responses of molecules adsorbed on their surfaces. This phenomenon is widely known in particular for surface-enhanced Raman scattering (SERS). The enhancement factor reaches $10^{8\text{-}11}$, allowing us to detect single molecules (SMs). However, the mechanism of enhancement is not well quantitatively evaluated. In the current work, to clarify the mechanism the electromagnetic (EM) mechanism, which is one of the candidates of SERS mechanism, is quantitatively examined using rhodamine 6G (R6G) molecules adsorbed on Ag nanoparticle (NP) dimers.

Relationship among plasmon resonance, SERS, and morphology of single dimers was observed by micro-spectroscopic systems. The observations were compared with finite-difference time-domain simulations. The experimental enhancement factors ~ 10^9 were consistent with those of the simulations within a factor of ~ 2 for several experimental conditions (Fig. 1). The results fortify the indispensible importance of EM mechanism for SERS [1]. Furthermore, we examined SERS blinking phenomena, which have prevented us from SERS applications, within the framework of EM mechanism. SERS is usually accompanied by surface enhanced fluorescence (SEF) as a background. Both SERS and SEF blinking have exclusively treated by EM enhancement of Raman scattering and fluorescence. The intensity instability is inversely proportional to the enhanced nonradiative decay rate of R6G molecules. The estimation suggests that separation of the molecules from Ag NP surfaces is several angstroms. The spectral instability is induced by blue-shifts in the plasmon resonance. This analysis provides us with a quantitative picture for SERS blinking [2].

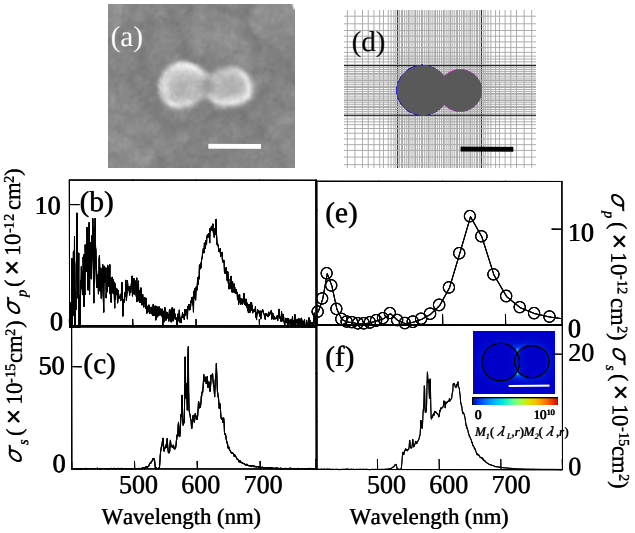

Fig. 1. (a) SEM image of an Ag dimer, (b) experimental plasmon resonance spectrum, and (c) experimental SERS spectrum excited at 532 nm. (d) Modeled structure of an Ag

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O-33

Transparency through a metallic film and non-Reyleigh scattering with anisotropy particles

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We propose an anisotropy route to realize perfect electromagnetic wave tunneling through a metallic film. EM transparenency is achieved in such an anisotropy-metal-anisotropy structures for both polarizations and over nearly all incident angles. The criterion for perfect transmission is obtained by analyzing the effective medium theory and the EM fields of such an anisotropic structure. The solutions hold for both lossless and lossy cases in a quite large frequency range. In addition, for anisotropic Rayleigh nanoparticles (or nanowire), one observes unusual non-Rayleigh scattering behavior, which makes enhanced transparency of the anisotropic particles.

O-34

Graphene plasmonics

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Grapheneplasmons produce unprecedented levels of light confinement and can be easily tuned by electrostatically charging this atomically thin carbon-layer material. Here, a tutorial description of plasmons in nanostructured graphene is given, supported by first-principles calculations and a review of existing experimental results. We further discuss applications to extraordinary optical phenomena, such as record-high near-field enhancement and complete optical absorption, as well as quantum physics in a robust solid-state platform. These results are configuring the birth of a new bold direction in nanophotonics, in which plasmons can finally meet the high expectations that they have arisen during the last decade.

O-35

Noble metal nanoparticles as window into the nanoworld

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Noble metal nanoparticles allow us to access certain aspects of the nanoworld. At the sensoric side, they provide the base for ultrasensitive detection based on changes in electronic and optical properties upon the binding of analyte molecules. These changes can be read-out using established approaches like microelectrodes or optical far-field techniques. So these particles connect the nanoworld with their enhanced or even novel sensoric abilities with the established technical environment. Special manipulation techniques such as dielectrophoresis allow for a parallel manipulation of particles and their integration into this environment. On the other side, the highly efficient light scattering abilities enable an optical readout even of single nanoparticles using quite established optical setups. Moreover, this efficient interaction with light allows the utilization of a nanoantenna effect for manipulations, using these sub-wavelength structures to focus and couple energy in the nanoworld with nanometer resolution.

O-36

State of the Art and Applications of THz Plasmonics and Metamaterials

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Plasmonics open new ways for many applications especially at THz frequencies. The talk will be divided into three parts:

-Terahertz Quantum Cascade Lasers (QCL) beam-shaping

-Terahertz Split Ring Resonators with different excitations

-Terahertz Microscopy

QCLs are probably the most promising sources for Terahertz wave generation. The key issue especially for double metal QCLs is the extraction and the beam shaping of the emitted power. I will present and compare the most recently proposed solutions in different groups. The first approach for single plasmon QCL is well-known at THz frequencies and uses a Si-lens (Q. Hu's group at MIT). In a second approach horn antennas can be placed at one or two facets of the QCL. These horn antennas can be made in different manners. The first one is made with etched Silicon covered by metals. As for us at IEMN in collaboration with MPQ-laboratory, we have developed a TEMHA (Transverse Electromagnetic-Horn Antenna) with very interesting properties for general THz applications. This TEM-HA is also very useful for the beam shaping of THz metal-metal QCL. The ground plane can be used and usinated for the launching of Zenneck-Surface waves. The last and also very promising approach has been proposed by Capasso's group (Harvard University). It is based on plasmonic effects and constructive interferences for lattices at one facet of the QCL. All of these different approaches have quite similar main-lobe beamwidths at THz frequencies in the order of ~10° x 10°. The challenge is now to reduce even more this beamwidth with original approaches. We are developing bull-eye arrays for THz QCL in collaboration with Prof. M. Sorolla's group (Navarra University).

In the second part of the talk, I will present the propagation of THz waves on a single metallic strip which is a Plasmon-like mode. The properties and basic applications of this Planar Goubau- Sommerfeld Line (PGSL) will be shown. For example one can realize filters in different ways. The topology of this line is well suited for the excitation of metamaterial's unit cell like split ring resonators (SRR) [1]. We can also take benefit of the propagation on a single strip for microscopy and nanoscopy applications. This is an original approach especially in order to "bring" the THz wave to the sample in a guided way instead of a commonly used free space propagation and scattering by a tip. Preliminary results show a highly subwavelength resolution.

This study is done in the framework of HI-TEQ ANR project leaded by S. Dhillon (LPA-ENS).

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O-37

Applied plasmonics based on Kretschmann configuration

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Efficient excitations of surface plasmon polaritons (SPPs) are achieved by Kretschmann configuration under the condition of matching the wave vector of the incident light in a prism with the wave vector of the surface plasmon in a metal surface. In Kretschmann configuration, the localized and enhanced electric field is generated on the metal surface by the excitation of propagation mode of SPPs. We have applied the enhancement and the localization of photons to the nanofocusing, the fluorescence enhancement, and the nonlinear enhancement.

We proposed a focusing device of a metal-coated axicon prism for the localization of photons in nanometric region by surface plasmon excitation (Fig. 1). The excitation mechanism and the localization of photons by the axicon prism were investigated using a finite-difference time-domain (FDTD) simulation [1]. Experimental demonstrations and verifications of the excitation and converging of SPPs, i.e., plasmonic nanofocusing, were achieved by observing the scattered and reflected light from the metal-coated axicon prism [2].

We demonstrated that SPPs on aluminum excited by Deep-UV light enhance the fluorescence. Considering the oxidized thickness of aluminum, the experimental results of incident angle dependence of the reflectance show good agreements with the calculation results. We also present about the enhancement of second harmonic generation with a polymer thin film by surface plasmon excitation.

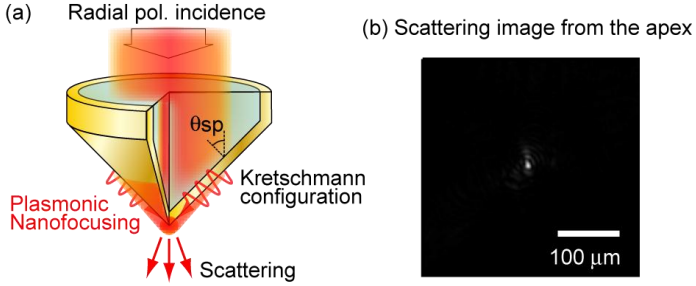

Figure 1. (a) Schematic of a metal-coated axicon prism. A localized spot in nanometer region is generated at the apex by constructive interference of surface plasmons. (b) Scattering image for radial polarization incidence.

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O-38

Fano resonances in plasmonic nanostructures

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Strongly interacting nanostructures offer highly tunable platforms for the study of radiative interference and coherence effects such as subradiance, superradiance, and electromagnetically induced transparency (EIT).[1] In structures with reduced symmetry, narrow Fano resonances can appear in their extinction spectra resulting from the interference between superradiant and subradiant modes.[2] Apart from their fundamental importance, such phenomena are also of practical interest in chemical sensing,[3] waveguiding,[4] and SERS applications[5] because of their extraordinarily narrow linewidths and large electric field enhancements. In this talk, I will present a general framework for the description of Fano plasmonic Fano resonances and illustrate the concepts with examples from recent applications to symmetry broken nanoshells[6] and nanodisks,[7] small nanoparticle clusters,[8], planar ring-disk systems (Fanocavities) [9], plasmonic heterodimers,[10] and nanocubes on dielectric substrates[11] .

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O-39

Realization of Variable Three-dimensional Terahertz Metamaterials Tubes for Passive Resonance Tunability

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Metamaterial with resonance tunability is one of the most important developments in the metamaterials research, which can make terahertz devices working over broadband flexibly. In this work, passive resonance tunability is realized by three-dimensional (3D) ‘metamaterials tube’, which gets rid of the external controlling resources. The 3D metamaterials tubes, in the form of a single-layer cylindrical hollow-core tube with the split ring resonators (SRRs) array built on the inner wall, are designed and fabricated by simply rolling up two-dimensional (2D) planar metamaterials (resonance frequency f0=0.75 THz) fabricated on the flexible PEN substrates. Varying the diameter from 6.20 to 4.00 mm, the resonance frequency shows a blue-shift of 0.38 THz (tuning range: 50.6% of f0) from 0.75 to 1.13 THz when the polarized terahertz wave propagates through the metamaterials tube.
FDTD simulation reveals that the passive resonance tunability is attributed to the destructive magnetic coupling among the neighboring SRRs on the curved space of the metamaterials tube. The metamaterials tube with this blue-shift performance provides a novel approach to achieve flexible resonance tunability into higher terahertz frequency above 1.1 THz. Meanwhile, the solid-core metamaterials tube, wrapping the 2D planar metamaterials against the transparent unknown materials in terahertz regime, can be applied to identify the materials by measuring the resonance frequency shift due to the refractive index change of the core materials. The solid-core metamaterials tube can measure the refractive index change of 0.0075, which would be an ultra-sensitive characterization method for the sensing applications.

O-40

Ultra-thin Dielectric Coating on Metal Nanoparticles for Surface-Enhanced Fluorescence and Raman Spectroscopy

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Noble metal nanoparticles exhibit unique, remarkably vivid optical properties due to excitation of their surface plasmon (SP) modes by incident light [1]. Plasmon excitation results in significantly enhanced local electric fields around the nanoparticle surfaces, which gives rise to fundamentally interesting phenomena and technologically important applications, such as surface-enhanced fluorescence (SEF) [2] and surface-enhanced Raman spectroscopy (SERS) [3].

In the applications of the SERS, a convenient way to build an active substrate is to use silver or gold nanoparticles, either in a solution or immobilized at a dielectric surface. Silver is generally preferred over gold as a SERS active element, because of its up to 2 orders of magnitude enhancement factor especially in the visible spectrum region. However, using silver as a substrate is also associated with serious drawbacks for, specifically, chemical stability and biological applications. A dielectric coating is usually preferred, although it is widely thought that this will sacrifice to some extent the field enhancement effect. In the context of the SEF, there are two competitive mechanisms depending on the separation distance between the fluorophores and metal surfaces. One is the quenching due to electron transfer or nonradiative energy transfer from the fluorophores to the metal. Another is the electric field enhancement mechanism through the Purcell effect which takes place at the stages of optical excitation and the fluorescence emission. To obtain the maximum SEF enhancement, how to maximize the local field at the interface and at the same time to minimize the quenching effect is the key point.

Here, I will first show that in the context of electrodynamics, the electric field on the surface of a core/shell metal/dielectric nanoparticle has a unique dependence on the dielectric layer thickness instead of a monotonous decay upon the increase of the dielectric coating thickness. Interestingly, we predict that the electric field enhancement on the composite nanoparticle surface could be improved in relative to uncoated metallic nanoparticles at their corresponding resonances. In the dipole approximation, an analytical formula is derived for the optimal layer thickness that depends on the dielectric constant of the coating layer, which is found to be normally around 1 nanometer for optical transparent dielectric materials.

To implement this property of ultra-thin dielectric coating for SERS and SEF, we deposit an ultrathin tetrahedral amorphous carbon (ta-C) film of different thickness on Ag nanoparticles prepared by nanosphere lithography. The ta-C film has the element of sp3 (as in diamond) bonding up to 90%. It is found that an ultrathin ta-C layer can modify surface plasmon to produce even a higher local electric field than the uncoated particles. In the experiment, we observe that Ag nanoparticles substrate coated with a 10 Å ta-C film shows a maximum enhancement of Raman signals [4]. Furthermore, since an ultrathin ta-C film could efficiently reduce the quenching, the ta-C coated metal nanostructures can also be used to realize the maximum enhancement in SEF [5]. In addition, the ta-C coating has many desirable properties, such as pinhole free, chemical inertness, thermal stability, biocompatibility, high electrical resistance, and optical transparency in the visible and infrared.

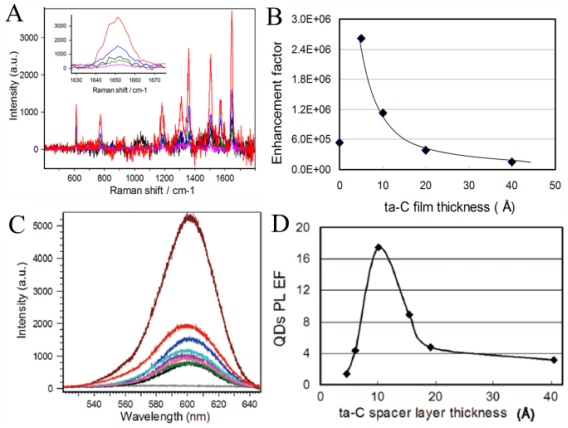

Figure 1. (A) SERS spectra of 10-6 M R6G molecules absorbed on the Ag nanoparticle substrates coated with the ta-C layer with different thicknesses. (B) Dependence of the SERS enhancement factor on the ta-C layer thickness. (C) PL spectra of CdSe/ZnS QDs absorbed on the Ag nanoparticle substrates coated with the ta-C layer with different thicknesses. (D) QDs PL enhancement factor as a function of ta-C spacer layer thickness.

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O-41

Trapping, Manipulation, and Patterning of Gold Nanoparticles by Optical Tweezers

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Gold nanoparticles have found applications in many areas such as nanophotonics, biomedicine, and sensitive fluorescence and Raman signal detection, due to their promising properties of surface plasmon resonance (SPR). Usually they are too tiny to be manipulated with conventional mechanical methods. In this talk, we will report our recent experimental efforts on trapping and manipulation of gold nanoparticles by means of optical tweezers.

First, we have developed a technique based on dual-optical tweezers to perform trapping, transferring, positioning, and patterning of gold nanorods. The convenient manipulations are achieved by taking advantage of the longitudinal surface plasmon resonance of gold nanorods and the anisotropic optical trapping forces formed by two linearly polarized Gaussian beams. The dual optical tweezers is very promising for controlling the property of SPR through creating a wide variety of complicated patterns. The technology can be further harnessed to produce a desirable SPR that comes from computer design, and become a versatile experimental "design" tool to create controllable patterns from two gold nanorods.

Second, we have developed optical tweezers made from radially and azimuthally polarized beams and realized optical trapping of gold nanoparticles. The transverse optical trapping stiffness of gold nanoparticles is measured, which shows that the radially polarized beam exhibits a higher trapping efficiency than azimuthally polarized beam and Gaussian beam. The transverse stiffness of particles with different diameters is measured experimentally and calculated via the discrete-dipole approximation method, and good agreement between theory and experiment is found.

The success of optical tweezers technology in application to nanophotonics of metal nanoparticles opens up a new avenue to manipulate single or several metal nanoparticles to create a controllable system for exploring new plasmonic, optical, and quantum physical properties of light-matter interaction.

O-42

Quantum Plasmonics: Dynamical Interactions Between Plasmons and Other Excitations

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In the past decade, the emerging field of plasmonics has received enormous attention due to its spatial and temporal advantages in applicationsthat potentially integrate electronics and photonics.Classical studies treatplasmons as waves of electromagnetic field concentration with the microscopic electronic nature hidden in the phenomenological dielectric responses. As the fabrication techniques continue to improve and the system sizes continue to shrink down to the quantum regime, the coupling of the plasmon modeswith other elementary or collective excitations, e.g. phonons, excitons, and polarons in systems of close vicinity, cannot be ignored. In this presentation, we will attempt to give a comprehensive view on the interactions between plasmons and other types of excitations. In particular, we will focus on several interesting experimental and numerical observations, where microscopic descriptions of the dynamical processes involved are essential.

O-43

Real-space mapping of infrared plasmons on antennas, transmission lines and graphene

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We study the near-field distribution, hot spot generation and energy transport in infrared antenna and transmission line structures by using a scattering-type scanning near-field optical microscope (s-SNOM) equipped with dielectric tips. While scanning the sample surface, the tip scatters the local near fields, which are subsequently detected by a distant detector in the far field. Interferometric and polarization-resolved detection yields amplitude and phase images of the different near-field components, which allows for mapping of the polarization state in nanoscale antenna gaps [1], super- and subradiant antenna modes [2] and of mid-infrared energy transport and compression in nanoscale transmission lines (Fig. 1) [3]. We furthermore provide experimental evidence that the intensity elastically scattered off the dielectric tip scales with the fourth power of the local field enhancement provided by the antenna, and that the underlying electromagnetic mechanism is identical to the one commonly accepted in surface-enhanced Raman scattering [4].

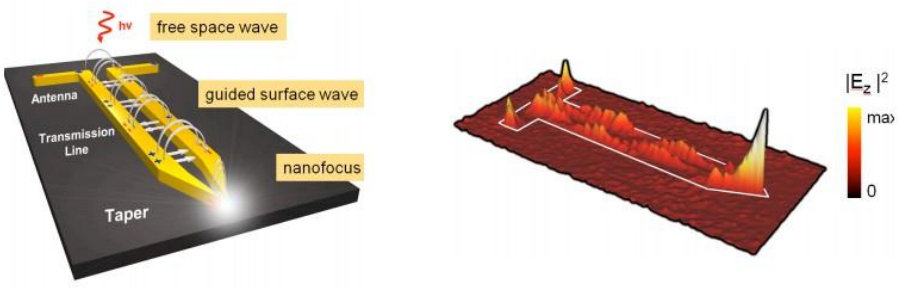

Figure 1. Infrared nanofocusing with tapered transmission lines. Left: Concept. Right: s-SNOM image of the tapered transmission line structure, taken at 9.3 μm wavelength. It shows the infrared field intensity (vertical axis) along the transmission line, revealing the nanofocus at the taper apex.

s-SNOM also enables the launching and detecting of propagating and localized plasmons in graphene nanostructures. Spectroscopic real-space images of the plasmon modes allow for direct measurement of the ultrashort plasmon wavelength and for visualizing plasmon control by gating the graphene structures. With our studies we establish a basis for the development of nanoscale infrared circuits, which could have interesting application potential for the development of ultra-compact infrared sensors, spectrometers and novel near-field probes.

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O-44

Propagating surface plasmons on silver nanostructures

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The control of light propagation at the nanometer scale is critical for the development of nanophotonic chips and novel sensors, and is a hot research topic in the field of Plasmonics all over the world[1-3]. Recently, we made a series of progresses in the study of propagating surface plasmons in silver nanowires.

We observed that light from the end of a silver nanowire, following excitation of plasmons at the other end of the wire, is emitted in a cone of angles peaking at nominally 45-60 ° from the nanowire axis, with virtually no light emitted along the direction of the nanowire [4]. We also investigated the correlation between the incident and emission polarization in plasmonic Ag nanowire waveguides. We find that the polarization change depends only slightly on the diameter and length of the wire, but sensitively on the shape of the wire terminations[5]. Very recently, we investigate how the properties of a nearby substrate modify the excitation and propagation of plasmons in subwavelength silver nanowires [6]. With decreasing nanowire-substrate separation, the in-coupling efficiency shows strongly oscillatory behavior due to coherent interference. The plasmon damping increases with decreasing separation, due to increasing coupling of the wire plasmons to photonic modes of the substrate through image-like interactions. We also demonstrate an interference-based, nanowire all-optical modulator[7]. The device consists of two nanowires: a short nanowire with one of its ends directly adjacent to a main, or "trunk" nanowire of longer length, forming a "y" structure. The two adjacent arms of the structure serve as input terminals, with the remaining end of the longer wire as the output. By changing the relative phase or the relative polarization angle of the two input signals, constructive and destructive interference of the plasmons launched onto the main wire occurs, resulting in a strongly modulated emission of the signal at the output.

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O-45

Non-planar nano-arc-gap arrays fabricated via colloidal lithography

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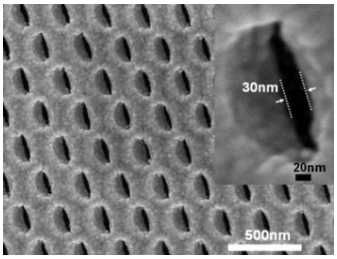
We report a method to fabricate non-planar nano-arc-gap arrays via colloidal lithography and shadow metal deposition. It is found that there is a localized surface plasmon resonance which results an extraordinary optical transmission. The electric field is strongly localized at the nano-arc-gap region, therefore it induces a resonance which has an ultrasmall mode volume of less than $2.44\times10^{-6}\mu m^3$, this would be valuable for the design of the optoelectric circuits.

Noble metal nanostructures have attracted lots of attention due to their splendid applications in the fields of sensors, biology, optoelectronic circuits. Since Ebbesoniii found an unusual phenomenon of extraordinary optical transmission and Pendryiii re-dug the concept of negative refractive index, lots of structures have been proposed and fabricated, for example, periodical holes, split-ring resonators, fishnet structures, and so on. Most of the structures are fabricated via electron beam lithography, focused ion beam lithography, and nano-print as well as photolithography. Colloidal lithography is a cost-effective method to prepare nanostructures; however it is rare used, even though crescent holes, crescent ring metal cups and bow-tie structures can be prepared via colloidal lithography. Here we report a novel method to prepare non-planar metal nano-arc-gap arrays based on inverted colloidal lithographyiv and shadow metal deposition. The fabricated structure is shown in Fig. 1v. The gap-width at the middle is around 26 nm. Before silver evaporation, the depth of the dimple and diameter of the upper circle of the dimple are around 90 nm and 243 nm respectively, the period of the nano-arc-gap array is 285 nm. After silver evaporation, the silver thickness out of the dimple is 64 nm, and the thickness of the silver at the dimple area is various because of the evaporation angle is various due to the curvature of the dimple. The estimated thickest thickness of the silver at the dimple is around 46 nm.

It is found that there exists an extraordinary optical transmission (EOT) in transmission spectrum when the electric field of the incident wave is along to the gap, which is shown in Fig. 2. The EOT resonator is insensitive with the incident angle. It is confirmed that this EOT resonator is induced by a localized surface plasmon. Finite difference time domain method is used to simulate the optical transmission of this structure shown in Fig. 2 as well. It is found that each of the nano-arc-gap can support a resonator with ultrasmall mode volume of $2.44\times10^{-6}\mu m^3$. This structure would be useful in sensors and optoelectronic circuits.



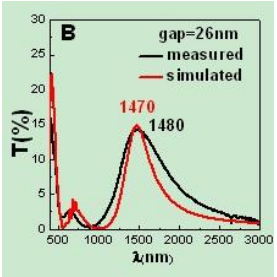


Fig. 1 Scanning electron microscope picture of non-planar nano-arc-gap array. Inset is an enlarged picture of single nano-arc-gap.

Fig. 2 Measured and simulated transmission spectra for electric field perpendicular to the gap at normal incident angle

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O-46

Excitations of surface plasmonpolaritons in double layer metal grating structures

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We study the light scattering properties of double layer gratings (DLGs) made from Au on SiO2 substrates. It is found that surface plasmonpolaritons (SPPs) can be excited in the DLGs for a separation of up to 150 nm between the two Au grating layers and the collective reflectance spectra exhibit a strong resonant peak and a closely lying dip as a result of the surface plasmonpolariton excitations. It is also found that the angle-resolved specular reflectance spectra show a dip-peak pair structure, while the angle-resolved reflectance spectra of higher diffracted orders show a complementary peak-dip pair structure. Finally, operation of the DLGs for efficient wavelength demultiplexing is proposed and discussed in light of these results.

O-47

Switching the electric and magnetic responses of metallic microstructures at the same frequency: an approach to realize negative refractive index

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Controlling the transmission features of the electromagnetic (EM) waves is an important issue in optics. The magnetic and electric resonances of the *same* metallic microstructure are shown to be switchable at the same frequency band by simply rotating the polarization of incident light by 90°. This property originates from the constructive /deconstructive superposition of electric and magnetic responses of four orthogonally placed U-shape resonating (USR) elements. Although each individual resonator exhibits distinctive electric and magnetic responses, the collective response of all the resonators in the unit can be purely electric or magnetic. In USR, once the horizontal bar in the U-shape is moved to center of the vertical bars, an H-shaped metallic resonator is constructed. We further show that both the magnetic and the electric resonances can be realized simultaneously at the same frequency band. Negative refractive index (NRI) is consequently realized. The frequency band with NRI can be tuned by the structural parameters of the H-shaped resonators. This design demonstrates a unique example to construct metamaterial with negative refractive index.

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O-48

Putting Plasmonic Probes in Perspective: The Case for the Campanile Tip

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Efficiently converting photonic to nano-plasmonic modes for localizing and enhancing optical near fields is of high interest for applications ranging from nano-optical imaging and sensing to computing. Based on extensive simulations of various "optical transformer" geometries, we propose a novel photonic-plasmonic hybrid Scanning Near-field Optical Microscopy (SNOM) probe called the "campanile" tip. These campanile tips couple the photonic to the plasmonic mode, then adiabatically compress the plasmon mode, over a broad bandwidth, which is crucial for many optical spectroscopy techniques. The confinement of the optical near field is determined by the gap size between the two antenna arms, which can be well below 10nm given the appropriate resolution of the dielectric deposition method. Based on excitation through the back of the tip similar to traditional aperture-based NSOM tips, these campanile tips are an excellent candidate for background-free nanoscale imaging and spectroscopy applications on dielectric, non-transparent substrates. We used FEM to simulate conventional aperture-based probes, the coaxial plasmonic probes, traditional apertureless SNOM tips and the state-of-the-art adiabatic-compression-type probes, and compared them all with the campanile tip geometry. The understanding of relative strengths and weaknesses of each SNOM probe geometry served as the guideline for the design of the campanile tips, resulting in their superior field coupling, enhancement and resolution capabilities.

O-49

Plasmonic photothermal effects and their applications

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Photothermal effects in plasmonic nanostructures have great potentials in applications forphotothermal cancer therapy, optical storage, photo-thermo-voltaics, etc.Most of previous work focused on photothermal effects at visible or near infrared (wavelength <1 m), while the research on longer wavelength is limited. We have recently demonstrated plasmonic metamaterial absorbers at optical communication wavelength [1-3], polarization dependent or independent. We have even observed close-to-instantaneous fusion and re-shaping of the nanoparticles with a nanosecond pulse train in such metamaterial absorbers, due to extremely strong photothermal effects enhanced by the plasmonic resonances [4]. The generated heat profile has a subwavelength resolution, and the resonance wavelength can be in principle tailored to arbitrary wavelength region by choosing an appropriate geometry for the resonator structure. We have even developed a heat transfer model to investigate the temporal variation and spatial distributionof temperature in such plasmonic gold nanostructures [5]. The model shows that the temperature of the gold nanoparticles can be raised from room temperature to >600 K in just a few nanoseconds with a low light luminance, owing to enhanced light absorption through strong plasmonic resonance.Our heat transfer model of plasmonic nanostructure can serve as an excellent numerical guideline for designing nanophotonic devices with functioning photothermal properties, which is critical in applicationsincluding drug delivery, optical storage and photo-thermo-voltaic.

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O-50

Tuning asymmetry parameter of Fano resonance of spoof surface plasmons by modes coupling

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To explore the tunability of the spoof surface plasmon (SSP) based Fano resonance [1], whose steep dispersion can facilitate applications such as biochemical sensing, we have designed a kind of complex hole arrays on gold film to tune the asymmetry parameter (q) of Fano resonance of SSPs in the far-infrared regime. It was found that the q value of the SSP based Si(1,1) mode varies linearly with the diameter (d') of the smaller, interstitial holes and experiences a sign reversal due to the SSP modes coupling between two different square lattices which constitute the complex hole arrays.

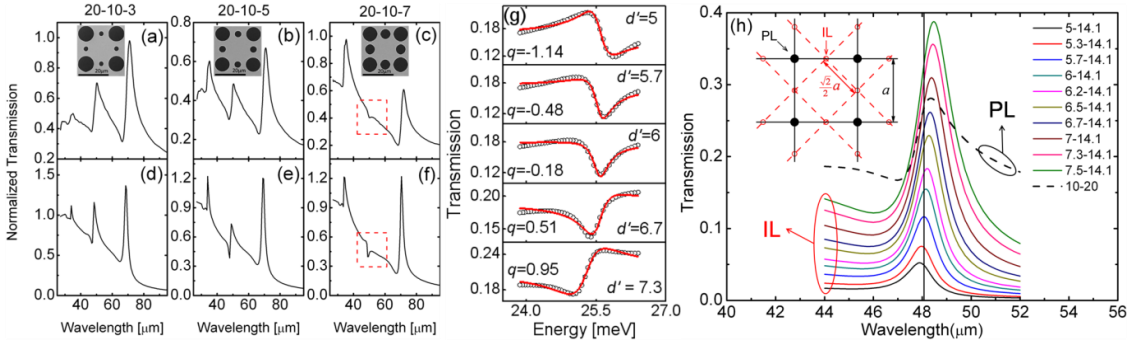

Figure 1. Experimental (a-c) and simulated (d-f) transmission spectra with SEM images inset. (g) Simulated (circle) and fitting (curve) of the Si(1,1) mode for different hole arrays. (h) Simulated Si(1,0) mode of the IL (solid curves) with different d' and Si(1,1) mode of the PL (dashed curve). The inset shows the schematic geometric configuration of the complex hole array. The vertical line denotes the resonant wavelength (48.1 μm) of Si(1,1) mode of the PL.

Fig. 1 (a-c) show the transmission spectra of complex hole arrays with periodicity a = 20 μm, diameter of the primary hole d = 10 μm and different interstitial holes (d' = 3, 5, 7 μm and denoted as $a - d - d'$). The Si(1,1) mode of the 20-10-7 lattice turns into an anti-resonant dip, marked by the dotted line box in Fig. 1(c). Numerical simulations using finite element method have been carried out (Fig. 1 (d-f)), showing that the q value of the Si(1,1) mode varies linearly with d' and experiences a sign reversal as d' approximates 60% of d, as shown in Fig. (g).

The complex hole arrays are actually comprised of two kinds of square lattices: the primary lattice (**PL**) with periodicity $a_{PL} = a$ = 20 μm and the interstitial lattice (**IL**) with periodicity $a_{IL} = a/\sqrt{2}$ = 14.1 μm (Fig. 1 (h)). According to the Bragg coupling relation, the Si(1,0) mode of the IL locates nearly with the Si(1,1) mode of the PL. From Fig. 1 (h), we can see that as d' increases from 5 μm to 7.5 μm, the resonant wavelength of Si(1,0) mode of the IL red-shifts from 47.8 μm to 48.4 μm, passing through the resonant wavelength of Si(1,1) mode of the PL (48.1 μm) as d' approximates 6 μm. The phase of the latter mode reverses [2] and as a consequence the asymmetry parameter of the Fano resonance of the complex hole array flips its sign from negative to positive, as is shown in Fig. 1 (g). The proposed complex hole arrays may serve as candidates of building blocks for new metamaterials and hold promise for a wide range of future applications in science and engineering.

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O-51

Surface Polariton Resonances with Magnetic Materials

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Surface plasmon-polariton is important for plasmonic and nanophotonic applications [1]. It has become a common perception and textbook fact that only the p-polarized light fields can excite surface plasmon resonance in dielectric and metallic medium [2]. In the case of magnetic materials, new possibilities arise.
For surface-plasmon polariton (SPP) between two arbitrary magnetic and/or dielectric/metallic materials, it is found that SPP waves can also exist for s-polarized field. We obtain expressions of the SPP wavevectors for s- and p-polarized fields. Conditions for acquiring large tangential wavevector are obtained. We also study the property of the wavevector for the cases when one of the medium is superconductor [3] and quantum coherence material that can be controlled by a laser [4].
This research provides new directions for studying the spectrum of the surface polaritons using various combinations of metallic, dielectric and magnetic materials.

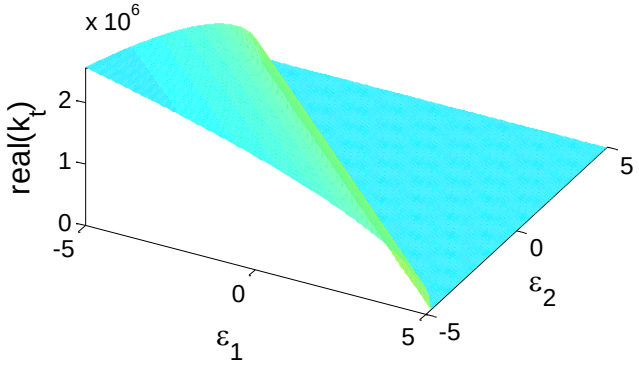

Figure 1. Tangential wavevector between two medium with magnetic permeabilities μ_1=1 and μ_2 = -0.95.

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O-52

Enhanced Transmission and Emission in Active Plasmonic Hybrids

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At first, we introduce Fano resonances in a dipole-quadrupole plasmon nanorod (NR) dimmers, where the quadrupole mode of a plasmon NRs is excited by a nearby dipole source of plasmon resonances or nano-emitter radiations [1,2]. The transparency is induced in the dipole-quadrupole NR dimmers. The emission rate of the nearby nanoemitters is strongly modulated by plasmonic interferences.

Then, we investigate enhanced transmission and emission in the plasmonic hybrids consisting of arrayed metal nanoparticles (NPs) and NRs. Owing to higher Q-factor of AgNRs, the AuNP-AgNR hybrids exhibit larger enhancement of transmission and more efficient energy transfer from NPs to NRs comparing to AuNP-AuNR hybrids. Furthermore, the AuNP-AuNRs hybrids shows strongly enhanced upconverted interband radiations in the visible region, while the AuNP-AgNR hybrids exhibits amplified intraband radiations (continuum generation) in the near infrared (NIR) region [3,4].

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O-53

Enhanced Raman scattering from self-assembled Si nanoclusters grown on siC: Spectrum and Imaging

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Si nanoclusters spontaneously form when GaN thin layer was grown on Si-rich SiC surface with molecular beam epitaxy. Such Si nanoclusters assembled into two kinds of structures: hill like and flattened islands. The former structure shows remarkably enhancement effect of Raman light scattering when the latter does not. Detailed micro-Raman spectral and imaging measurements were done. Tip-enhanced near-field Raman images show some interesting structures. In the talk, we will present the experimental results and discussion on the enhancement mechanism of Raman light scattering by these hill-like Si nanoclusters.

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O-54

Recent Progress on super-focusing Plasmonic lenses

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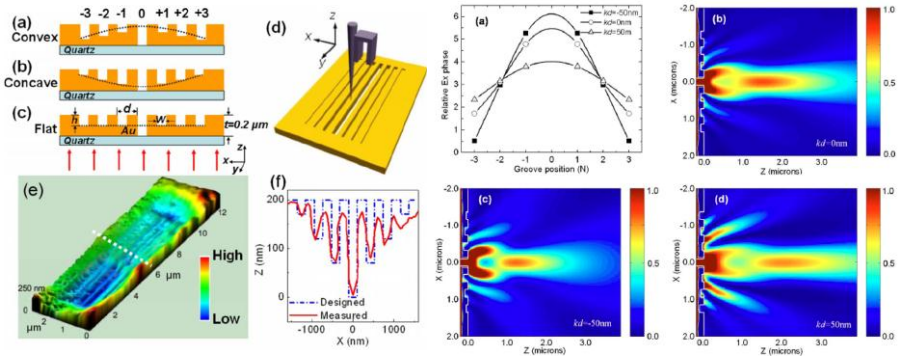
In recent years, plasmonic lenses that can super-focus light into subwavelength scale has attracted an increasing research interest, due to its promising application in optical data storage, nano-photolithography and optical antennas.

In this talk, we will review the recent progress of plasmonic lenses related researches in our group.[1-7] The presentation is focused on basic theory, design, fabrication and characterization of various super-focusing plasmonic lenses. We also show the application of the super focusing in nano-photolithography and demonstrate the 30nm resolution with our homemade system.



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O-55

Recent Instrumental Advances in Scanning Near-field Optical Microscopy and Tip Enhanced Raman Scattering

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We review modern experimental approaches and instrumental developments in the field of optical imaging and spectroscopy with subwavelength spatial resolution.

Different types of conventional aperture-type Scanning Near-Field Optical Microscopy (SNOM) are discussed with respect to various types of samples. SNOM techniques based on optical fibers and on cantilever-type SNOM probes are compared from the point of view of resolution, sensitivity, spectral range etc.

Apertureless SNOM (a-SNOM) techniques are described and compared to aperture-type SNOM. A-SNOM applications in plasmonics, photovoltaics and other areas are demonstrated.

Raman and fluorescence mapping with subwavelength resolution can be achieved by Tip Enhanced Raman and Fluorescence Microscopy (TERS, TEFS). We report TERS results on various samples such as carbon nanotubes, graphene, silicon and others. We discuss various modern approaches for fabrication of optical nanoantennas for TERS and TEFS.

O-56

Super-resolution imaging of plasmonic nanoparticle hot spots

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Surface-enhanced Raman scattering from a single molecule has been recognized for over a decade within the SERS community, but the phenomenon remains poorly understood. Because the metal nanoparticles that support single molecule SERS are smaller than the wavelength of light, they appear as diffraction limited spots in optical images, which obscures the location and dynamics of the molecule on the nanoparticle surface as well as the shape of the nanoparticle itself. This talk will describe recent efforts to use super-resolution imaging techniques to measure how molecules behave on the surface of noble metal nanoparticles in order to characterize electromagnetic field "hot spots." Super-resolution imaging allows us to defeat the diffraction limit by two orders of magnitude and resolve the position of the both SERS signal from the molecule as well as the inherent luminescence of the silver nanoparticles.

O-57

Strong light induced forces in plasmonic resonating systems

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The electromagnetic force/pressure acting on a pair of parallel metallic plates under electromagnetic illumination is considered and we find that in the plasmonic regime, the metal plates would experience a sizable electromagnetic pressure that is two to three orders of magnitude stronger than the usual photon pressure if the metallic sandwich is at resonance with the incident electromagnetic wave. In the resonant cavity, the induced electric fields give attractive forces and the induced magnetic fields give repulsive forces and these two opposing effects tend to cancel each other. Strong forces can be obtained if the effect of one of the fields can be suppressed one way or another. In the plasmonic regime, the magnetic field repulsion is suppressed by the shifting of the magnetic field energy into the kinetic energy of electrons, and that leads to an attractive force coming from the electric field. If we go to the low frequency regime in which field penetration is small, the electric field leakage diminishes the attractive electric forces, leaving behind the repulsion due to magnetic field. The effect of surface corrugation and surface roughness is also investigated, and we find that corrugation/roughness generally induces attraction between the plates.

O-58

Plasmonic Metamaterials Fabricated by Multiphoton Photoreduction

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Metamaterials, artificial composite structures with exotic material properties, have emerged as a new frontier of science involving physics, material science, engineering and chemistry in the past decade, which offered an entirely new route to design material properties. Plasmonic metamaterials is one area of the fastest develop in metamaterials research, because plasmonic polariton plays important role in metallic nanostructures. As an emerging technique to fabricate micro/nanostructures, multiphoton processing has been widely used to fabricate micro/nanometer-scaled patterns in the past decade as one of the recognized powerful lithography tools. A number of two-dimensional (2D) and three-dimensional (3D) microstructures have been successfully created using multiphoton processes toward photonic, electronic and plasmonic applications with polymers, dielectrics and metals. Progress has been made on patterning metallic nanostructures with the multiphoton photoreduction of femtosecond laser. However, comparing to the spatial resolution of nanometer scale achieved with polymers, obtaining the resolution in nanometer scale with multiphoton photoreduction is still a hard challenge for fabricating metallic nanostructures. In this presentation, we will report the laser direct patterning of metallic nanostructures, which improve the resolution upon diffraction limit in the fabrication of metallic microstructure. The plasmonic metamaterials constructed by the metallic micro/nanostructures fabricated by multiphoton photoreduction technique will be exhibited with their optical properties.

O-59

From Single Nanoparticles to Tip-enhanced Raman Spectroscopy

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The localized surface plasmon resonance(LSPR) is closely related to the surface enhancement phenomenon, such as tip-enhanced Raman spectroscopy (TERS) and surface-enhanced Raman spectroscopy (SERS), as well as the plasmonic materials, devices, and sensing. It also finds important application in plasmon assisted phototherapy. The UV-vis spectra (the extinction spectra) of metallic nanoparticles contain the contribution of absorption and scattering. However, a clear understanding of the relative contribution of absorption and scattering to the photothermal effect and the near-field enhancement effect is still absence. For this purpose, we successfully developed a simple method capable of separating the absorption and scattering contribution. In agreement with the theoretical prediction, Ag shows much higher scattering efficiency compared with Au and Pd. The latter shows a very high absorption but negligible scattering effect, and has found to be a very efficient photothermal therapy agent. The conclusion obtained from the measurement will guide the synthesis of nanoparticles to suit the end application in SERS and thermal therapy. The correlated single-nanoparticle dark field spectroscopy and SERS study reveals a clear correlation of SERS with the scattering effect, supported also by theoretical simulation.

When nanoparticles are dispersed on a metallic substrate, the near field distribution sensitively depends on the wavelength of the excitation laser. For example, when Au nanoparticles of 55 nm diameter are dispersed on a flat Au film, a clear switch of the hotspot from between the nanoparticles to between the nanoparticle and the film was found, when the laser wavelength changes from 532 nm to 632.8 nm. At 632.8 nm, the enhancement is not sensitive to the distance between Au nanoparticles but between the nanoparticle and the film. Such kind of structure can be an ideal model system for a homogeneous SERS substrate. By putting two nanoparticles on different sides of the film and illuminating on one nanoparticle, we found the LSPR can be transferred to the nanoparticle on the other side of the film depending on the wavelength and the polarization. Therefore, we can transmit the optics logical signals 3 dimensionally (3D) by simply tuning the polarizations and wavelengths of light, which points to the promising future of 3D plasmonic devices by using the strong interaction of nanoparticles with the substrate.

When the Au nanoparticle is replaced by a Au tip, it forms a TERS configuration, which can be used to study systems from monolayer species to single molecules, on single crystal Au substrates. Taking thiols for example, they can already form a compact layer on the surface after 2-hr immersion time. The scanning probe microscopy was unable to identify the difference clearly when the assembly time was further increased, but the TERS spectra showed a clear immersing time dependent behavior, which is a reflection of the strong interaction between the thiol molecules. The ability to simultaneously obtain STM images and Raman spectra of molecular SAM on gold single crystal surfaces clearly points to the promising future of using TERS to investigate the SAM process on surface. The single molecule sensitivity has been obtained both for resonant and non-resonant molecules and the latter is particularly important because the influence of resonant Raman effect can be neglected.

The present study points to the promising future of making use of the strong coupling interaction at the gap of nanoparticles as well as that of nanoparticle with the planar metal film.

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O-60

Plasmonic Controlled Molecular Junctions

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The ability to squeeze light by means of plasmons into nano-scale metal gaps offers exciting possibilities to probe, control, switch, and gate the conductance of nano-scale and molecular junctions.
Several experimental systems will be presented in which the enhanced plasmonic field within junctions is utilized to affect their *dc*-conductance properties by inducing current rectification at optical frequencies. The mechanism of rectification will be shown to be photo-assisted transport.
I willalso show that by the magnitude of current rectification it is possible to measure the plasmonic enhancement within metal gaps that are 1-2nm in size. Such determination is usually not trivial, and in many cases depends on certain assumptions and estimations. In contrast ourapproach is highly accurate and free of any estimations as to the size of the gaps, their shapes, or the number of molecules embedded within them.
Our study is a (necessary) step towards the realizationof ultra-rapid switching capabilities of molecular junctions by light. It also reveals valuable information on the interplay between conductance through metallic gapsand the properties of plasmons which can be induced within them.

O-61

Designing Three-Dimensional Silver Nanorod Arrays for Surface Enhanced Raman Scattering Applications

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Surface enhanced Raman spectroscopy (SERS) has the potential to act as a highlysensitive detection method for chemicals and biological agents due to its ability to simultaneously provide extremely low detection limits as well as structural and quantitative information about the analytes. However, the ultimate analytical usefulness of SERS has been hampered by the lack of a robust, simple and reproducible procedure to design high enhancement SERS-active substrates. Among different SERS substrates produced so far, silver nanorod (AgNR) arrays fabricated by physical vapor deposition method have shown superiorSERS performance. The main SERS enhancement mechanism for these AgNR arrays is believed to be the electromagnetic (EM) mechanism,where the local electric fields between the adjacent nanorods, on the tip of the nanorods and in the corner between the nanorods and Ag film, have been enhanced significantly due to the geometry of the nanorod arrays when excited by incident laser beam. The EM enhancement strongly depends on the shape, size, separation, arrangement of noble metal nanostructures, as well as thesurrounding dielectric environment; the enormous EM enhancement is believed to originate from the surface locations withspecificnanoscale topologies called “hot spots”. The “hot spots” are usually topologically singularities on metal surfaces, such as small gaps between two adjacent nano-objects,corners, or bends.It is expected that by rationallyengineeringAgNRs into three-dimensional (3D) structures such as zig-zag, bent, or helical rod arrays, one could potentially increase those “hot spots” to achieveeven better SERS performance. We have recently fabricated different kinds of 3DAgNR arrays, such as the square helical nanorods, arc nanorods, L-shaped nanorods, and bent nanorods using the dynamic shadowing growth method. For the helical nanorod arrays with fixed arm length, the SERS intensity is found to increase with the number of bending, while for the L-shaped nanorod array (with only one bend), the SERS intensity increases with arm length. For the bent nanorods with fixed total nanorod length, the SERS enhancement reachesa maximum at a fixed bent number. Potential explanations for those behaviors are proposed based on the number of “hot spots” generated through 3D nanorod design. Our results demonstrate that 3D nanorod arrays provide another dimension to design SERS substrates, and have great potential for other plasmonic based applications.

O-62

Manipulating microparticles by laser-induced vapor bubble on a metal film

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A low power weakly focused continuous-wave laser (532 nm) was applied to create a vapor bubble on a silver film. Microparticles dispersed in water were carried by the convective flow to the vapor bubble and accumulated on the silver film. By moving the laser spot, we easily manipulated the location of the bubble, allowing us to direct-write micropatterns on the silver film with accumulated particles. The reported simple controllable accumulation method can be applied to bimolecular detection, medical diagnosis, and other related biochip techniques.

The experiment setup is illustrated in Figure 1. A 120μm thick water sheet was sandwiched between a glass cover slip and SiO2 substrate, and then covered by a sputtered silver film. Red fluorescent polystyrene particles with 1 μm diameter were dispersed in deionized water. A green laser beam was expanded, collimated, and focused to the surface of silver film. When a 250 mW laser beam was focused on the interface between the silver film and water, a vapor bubble was created on the surface of silver film. When we changed the location of laser spot on the film, the bubble was dragged by the laser spot and moved as a result. As the particles were accumulated under the bubble, when the bubbles were moved, the particles were deposited along the route in which the bubble passes through. Afterwards, we directly wrote any micropatterns (see Fig.3) with the accumulated particles on the silver film. Such a technique can be used to fast concentration and pattern of live viruses on metal surfaces and enhance the sensitivity of detection of them from biological media without damaging the virus structure [1-2].

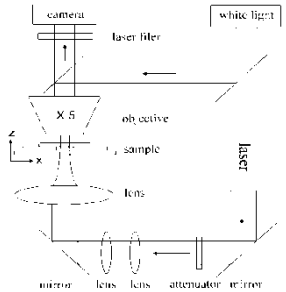

Fig.1 Schematic representation of the experiment setup.

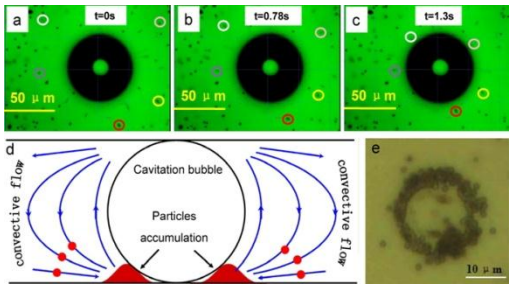

Fig. 2 (a)-(c): Pictures showing the movement of particles near bubble (marked by different color circles) at different moments, which are captured by the flow and dragged to the bubble; (d): a cartoon showing the convective flow and movement of particles around bubble; (e): a picture showing a ring formed by accumulated particles around the bubble.

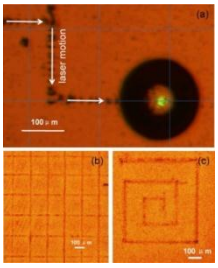

Fig. 3 (a) A picture showing the particles accumulated along the route the bubble pass through (white arrows presenting the relative moving direction of bubble on the film); two micropatterns of particles written by bubble: (b) square lattice and (c) Swiss roll.

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O-63

Generating and Manipulating Higher Order Fano Resonances in Dual-Disk Ring Plasmonic Nanostructures

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Fano resonances result from interference of excitation modes, thus, are intrinsically more sensitive to changes of the wavelength or the refractive index of the environment. In the last decade, it has been realized that Fano resonances can also be generated in plasmonic nanostructures with relatively easy control. Thus, considerable interests has emerged with many promising applications [1-2]. How to excite the higher order Fano resonances and to provide tunability to Fano line-shapes has become a very hot topic in recent years. We have recently proposed a silver dual-disk ring (DDR) plasmonic nanostructure to achieve Fano resonance [3], resulting from the coupling of higher order modes.

In this presentation, we report our observations on the optical behavior of higher order (quadrupolar, octupolar, hexadecapolar and even triakontadipolar) Fano resonances generated in disk ring (DR)silver plasmonic nanostructures. With dual-disk ring (DDR) nanostructures, a rich set of tunable Fano line-shapes is provided. We investigate DDRs including asymmetric cases either in two disks with different sizes or their asymmetric locations inside the ring. In the case of symmetric dual-disk ring (SDDR) nanostructures, we demonstrate that the quadrupolar and hexadecapolar Fano resonances are suppressed, which can reduce the neighbor-to-neighbor crosstalk of the spectrum, while the octupolar and triakontadipolar Fano resonances are enhanced. The potential of using the plasmonic nanostructures as a biochemical sensor is evaluated with the figure of merit (FOM) and the contrast ratio (CR).

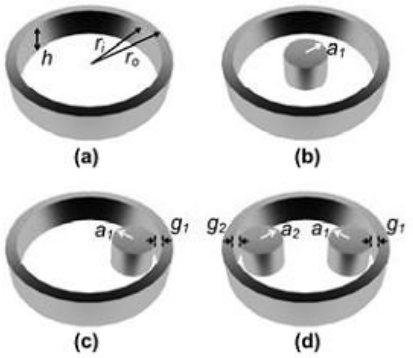

Figure 1. Schematics of various silver (Ag) disk ring plasmonic nanostructures under consideration: (a) a ring structure with geometric parameters of inner radius ri, outer radius ro and thickness h, (b) a concentric single-disk ring (CSDR) structure consists of the ring and a single-disk with variable radius a1, (c) a nonconcentric single-disk ring (NCSDR) structure with nanogap g1 and variable radius of disk a1, and (d) a dual-disk ring (DDR) structure consists of the ring and two disks with radii of a1 and a2 respectively. Symmetric dual-disk ring (SDDR) means a1 = a2 and g1 = g2, while asymmetric dual-disk ring (ADDR) means either a1 $\neq$ a2 or g1 $\neq$ g2.

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O-64

Bending waveguides made of anisotropic epsilon-near-zero metamaterials

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We study metamaterials with an anisotropic effective permittivity tensor in which one component is near zero. We find that such an anisotropic metamaterial can be used to control wave propagation and construct almost perfect bending waveguides with a high transmission rate (>95%). This interesting effect is due to the surface waves induced by the zero permittivity component that can redistribute the power flow on the surfaces of the metamaterial to smoothly connect with the propagating modes inside the metamaterial. Waves in such anisotropic epsilon-near-zero materials can be reflected by small-sized perfect magnetic conductor defects. Numerical calculations have been performed to confirm the above effects.

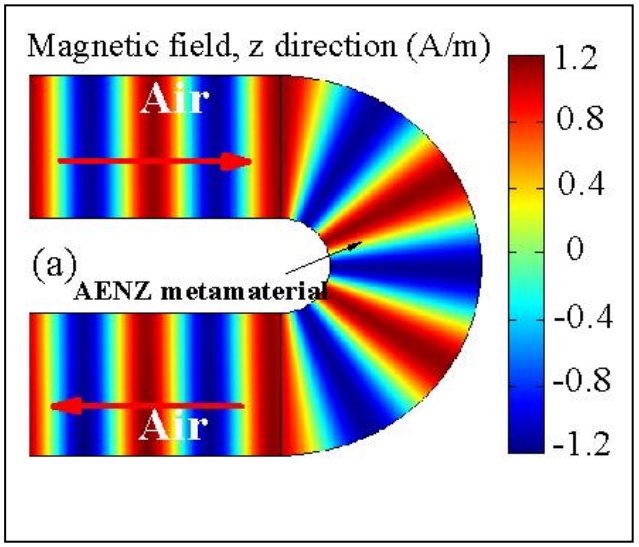

Figure 1. Magnetic field distribution in a waveguide with the bend part filled with an AENZ metamaterial.

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O-65

Optoplasmonic Molecules and Superlenses

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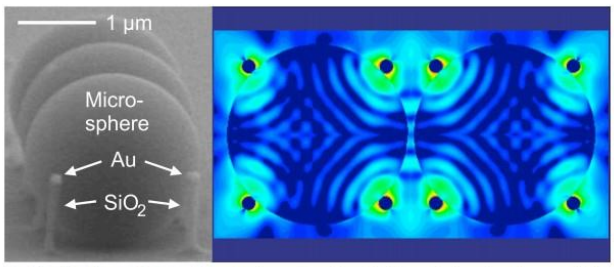
In this seminar I will review our recent activities in developing an on-chip integrated optoplasmonic nanocircuitry that combines the capability of optical microcavities to insulate molecule-photon systems from decohering environmental effects with the superior light nanoconcentration properties of nanoantennas. We fabricated discrete networks of optoplasmonic elements, referred to as optoplasmonic molecules, through a combination of top-down fabrication and template guided self-assembly. This approach facilitated a precise and controllable vertical and horizontal positioning of plasmonic elements relative to whispering gallery mode (WGM) microspheres. The plasmonic nanostructures were positioned at pre-defined locations in or close to the equatorial plane of the dielectricmicrospheres where the fields associated with the plasmonic modes can synergistically interact with the evanescent fields of the WGMs. We characterized the far-field scattering spectra of discrete optoplasmonic molecules and observed a broadening of the TE and TM modes indicative of an efficient photonic-plasmonic mode coupling between the coupled photonic modes of the WGM resonators and the localized surface plasmon modes of the NPs. Our experimental findings are supported by generalized multiple particle Mie (GMT) theory simulations, which provide additional information about the spatial distributions of the near-fields associated with the photonic-plasmonic hybrid modes in the investigated optoplasmonic molecules. The simulations reveal partial localization of the spectrally sharp hybrid modes outside of the WGM microspheres on the Au NPs where the local E-field intensity is enhanced by approximately two orders of magnitude over that of an individual Au NP. Optoplasmonic molecules amalgamate the advantages of conventional photonic and plasmonic nanomaterials and facilitate a tailoring of near- and far-field responses through photonic, plasmonic, and photonic-plasmonic mode coupling. Potential application of these materials for long-range photon transfer, light nanoconcentration, and information processing will be discussed.



SEM sideview of optoplasmonic molecules (left) and simulated near-field intensity distribution in an optoplasmonic dimer (right). Reproduced with permission from W. Ahn et al. ACS Nano 2011. Copyright the American Chemical Society.

O-66

Symmetry and the plasmonic molecule

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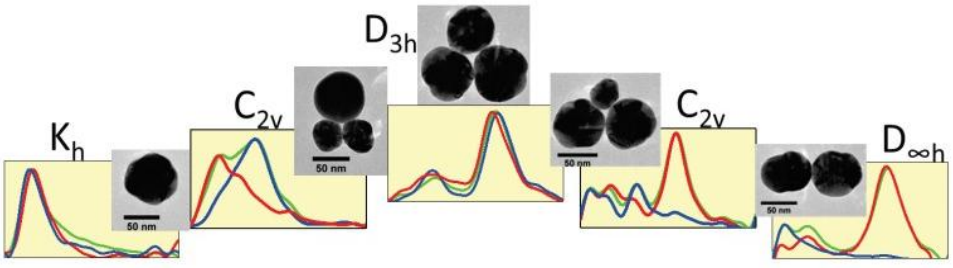
Plasmonic molecules (PMs) are nanostructures in which individual plasmon modes strongly interact and show distinct collective behavior. Interactions between such modes themselves and with external perturbations may lead to phenomena analogous to those found in atomic and molecular systems. Recognition of this analogy paves the way to the application of concepts developed in chemical physics to PMs. Such an analysis may reveal new insights on the physics of the interaction between light and surface plasmons, as well as on the way 'real' molecules might be influenced by this physics.

We used concepts from molecular group theory to understand the spectroscopy of trimeric PMs self-assembled from silver nanoparticles (1, 2). The equilateral triangle has high symmetry, described by the point group D3h. One way to break this symmetry is to systematically increase one of the triangle's vertex angles from 60° to 180°. This change lifts the degeneracy of the plasmonic spectral modes, and the new modes, which gradually shift from each other, can be classified based first on point group C2v and then on the group D∞h (linear chain). But we can also break the symmetry of the equilateral triangle in additional ways. Thus, it is possible to 'shrink' one particle, creating a series that ends with a dimer, or resize two particles, creating a series that ends with a monomer. All series mentioned above were created experimentally, studied on the single PM level and analyzed theoretically. One of our most intriguing observations was an avoided crossing of two plasmonic modes, yet another phenomenon that is very familiar to the molecular spectroscopist.

The symmetry of PMs also affects their electromagnetic interaction with molecules. This enables a surprising modulation of the polarization of the molecular emission, which we observed experimentally and analyzed using generalized Mie theory (3, 4). In these experiments a molecule interacted with the hot spot formed between two particles in a trimer. In the case of an equilateral triangle the dipolar symmetry of the hot spot was preserved by the molecular emission. However, when this symmetry was broken, the dipolar symmetry was broken too, and the polarization of emitted light was not only rotated significantly, but in some cases even became close-to-circular. This effect might be understood based on the coupling of the molecular dipole to the symmetry-broken modes of the PM.



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O-67

Surface-plasmon-polaritons-assisted nanolithography with high exposure depth

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High-quality masks with complicate structures and frequent design changes play a key role for nowadays semiconductor fabrication industry. Some maskless lithography tools, such as electron beam writing, focused ion-beam lithography, etc. are developing toward mass production of above-mentioned masks. However, these tools confront a fabrication bottleneck for fine mask due to expensive price and low throughput, which hinders their application in the micro/nano-fabrication domain. In this paper, we propose a direct writing nanolithography approach using a plasmonic focusing device and a nano silver mirror with dual-wavelength illumination for high exposure depth. A pyramid aperture is used to focus the incident light beams. By combining with a thin silver film coated on the substrate, a surface plasmon polaritons (SPP) coupling cavity is constructed, which amplifies the intensity of the light field in it by SPP effect and resonance. The transmission depth of the standing wave formed by forward and reflected light could reach hundreds of nanometers. Two lasers with different wavelengths are used as illumination sources to homogenize the light field through complementation between the two standing waves. Simulation results show by using 355 nm and 441 nm wavelengths, a space of 44 nm at the bottom of the photoresist could be obtained after exposure and development.

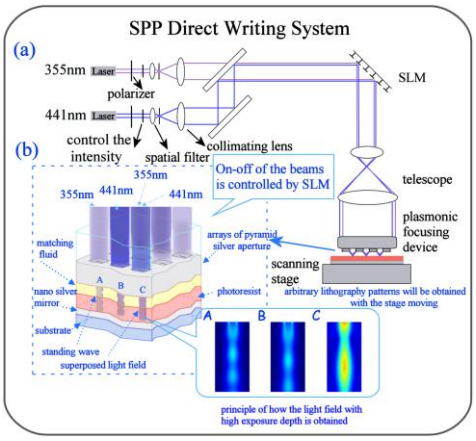

Figure 1. Schematic of the plasmonic direct writing system constructed by two lasers with different wavelengths as illumination source. (b) Structure of plasmonic focusing device containing arrays of inverted pyramid silver aperture.

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O-68

Fourier optics theory for invisibility cloaks and optical illusions

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Currently, the most popular method for technically obtaining the geometric and electromagnetic parameters of invisibility cloaks is mainly based upon transformation optics. However, not only is transformation optics generally based upon resonance produced electromagnetic parameters, which means strong dispersion, loss, and narrow band, as well as a challenge to the fabrication technologies of realistic realization of the cloaks, but also transformation optics is hard to successfully deal with lossy Pendry cloaks.

In this talk, we will present a Fourier optics theory to intuitively understand the physical mechanism of invisibility cloaks and perfect lenses in hiding objects, creating illusions, and performing perfect imaging. The theory will not only unify both Pendry cloaks and complementary media based invisibility cloaks into one kind of cloaks mathematically and physically, but it also provides a way to get the electromagnetic parameters of the cloaks and further deal with some related complementary media-based functional devices by introducing transfer functions to elucidate the roles of the invisibility cloaks played on angular spectrum of the objects. Our theory is completely different from the current coordinate transfer method and may provide another point of view to more clearly understand the mechanism of invisibility cloaks.

In terms of the theory, we will demonstrate a carpet cloak, which is usually used to hide an object beneath it, to hide objects and create illusions above it. By further adding a functional layer onto the cloak, we can even camouflage the object so that it appears to be a different object. Furthermore, we will also present other two cloak devices for realizing another invisibility method: optically camouflaging an object at one place to appear at another place with parallel displacement or orientation changeable displacement, respectively. The analytical results are confirmed by numerical simulations.

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O-69

Hidden Fano resonances enable crescent type SERS enhancement

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We present experimental and theoretical results on crescent type SERS substrates with Fano resonances as the origin of signal enhancement. Interestingly, the far field response of the pattern does not exhibit a strong asymmetric line shape and only near field calculations unambiguously show that Fano resonances are at the origin of the observed electromagnetic enhancement.

Recently there has been a substantial revival of interest for Fano resonances. The sharp features associated with their far field response is particularly well suited for many applications[1] and extended theoretical models have been found that allow for an accurate descriptions of the resonance effect[2]. Due to their sharp Fano resonances, SERS sensors usually lead to less signal enhancement due to the necessity to enhance both the incident photons and the emitted photons separated by up to 100 nm in the optical spectrum[3].Here we show that even for negligibly small far field characteristics of a Fano type sensors, its near field effect can lead to strong SERS enhancement. Figure 1 shows 2D nanoline pattern with a nano-crescent cross section that we have fabricated using EUV interference lithography followed by angular evaporation[4].The technique can be applied over square mm areas and SERS enhancement factors of $1x10^6$ are obtained, with a very low areal signal deviation of less than 3 %. In a first sight the reflection spectrum of the pattern, shown in Fig. 2, does not evidence the existence of Fano resonances. Interestingly the SERS enhancement is however maximal (not shown) even when both the incident (633 nm) and Raman Stokes photons (676 nm) are below the pattern resonance wavelength (710 nm). Near-field simulations were performed to show that the origin of the SERS enhancement is Fano interferences that are only visible when the near-field intensity at the hot spot is plotted over the full spectrum, Fig. 2.

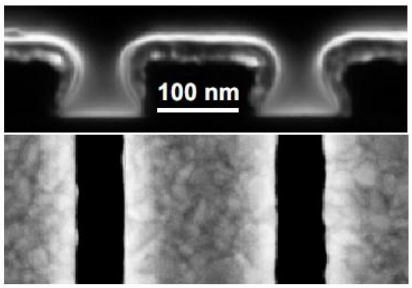

Figure 1. SEM image of the nanocrescent SERS pattern

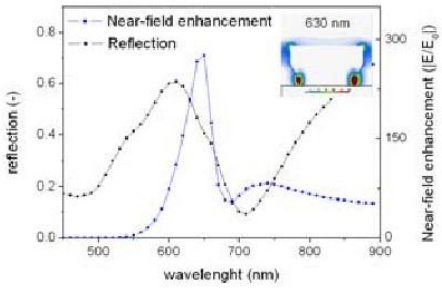

Figure 2. Simulated reflection spectrum and Near-field enhancement

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O-70

3D Transport in Charged and Crowded Environments

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The ability to sequester and transfer charge and matter via functionally responsive materials requires a detailed und erstanding of mechanisms driving transport within these materials. Functional polymer-s possessing specific chem istry and morphology play a key role in the future charge storage applications. One challenge is an incomplete des cription of transport, especially within charged and crowded interfacial regions. Here, we use single-molecule fluo rescence spectroscopy to reveal 3-dimensional details of mechanisms underpinning ion transport in an ordered pol yelectrolyte polymer-brush. Resolving fluorescence emission over three discrete polarization angles allows reporti ng the extent to which these materials impart 3-dimensional orientation to charged guest molecules diffusing in the film. We report a global orientation parameter for the films, track coherent dipole angle progressions over time, an d identify a unique transport mechanism: translational diffusion under restricted orientation.

O-71

LSPR Biosensing Properties of Metal Nanoparticle Arrays

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Optical biosensors based on localized surface plasmon resonance (LSPR) of metal nanoparticles, often called "LSPR biosensors" for shot, have recently been the focus of intense scientific study. LSPR biosensors transform the tiny changes of local dielectric environment around metal nanoparticles to the measurable wavelength shift, and then get the change in refractive index of local environment from the wavelength shift [1]. Refractive index sensitivity is one of most important factors which have great influence on the response of LSPR biosensors. Refractive index sensitivity of LSPR biosensors is closely related with the material, size, shape and spacing of nanoparticles [2]. This paper describes the LSPR properties and size-dependent dielectric function of metal nanoparticles in detail; it also introduces the basic principles of LSPR biosensor and gives several approaches to the measurement of nanoparticle LSPR spectra. We use classical Mie scattering theory and discrete dipole approximation (DDA) to investigate the LSPR spectra properties of metal nanoparticles with different size and various shapes, and make quantitative analysis on the effect of nanoparticle size and shape on the refractive index sensitivity. In this work, we also investigate the optical properties of a periodic array of metal nanospheres, and the effect of the size and spacing of nanospheres on the refractive index sensitivity is analyzed. This paper provides theoretical basis to design high sensitive LSPR biosensors.

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O-72

The study of electron charging of Ag/Au core shell nanorode by SERS

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The gold nanorods were prepared in aqueous solution by seeding growth method[1-2]. Aspect ratio of the nanorods was controlled accurately by changing the silver ions concentration. Ultraviolet-visible (UV-vis) spectra demonstrate the regularation that longitudinal plasmon resonance absorption wavelength of gold nanorods reveal red shift with the increase of aspect ratio. Gold nanorods were wrapped with Ag shells by chemical reduction silver ions on its surface. Different from gold nanorods, the transverse modes of the Au@Ag core-shell nanorods have two bands which contributed from the Ag and Au, respectively. Figure 1(A-F) True color photographs of (A) Au NRs and (B-F) Au@Ag core-shell nanorods with different thickness of Ag shell. and Figure 2 is the corresponding UV-vis spectra of the samples shown in fig.1 (A-F), respectively. here the longitudinal plasmon resonance wavelength of the nanorods blue shift significantly. These observation hint the electron charging effect of Ag/Au core shell nanorode[3], also we discussed this effect by SERS experiment.

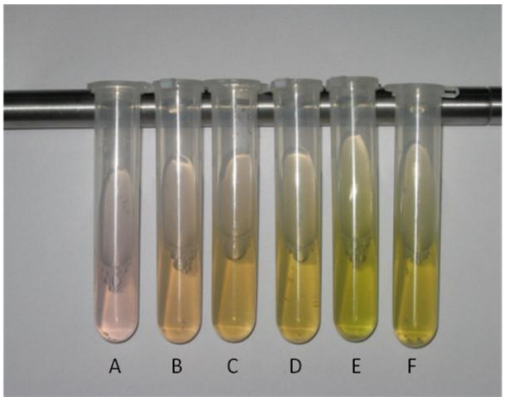

Figure 1. True color photographs of (A) Au NRs and (B-F) Au@Ag core-shell nanorods with different thickness of Ag shell.

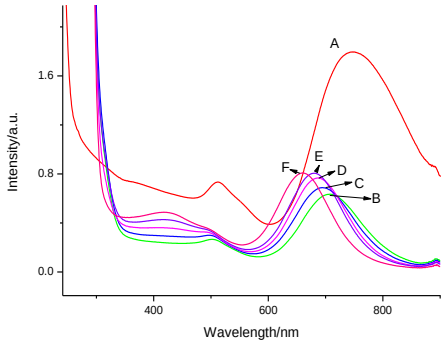

Figure 2. UV-vis spectra of (A) Au gold nanorods and (B-F) Au@Ag core-shell nanorods shown in Fig. 1 (A-F).

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POSTER PRESENTATION

P-01

Anomalous reflection based on gradient metamaterial

Kuang-Yu Yang[1], *Shulin Sun* [2,3], *Chih-Ming Wang*[4], *Ta-Ko Juan*[4], *Wei Ting Chen*[3], *Guang-Yu Guo*[1,3], *Lei Zhou*[5], *Din Ping Tsai*[1,3,6,7*]

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Plasmonic metamaterials are artificial composites made by sub-wavelength local resonance structures of electric and/or magnetic type(s) exhibiting novel electromagnetic properties, such as negative refraction, perfect imaging, etc. In last several years, various graded metamaterial systems have brought us new fascinating phenomena such as invisibility cloaking [1], trapped rainbow [2], etc. Recently, N. Yu et. al. showed that a graded optical antenna array could realize anomalous reflection and refraction for light at infra-red (8 m), following a generalized Snell's law [3], and X. Ni et. al. soon pushed the idea to 2m wavelength with a relative broad operation bandwidth [4]. Sun et. al. further proved that a particular gradient-index meta-surface can convert a propagating wave to a surface wave with nearly 100% efficiency [5], and demonstrated the idea in microwave frequency regime. The key idea behind this set of works is to utilize the local reflection/refraction phase properties of a gradient metamaterial, so that coherent beams can be formed by constructive interference.

In this work, we push the idea to visible frequencies. We designed and fabricated a graded meta-surface working around 750nm, and demonstrated that an incident beam can be redirected to a non-specular channel after reflection by our system. The measured conversion efficiency from the incident beam to the anomalous reflection one is quite high (up to 52%), and the working bandwidth is very broad (about 300nm). We believe that our systems can have broad applications including anti-reflection, light absorber, etc.

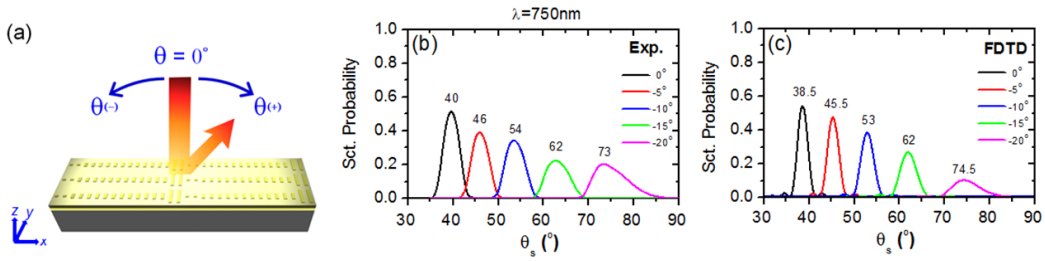

Figure 1. (a) Schematic representation of the anomalous reflection by our designed gradient metamaterial with y-polarized incident wave. (b) and (c) are the experiment and simulation results of the anomalous-reflected signals at 750 nm wavelength. Various incident angles are plotted, and each was normalized by the intensity of incident wave.

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P-02

Engineered substrate for metallic nanowires toward high performance plasmonic waveguiding

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Metallic waveguides receive growing interest due to their capability of reducing the conventional optical devices into nanoscale, taking advantage of the localization of surface plasmon polaritons (SPPs) [1-4]. Though the properties of SPPs on a cylindrical wire in homogenous medium have been known analytically for a long time, those solutions do not hold when the wire is brought into the vicinity of a dielectric substrate due to the symmetry breaking. We theoretically study the properties of SPPs on a metallic nanowire on top of a dielectric substrate. The substrate breaks the symmetry of the system and mediates the couplings of primary wire plasmons, resulting in a new set of hybridized modes. The fundamental mode of the system is found to be a candidate for high performance plasmonic waveguiding. Further improving the performance in the near infrared region can be achieved by simply adding a high permittivity layer onto the substrate. This finding adds to the tool box for future nanoplasmonic circuits.

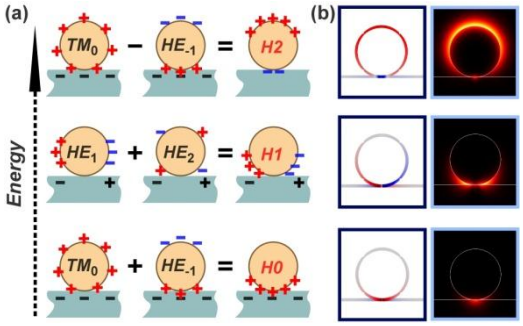

Figure 1. (a) Schematically drawing how the primary wire plasmons interact through the dielectric substrate and construct the three lowest hybridized modes. (b) Normalized surface charge contour (left) and time-averaged power flow (right) of the three hybridized modes. The nanowire (R = 100 nm) is supported on glass substrate.

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P-03

Ultrasensitive Stokes and Anti-Stokes Raman Spectroscopy of benzenedithiol in HV-TERS system

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Tip-enhanced Raman spectroscopy (TERS), firstly demostrated by Stöckle Hayazawa and Anderson in 2010, is a high-sensitivity optical analytical technique with high spatial resolution beyond the diffraction limit of light. In TERS, a sharp metal tip is used to create a "hot site" to excite localized surface plasmons and consequently enhance the electromagnetic field and Raman signals in the vicinity of the tip apex. The tip can be moved three dimensionally to control the position of the "hot site" and the corresponding enhancement factor by changing the gap distance between the tip and the substrate.

TERS may solve a wide variety of problems in high vacuum (HV) single crystal surface science, electrochemistry, heterogeneous catalysis, microelectronics, and tribology, thus offering new opportunities for gaining insights in the physics and chemistry of these diverse systems. In this paper，Ultrasensitive Stokes and Anti-Stokes Raman spectra of 1,2-benzenedithiol (1,2-BDT) were obtained in home-made instrument of high vacumm tip-enhanced Raman spectroscopy (HV-TERS). The very weak Raman peaks in Stoke and anti-Stokes Raman spectra were observed experimentally and assigned theoretically. The experimental temperature in HV-TERS is obtianed from Stokes and Anti-Stokes HV-TERS.

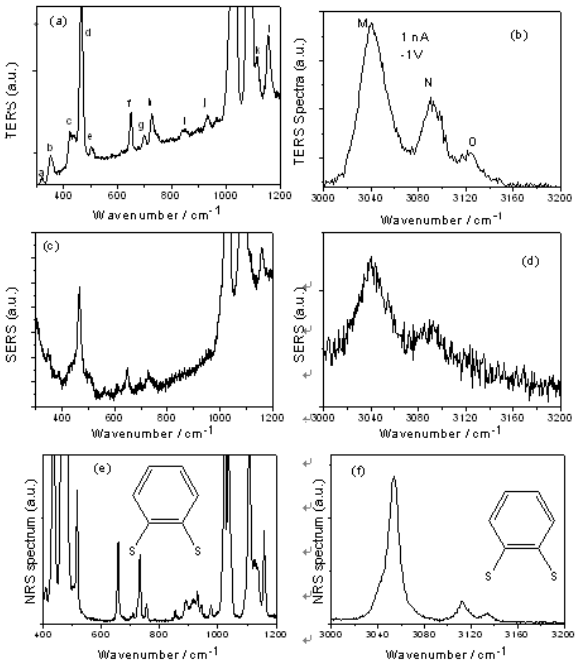

Figure 1. (a) HV-TERS spectrum of 1,2-BDT in the region from 300 to 1200 cm^{-1}, and (b) from 3000 to 3200 cm^{-1}, (c) and (d) SERS spectra of 1,2-BDT, (e) and (f) are the NRS spectra of 1,2-BDT powder.

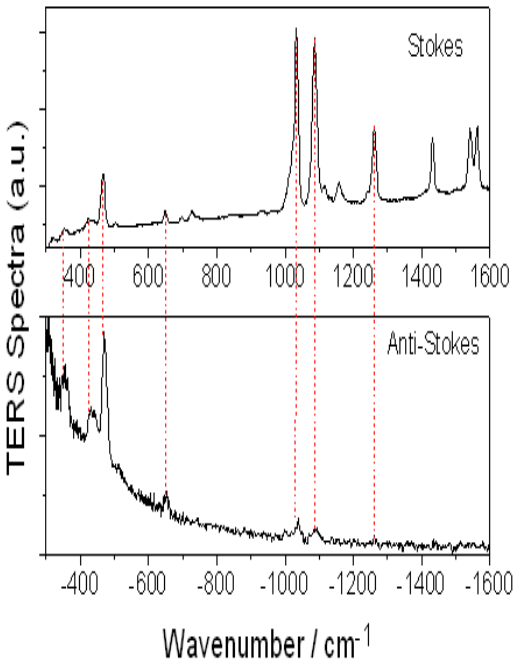

Figure 2. The measured Stokes and anti-stokes TERS spectra of 1,2-BDT adsorbed on Ag film in HV-TERS.

P-04

Coupling between semiconductor quantum dots and surface plasmon polaritons

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Semiconductor low-dimensional systems coupled with metallic plasmonic structures have attracted great research interest due to their potential in realizing new optoelectronic devices in subwavelength scale such as nanolasers [1]. Semiconductor quantum dots (QDs) with three-dimensional confinement provide a competing platform to construct this kind of ultra-small devices. For this sake, the plasmonic partners have to be well studied and optimized, and their interactions with QDs have to be understood comprehensively. Previously the enhancement of fluorescence from QDs excited by interaction with surface plasmon polaritons (SPPs) have been demonstrated in experiments[2,3]. The resonant surface-enhanced Raman scattering (SERS) of CdSe QDs attached to nanostructured plasmonic surfaces has been demonstrated. Tuning the SERS signal into resonance with the localized surface plasmon reveals the effects of optical absorption and emission on QD SERS[4].
Here a well-characterized plasmonic substrates was used :a commercially-available square array of micron-sized inverted pyramids.And study SPP-modified optical property and dynamics of the CdSe QDs. The underlying interaction mechanisms are analyzed . Possibilities of further improvement of the coupling strength between individual QDs and plasmons as well as photonics modes are also discussed.

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P-05

An exploration of photo detection in restrahlen band with plasmonic cavity

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The phonon modes of a crystal are subdivided into two general categories: acoustic or optical, transverse or longitudinal. It is the optical rather than the acoustic modes that are directly infrared active. These optically active phonons are able to absorb light at their resonant frequency and cause significant dielectric constant change [1-2], for example, there is a frequency range called Restrahlen Band where the dielectric constant is negative, this gives near 100% reflectivity, e.g. , the restrahlen band of GaAs is about 8-9THz, so, generally the infrared photodetector is not applicable in restrahlen band.

Here, we described a plasmonic cavity which consists of a perforated metal film, a Si layer, and a GaAs layer, we study the optical properties of this cavity in the restrahlen band of GaAs. Because GaAs reflectivity is still near 100% in restrahlen band, after light was coupled into plasmonic cavity through perforated metal film, it is difficult to escape from the cavity. The light was reflected by the metal film and GaAs for many times with every time a little absorption by GaAs/AlGaAs intersubband transition, thus the intersubband absorption is enhanced by more than 5 times, this result open a light for infrared photodetection in restrahlen band.

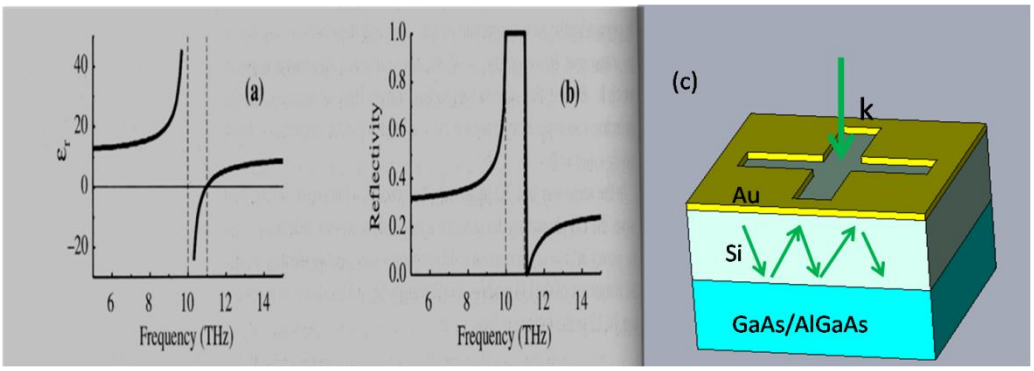

Figure 1. Frequency dependent dielectric constant (a) and reflectivity (b) of a crystal with restrahlen band between $\nu_{TO} = 10\text{THz}$ and $\nu_{LO} = 11\text{THz}$, $\varepsilon_s = 12.1$ and $\varepsilon_\infty = 10$, (c) The plasmonic cavity consists of a perforated metal film, a Si layer, and a GaAs/AlGaAs layer, and the principle of absorption enhancement for GaAs/AlGaAs quantum well in GaAs restrahlen band.

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P-06

Electromagnetic field enhancement and the potential application in microwave spin rectification

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In the past, metal structure was used to enhance either the electric or magnetic component [1] of the electromagnetic field bashed on the plasmon effect. A novel metal structure is introduced in this paper to enhanced both electric and magnetic components of the microwave. It is used to assist the spin rectification [2] to generate a stronger dc photovoltage.

The novel metal structure, electromagnetic resonator (EMR), was designed to enhance both the components of microwave and get a 23.8-fold electric field and a 140.9-fold magnetic field enhancement as shown in Fig. 1. The near fields generated by EMR could be used to assist spin rectification to generate a stronger dc PV.

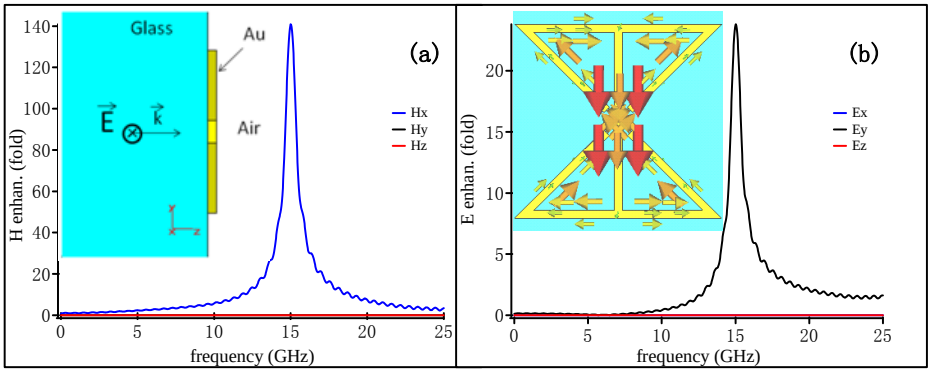

Figure 1. (a) and (b) are the magnetic and electric field spectral of electromagnetic resonator (EMR) at the center point which is 0.1mm far from the EMR. Inset of (b) is the electromagnetic resonator (EMR) and the arrows show the electric current flow at the

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P-07

Enhancement UV Emissions from the Ag/graphene/SiO_2/ZnO Hybrid Structure via Ag doping graphene

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It is well known that the electron density of graphene can be controlled by doping. Thus, they make graphene an appealing system to study new unconventional physics, but moreover, easy control of the electron density through doping, which make it also a promising material for applications.

We experimentally demonstrate the enhancement in band edge photoluminescence (PL) of ZnO films interacted with graphene plasmon. The graphene samples were prepared by micromechanical exfoliation of HOPG onto SiO_2/ZnO film. It is believed that the enhancement is attributed to the Ag film modification of local electromagnetic filed by interaction between the plasmon in graphene and the near band edge emission of ZnO. The number of graphene layers can be typically identified by Raman spectra and the thickness measured using AFM. PL peak and intensity are strongly dependent on the number of graphene layers. In single-layer graphene, the enhancement emission of ZnO film is larger than that of few-layer graphene. Further, the observation of the enhanced photoluminescence peak at 380 nm demonstrates that the superior properties of ZnO films as compared to the films only Ag coating. These results indicate that enhancement in UV emission intensity are related to excitation of surface plasmons of graphene. The modifications of the dispersion relation of graphene samples after Ag deposition are also discussed.

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P-08

Enhancement of Magneto-Optical Effect in Multilayer Heterostructures

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The development of integrated optical components like isolators, polarizer, circulators, etc. is limited by the reduced magneto-optical (MO) activity of existing materials. Recently [1], it was demonstrated that combining MO material with metal layer possessing extraordinary optical transmission, it is possible to obtain significant enhancement of the Faraday Effect. The authors of [1] studied the MO effect in a bilayer heterostructure (inset of Fig. 1a) consisting of a periodically perforated nonmagnetic metallic Au plate stacked with a thin uniform magnetic dielectric layer Bi:YIG. In our work, we propose to modify this heterostructure by introducing an additional dielectric layer between the metal and the magnetic layer (inset of Fig. 1b).

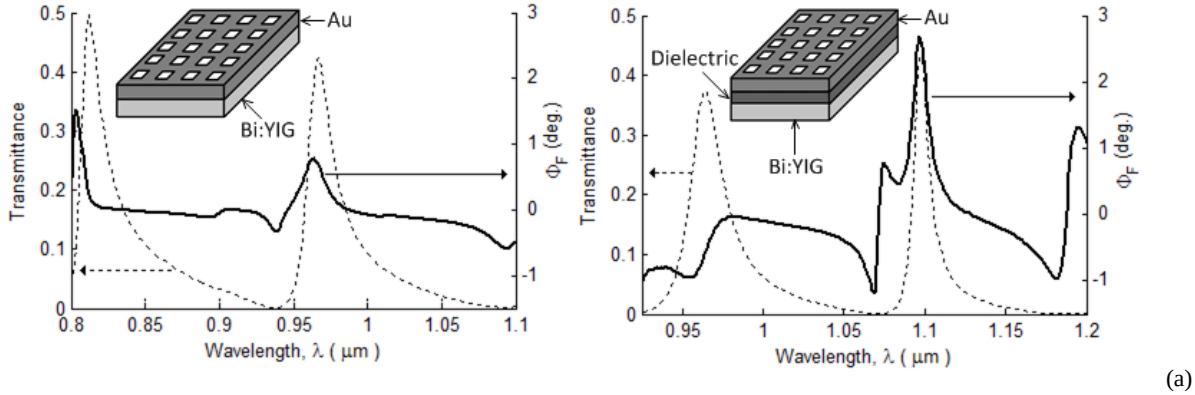

Fig. 1. Spectra of the Faraday rotation [solid lines in (a) and (b)] and optical transmittance [dashed lines in (a) and (b)] of bilayer and trilayer structures with perforated Au-film.

For numerical calculations we used the software COMSOL Multiphysics 4.0a [2]. With the same fixed parameters of the magnetic layer as in the original structure, the geometrical and physical parameters of the metal (Au) and the dielectric layer were optimized in order to enhance the Faraday effect. With the permittivity ε_r=2.2 of the dielectric (which can be for example, SiO_2) and with the thickness of 64 nanometers of the dielectric, we obtain in the optimized structure (Fig. 1b) the angle θ_F of the Faraday rotation four times higher than in the original structure (Fig. 1a) and 30 times higher than in the magnetic dielectric layer alone. In our structure, we preserved the same level of transmittance (about 43%) as in the original structure. Alternatively, optimizing the parameters of the trilayer, we succeeded to enhance significantly the transmittance preserving the angle of Faraday rotation. We discuss also distribution of the electric field in the structure.

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P-09

The amplification effect of the anisotropic shape of the plasmonic core by the shell material with high refractive index

Song-Yuan Ding[1], *Liang Chen*[1], *Song-Bo Li*[1], *De-Yu Liu*[1], *Hai-Xin Lin*[1], *Bin Ren* [1], *and Zhong-Qun Tian*[1*]

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The dielectric shell can shift the frequency of the localized surface plasmon (LSPR) of the plasmonic core to the near-infrared. In additionally, the shell can also enhance the absorption ratio and the total extinction [1]. It is interesting that the line-shape of the extinction and absorption is very sensitive to the detailed shape of the gold core rather than the shape of the Cu_2O core [1]. Here we extend our previous study to response properties of shape of the plasmonic core material by the shell material [2]. It has been reported that for spherical plasmonic core, there is only one dipolar peak in LSPR spectra. While for spheroidal plasmonic core there are two dipolar peaks, one is the longitudinal dipolar mode (LDM) in longer wavelength regime, and the other is the transverse dipolar mode (TDM) in shorter wavelength regime [3]. The presence of the dielectric core not only can move both of the two dipolar peaks to longer wavelength, but also can change the relative intensity of the two dipolar bands. Furthermore, as the increase of the shell thickness of the dielectric material, the speed of red-shifting of LDM is much quicker than that of TDM, and the relative intensity of the LDM will gradually preponderate over that of TDM. Aiming to explore the role of the semiconductor or dielectric shell in the core-shell hybrid structure with spheroidal plasmonic core, we further choose three types of shell materials with distinguished dielectric constants SiO_2 (~ 2), Cu_2O (~ 7.2) and Fe_3O_4 (~ 12), and study a series of core-shell nanoparticles, Au@SiO_2, Au@Cu_2O and Au@Fe_3O_4. Each type of core material has three types of aspect ratio. And we find that the shell with high dielectric constant, namely with high refractive index, can much more strongly enhance both of the LDM and TDM extinction bands than the lower refractive index counterparts. As the shell thickness increase, it can move the LDM even quickly and specially enhance the band of TDM [2]. With the help of Mie theory, we successfully derive the expressions of the sensitivity of LSPR peaks of TDM and LDM with respect to the aspect ratio of the plasmonic core materials, which are potentially applicable for analysis of the LSPR spectra. Further efforts on the analysis of the multipolar contribution to the asymmetric properties of the plasmonic core will be made in the near further.

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P-10

Watching outside while under a carpet cloak of invisibility

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Keywords: Transformation Optics, Optical cloaking, Complementary media

Recently, much attention has been paid to invisible cloaking both in the theory and in the experiments. In this work, we demonstrate a unique approach for watching outside while hiding under a carpet cloaking based on transformation optics. Unlike conventional carpet cloaking, which screens all the incident electromagnetic waves, we break the cloak and allow incident light get into the carpet. Hence outside information is detected inside the cloak. To recover the invisible cloaking, complementary techniques are applied in the broken space. Consequently, a hiding-inside and watching-outside (HIWO) carpet cloak is sewed, which works as an invisible cloaking and allows surveillance of the outside at the same time, *i.e.*, "seeing without being seen". We also demonstrate that the HIWO works well when it contains the absorption media in the system. The strong absorption of the sensor can be compensated for by applying an active medium as the anti-sensor in the HIWO. Our work provides a strategy for an ideal cloak with "hiding" and "watching" functions simultaneously.

P-11

Tunable multimodes and narrowbands in a photonic quasicrystal waveguide

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We have theoretical investigated a photonic quasicrystal waveguide, where a hollow core surrounded by coaxial dielectric quasi-periodic multilayer. Due to the self-similar in the cladding structure, multiple omnidirectional photonic band gaps (PBGs), frequency-selective transmission, and “rainbow” trapping are achieved in the waveguide. Further, we demonstrate that in the quasiperiodic waveguide the center frequency and the width of the omnidirectional PBGs can be tuned by varying the refractive indexes or generations of the quasi-periodic sequence in the cladding multilayer. As a consequence, both the quality factor and the confinement performance of the waveguide can be significantly enhanced by decreasing the width of the omnidirectional PBGs. The investigations make it possible to design miniaturized multifunctional optical devices, such as on-chip narrowband waveguide-based filters and laser resonators.

P-12

Exchange of electric and magnetic resonances in multilayered metal/dielectric nanocavities

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In this work, we investigate electromagnetic responses in multilayered Ag/SiO2 nanocavities at optical frequencies. Electric and magnetic resonances, which originate from localized surface plasmons. The electric and magnetic resonances can be tailored by the geometrical parameters of the nanocavities. With proper design, we have experimentally demonstrated that in a rectangular multilayered Ag/SiO2 nanocavitie array, electric and magnetic resonances are exchanged at the same frequency simply by changing the polarization of incident light for 90°. Both electric and magnetic resonances lead to negative permittivity and permeability, respectively. The numerical calculations on electromagnetic fields agree with the experiments. The investigations provide a simple building block for a metamaterial to switch electric and magnetic resonances by external excitation field.

P-13

Modeling of an optical slot antenna

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Antenna is a device that radiates and receives radio and micro waves. The counterpart in optics, optical antenna interacting with visible light, is not just a small size antenna in nano meter scale. In the visible range, plasmonic effects become involved and distinguished characteristics of optical antenna arise compared to the conventional antenna. Numerous studies have been made to figure out properties of optical antenna [1,2].

Here, we investigate a slot type optical antenna. Compared to rod or particle type antennas, slot antennas have merits such that it is easier to make aligned array or to embed in small devices [3]. Despite of its benefits, slot type optical antenna has received less attention compared to rod or particle types. Unlike conventional slot antennas, an optical slot antenna cannot be simply explained by treating it as a complementary structure of a wire antenna. Due to the plasmonic effect, we expect different and more interesting new characteristics of optical slot antenna to appear, which are absent in conventional slot antennas.

In this presentation, we address some novel properties of a rectangular slot type optical antenna. Resonance of slot antenna is modeled analytically. We find that rectangular slot antenna can be interpreted as a bound charge oscillator [4]. Also, we used the Finite-difference Time-domain method (FDTD) [5] to figure out the properties of optical slot antenna involving surface plasmons. Comparing with the perfectly conducting case, plasmonic effects on resonance and radiation properties of the optical slot antenna are demonstrated.

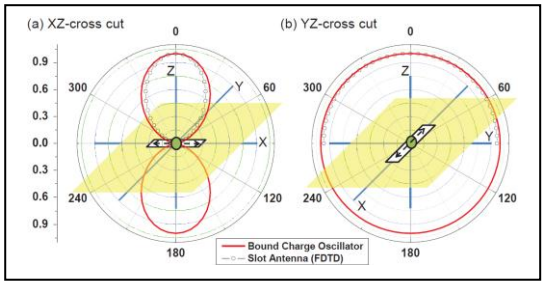

Figure 1. Radiation pattern of a slot antenna and an oscillating bound charge. FDTD and near to far field transformation [5] is used to analyze the slot antenna system. Both radiation patterns agree to each other.

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P-14

High-sensitivity nanosensor based on a sparse array of gold nanoparticle chains

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Plasmonic nanosensors have been intensively studied for biomedical applications in recent years. Here, we propose a high-sensitivity nanosensor based on a sparse array of gold nanoparticle chains (SPCA) [1]. Our theoretical analysis and preliminary experiments have shown that the sensitivity of the SPCA can reach as high as 1×10^3 nm/RIU in the wavelength range of 1.5-1.6 μm.

The proposed SPCA is shown in Fig.1 (a), which has an anomalous polarization-selective extinction effect [1]. Under normal incidence, the array is almost transparent for TM-polarized light; whereas it is fully opaque for TE polarization within a narrow band, even though the nanoparticles cover only a tiny fraction (say, 3.5%) of the substrate surface. Since the resonance is very sensitive to the refractive index change of the cover medium, we investigated the use of the SPCA as a novel refractometric nanosensor.

For a SPCA designed with particle size $200\times200\times30$ nm^3, d_x = 1000 nm, and d_y = 230 nm, our theoretical analysis shows that the sensitivity is about 690.8 nm/RIU, as shown in Fig. 1(b). We performed preliminary experiments using NaCl solutions with varied concentrations to test the resonance shift of the SPCA, as shown in Figs. 1(c)-(e). The results show that the experimental sensitivity can reach as high as 819.2 nm/RIU and 1221.1 nm/RIU in two samples, which is even higher than the theoretical precision. This is owing to the smaller nanogaps in the practical samples. To fully reveal the mechanism, we have thoroughly analyzed the impact of the nanogap and the other structural parameters on the sensing performance.

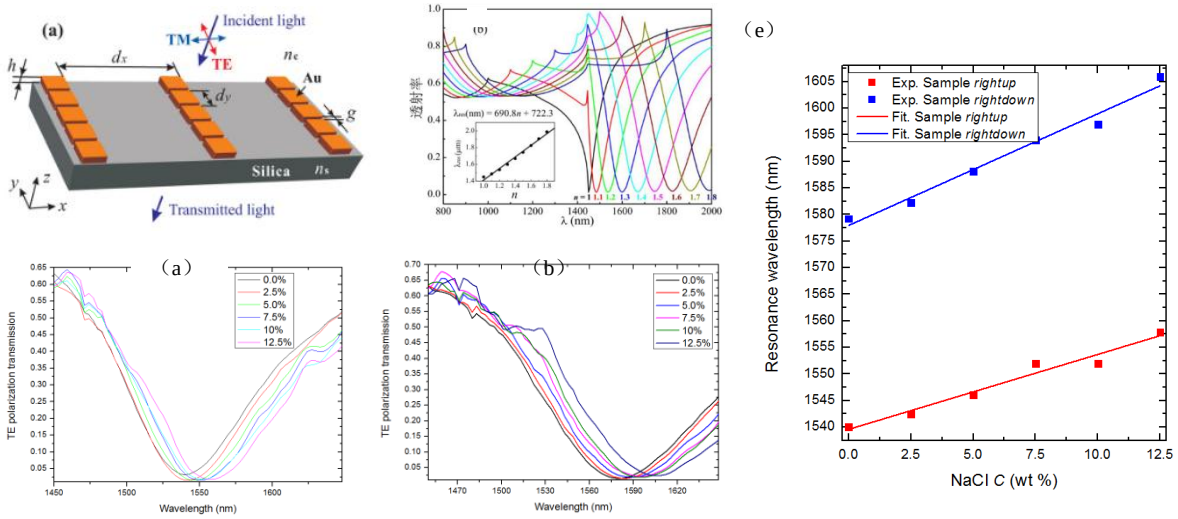

Figure 1. (a) Schematic geometry of the SPCA. (b) Numerically calculated transmittance spectra and the derived sensitivity of a SPCA with different cover media. (c,d,e) Experimental results of the SPCA for refractometric sensing.

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P-15

Plasmonic antenna array at optical frequency based on nanoapertures

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We have demonstrated that the plasmonic array based on nanoapertures in ultrathin silver film behaves as an optical antenna array and radiates at optical frequency. When the incident light illuminates the nanohole array, the localized surface plasmons are excited and serve as electric dipoles. The far field radiation originates from the coherent superposition of each dipole. The properties of far field depend on the in-plane rotation of the aperture array, and on the polarization and incidence angle of the excitation light as well. To understand underlying micro-mechanism, we investigate the contributions of the incident electric filed, the coupling between dipoles and the propagating surface plasmons to the excitation of plasmonic dipole, respectively. The investigation may have potential applications in designing plasmonic optical antenna, energy harvesting devices and optical sensors.

P-16

Extraordinary optical transmission studies in infrared regime on polycrystalline and epitaxial Ag films

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Polycrystalline and epitaxial Ag films on Si substrate were grown using MBE and TE, separately, and patterned with the same hole array. Their angle-resolved infrared transmission spectra of extraordinary optical transmission (EOT) [1] were measured. SPP bands of both kinds of Ag films reveal the similar Fano lineshape in far-infrared regime, in agreement with simulations (Fig. 1d-f,j-l). However, SPP bands of polycrystalline films exhibit broader linewidth and lower intensities than those of epitaxial films when incident wavelength gets shorter, especially for Air(1,0) band (Fig. 1a-c,g-i). We contribute such contrasting behaviors in different spectra regions to morphological difference between them: Ag/Si interfaces are smooth for both kinds of films, whereas grainy nature of polycrystalline films degrades the smoothness of air/Ag interface, resulting in an enhanced ratio of scattering in the air-side SPPs [2]. Simulations with inserting an adhesion layer between air/Ag validate our hypothesis (Fig. 1m,n). Significant reduced damping of SPPs on atomically smooth, epitaxial Ag film on Si open a new door towards monolithic integration of plasmonics and electronics on the same platform.

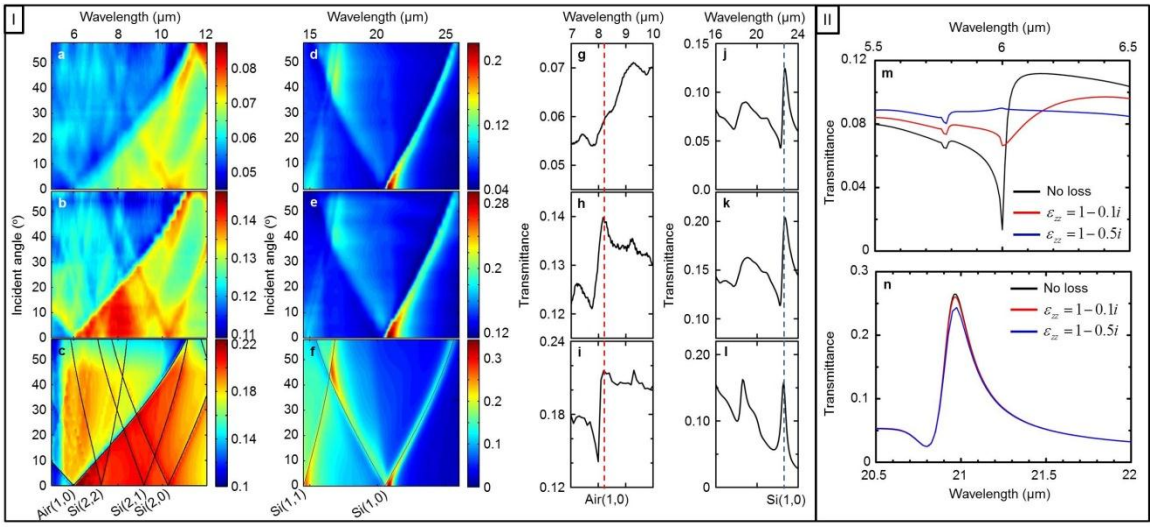

Figure 1. Angle-resolved infrared transmission spectra of EOT under TM-polarized illumination. (panel I, top and middle rows), Experimental spectra for perforated polycrystalline (top) and epitaxial (middle) Ag films. (panel I, bottom row), Simulation results using COMSOL. (g–l), Individual spectra at 20°. (panel II) Simulated spectra involving an adhesion layer between air/film with various loss factors for the Air(1,0) band (m) and the Si(1,0) band (n).

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P-17

Effects on enhanced transmission of middle-range rotational symmetry in 12-fold-quasicrystal-like hole arrays

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The peak position and transmission intensity of two-dimensional subwavelength hole arrays are strongly dependent on rotational symmetry [1]. Here we fabricate three kinds of 12-fold-quasicrystal-like hole arrays with the same short-range, similar long-range but different middle-range rotational symmetry and measure their zero-order transmission spectra (Fig. 1). All the structures have the same supercell (Fig. 1d, inset), a portion of 12-fold quasicrystal and the similar 12-fold rotational symmetry, confirmed by two-dimensional fast Fourier transform (2D-FFT) (Fig. 1c). However, their lowest-order modes exhibit different behaviors: the structure with the supercell arranged in a hexagonal lattice has higher transmission intensity, followed by that of a square lattice and then no lattice. That is to say, the higher is the middle-range rotational symmetry, the higher is the transmission intensity.

In order to make more detailed comparison, Fano-lineshape analysis is applied [2]. The transmission spectrum of randomly distributed holes is also measured (not shown here), fitted according to Bethe theory and used as the background of Fano resonance. The nearest neighbour distance is 10 μm, and hole diameter 4 μm for all the structures, resulting in the same duty factor, i.e. 13.54%. The non-resonant contribution is the same due to the same geometric parameters mentioned above, and therefore the resonant part of Fano resonance can be extracted. The damping can be got through fitting transmission curves by Fano-lineshape analysis method. Results show that the damping in 12-fold (hexagon) is lower than 12-fold (square) by ~30% and 12-fold (no) by ~40%. The higher intensity and lower damping in former structure result from that more holes within the same distance can interfere constructively due to higher rotational symmetry [3].

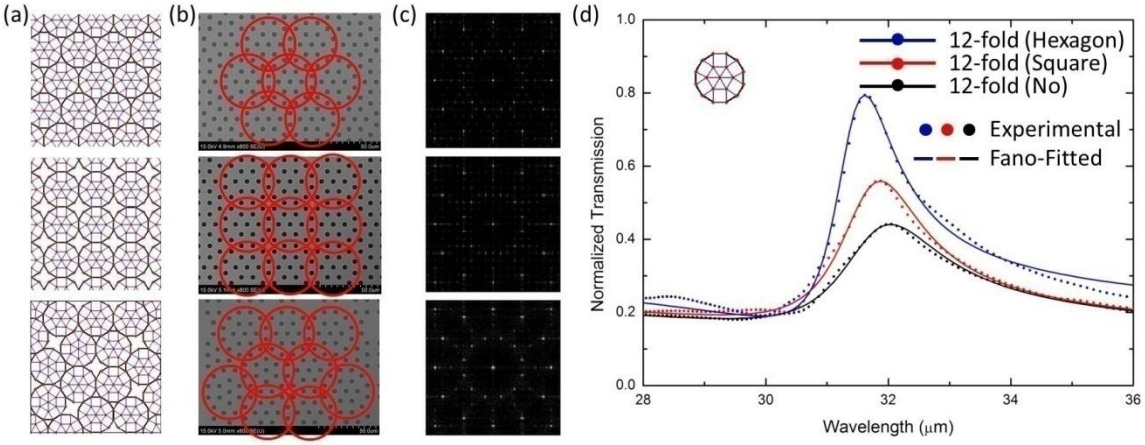

Figure 1. (a) Schematics of three kinds of 12-fold quasi-periodic structures; (b) Corresponding SEM images; (c) Results of 2D-FFT; (a-c) Top panel: 12-fold (hexagon), middle panel: 12-fold (square), bottom panel: 12-fold (no); (d) Normalized-to-area transmission spectra of lowest-order mode, inset: the supercell of three structures.

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P-18

Fabrication of high-aspect-ratio nanostructures by template stripping technique

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We report the fabrication of high-aspect-ratio nanostructures by simple high-throughput method such as template stripping technique [1-2], based on the production of precisely patterned nanoscale silicon template with ultrasmooth surface and high-aspect-ratio grooves. Both the dry etching by inductively coupled plasma (ICP) and anisotropic wet etching were used to produce high-quality silicon template, as shown in Fig. 1(a) and 1(b). Then the magnetron sputtering and thermal evaporating method were employed to deposit gold or silver onto the template, followed by epoxy baking and peeling off procedure. This fabrication technique can produce high-aspect-ratio nanostructures such as gratings, bow ties, cavities and so on (Fig. 1(c)). Near-field (Fig. 1(d)) and far-field (Fig. 1(e)) measurements were also carried out to characterize the prepared nanostructures, showing that the atomically smooth surfaces and steep walls would yield better resonant features and field enhancement.

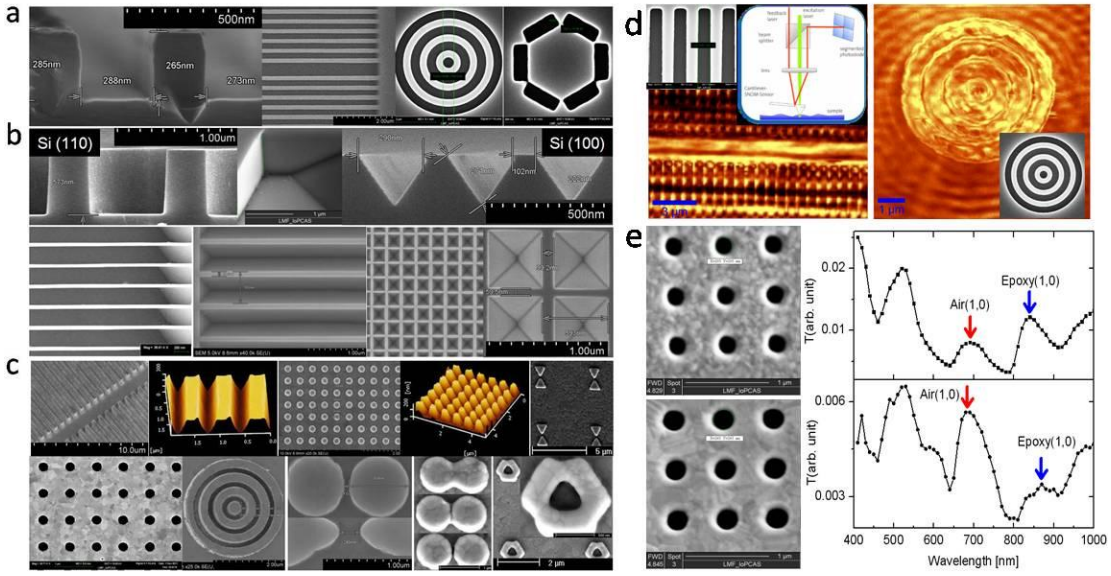

Figure 1. (a) Scanning electron microscope (SEM) images of silicon template by ICP etching. (b) SEM images of silicon template by anisotropic wet etching. (c) SEM images of metal structures peeled off the silicon template prepared by ICP etching. (d) The near field measurement of grating and bull eye structures (inset: SEM images of silicon template). (e) Transmission measurement of circular hole arrays (top: rough, lower: smooth surface).

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P-19

Enhancement variation of the gap electric field in gold bowtie nanoantenna arrays

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Optical antennas, analogues of microwave and radiowave antennas, are the attractive research subject in nanophotonics for their exceeding capability of manipulating and controlling optical radiation at subwavelength scales. Among the mostly used antennas structures, bowtie nanoantennae have gained a particular attention due to the efficient supperssion of field enhancement at the outer ends of the structure.

In this work, we calculated the optical enhancement characteristics of arrays of silver bowtie nanoantennae with the FDTD method, and found that the longitudinal and transverse array of the nanoantennae have a different influence on the light enhancement at the bowtie gap. The bowtie gap enhancemnet of the longitudinal array is usually weaker than that of the transverse array because the back-to-back coupling in near-field between the nergbouring bowties occupies a considerable energy fraction in the longitudinal arrangement. For the transverse array, the periodicity is a major factor to tune the enhancement value at the gap. With the periodicity approaching to the wavelength of the coupling surface plasmon, the light enhancement at the bowtie gap is significantly reduced due to the existence of propagation of surface plasmon in the bowtie array.

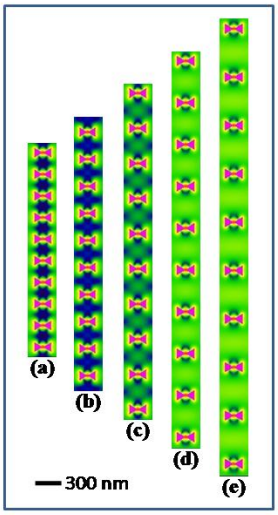

Figure 1. The transverse array of silver bowtie nanoantennae. With the array periodicity increasing (a)-(e), the light enhancement at the bowtie gap is significantly reduced.

P-20

Separation of Absorption and Scattering of Metallic Nanoparticles and Its Relation with SERS

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Surface-enhanced Raman scattering (SERS) has aroused widespread interest and found a wide range of applications in biology, medicine, materials science, electrochemistry and etc., due to its high sensitivity up to single molecule level. The SERS effect of metallic nanoparticles is closely related with their SPR effect. A common practice of SERS study is to measure the extinction spectra of sol of nanoparticles, and then choose an appropriate wavelength for excitation (normally at the peak of the extinction spectra, called LSPR peak). However, the story is never that simple. The LSPR peaks contain the contribution of both absorption and scattering processes. There are some studies indicating a correlation of the scattering part with the SERS enhancement effect[1,2]. But till now, there is still no clear conclusion how and to what extent these two processes contribute to the SERS effect. Therefore, it is meaningful to develop methods capable of separating the absorption and scattering contribution, which will guide the synthesis of nanoparticles with the strongest SERS effect. For this purpose we have developed a method for separating absorption and scattering of nanoparticles, In Fig 1, we can see that Ag shows a much higher scattering efficiency compared with Au and Pd. The latter shows a very high absorption but negligible scattering. It is in agreement with the theoretical prediction. Further correlated single-nanoparticle dark field spectroscopy and SERS studies reveal a clear correlation of SERS with the scattering effect, supported also by theoretical simulation.

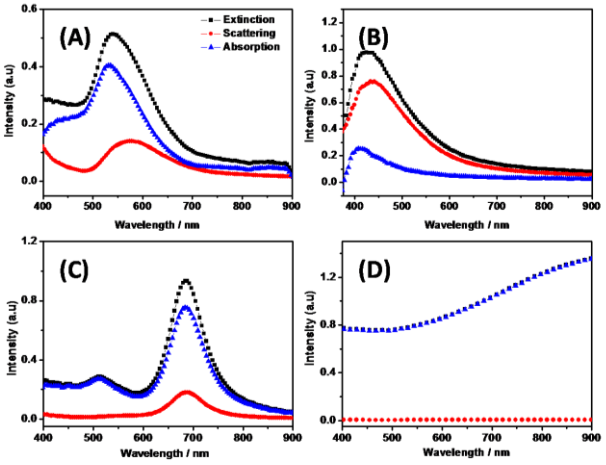

Figure 1. Separation of Absorption and Scattering of all kinds of nanoparticles. A: 60 nm gold nanosphere; B: 60 nm silver nanosphere; C: gold nanorods (length(60 nm)-diameter(20 nm) ratio 3:1); D: Palladium nanosheets (side length 60 nm, thick 1.8 nm)

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P-21

Electrical Detection of Surface Plasmon Polaritons by Quantum Point Contacts of Noble Metals

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Realization of integrated ultrafast nano-scale plasmonic circuits depends on the ability to convert plasmons to electrical signals. We demonstrate electrical detection at ambient conditions of surface plasmons polaritons (SPPs) by measuring their remote gating effect on Au and Pt single atom metal quantum point contacts (MQPC). Creation of SPPs is achieved by normal illumination of grating arrays coupled by transmission lines to the MQPCs. The effects of laser polarization and intensity on the electrical transport are explored and a model combining photo-induced and photo-assisted transport is generated to fit the results [1-3].

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P-22

Encoding Photonic Angular Momentum Information onto Surface Plasmon Polaritons with Plasmonic Lens

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Both spin angular momentum (SAM) and orbital angular momentum (OAM) of photons can be used to carry information in classical optics and quantum optics. In this work, the encoding of angular momentum (AM) information of photons onto surface plasmon polaritons(SPPs) is demonstrated using a nano-ring plamonic lens. Near field energy distribution on the metal surface is measured using a near-field scanning optical microscope (NSOM) when the plasmonic lens is excited by photons with different combinations of SAM and OAM[1]. It is found that both the SAM and OAM can be transferred independently from photons to SPPs. More interestingly, numerical and experimental studies reveal that the energy distribution on the plasmonic lens surface is determined by the absolute value of the total AM. This gives direct evidences that SPPs can be encoded with the photonic SAM and OAM information simultaneously and the spin degeneracy of the photons can be removed using the interactions between photonic OAM and plasmonic lens. The findings are useful not only for the fundamental understanding of the photonic AM but also for the future design of plasmonic quantum optics devices and systems.

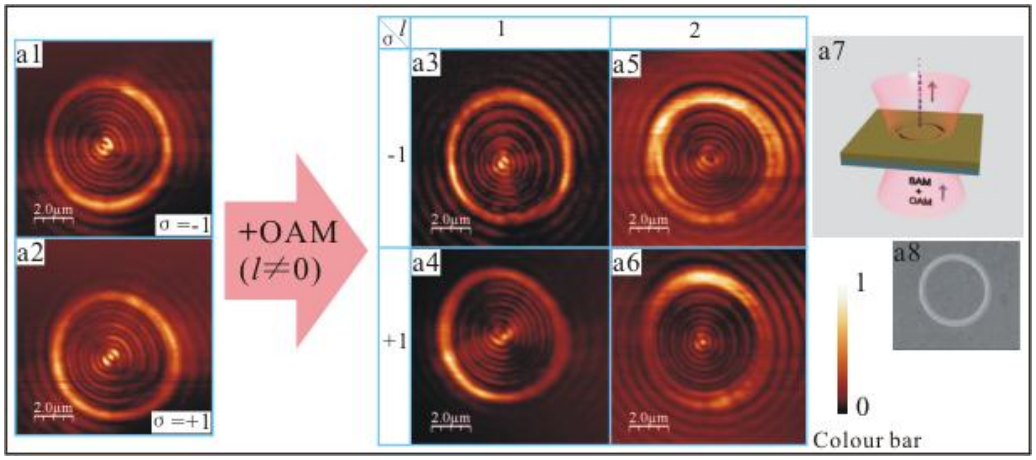

Figure 1. NSOM images of the SPPs on the plasmonic lens excited by photons with different combinations of SAM and OAM. a1 and a2 are the NSOM images of the SPPs with σ=-1 and σ=1of SAM respectively and they contain the same intensity distribution. Adding the OAM to the excitation photons, the NSOM images of the SPPs with different SAM are distinguishable as shown by a3, a4, a5 and a6, where σ and *l* are the topological charges of the SAM and OAM in the unit of ħ. a7 is the 3D drawing of the nano-ring structure excited by photons with different SAM and OAM. a8 is the SEM of the plasmonic lens on the gold film.

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P-23

Preparation of SiO2: (Tb3+, Ag) nanostructure for luminescent materials and fluorescence enhancement effect research

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Tb3+ single doped SiO2 and Tb3+, Ag co-doped SiO2 nanostructure luminescent materials have been successful prepared, microstructure of samples have been described, the influence of doping concentration on fluorescence properties have been explored. The results show that: the sample particles are sphere, when the doping concentration is 4.86%, the largest fluorescence intensity of samples get, internal quantum efficiency of the samples is 13.6%, and the external quantum efficiency is 8.2%. The absorption spectrum、fluorescence spectrum、and fluorescence life of the SiO2: (Tb3+, Ag) samples have been tested, explain Ag the introduction of local produce nanometer particle Plasmon resonance, 226 nm in absorption spectrum (Tb3+ excitation peak) significant enhancement, fluorescence life along with the increase of the nanoparticles Ag and decrease, and make Tb3+ glow with the samples than silver light increase 35%.

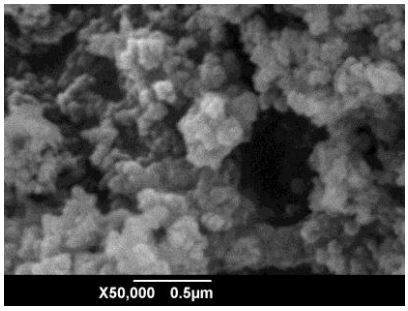

Fig 1 Microstructure fig use of $SiO_2(Tb^{3+},Ag)$

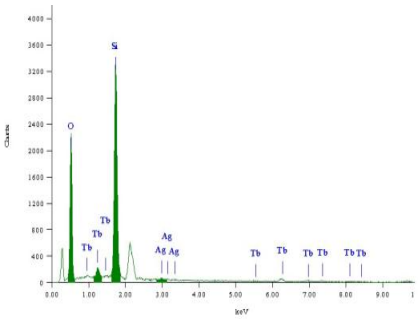

Fig 2 EDS of $SiO_2(Tb^{3+},Ag)$

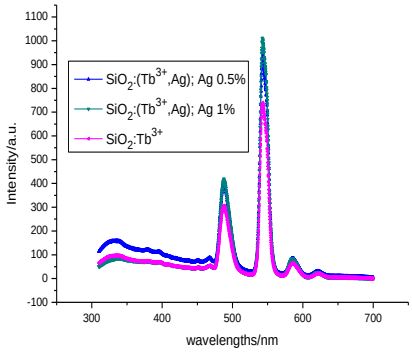

Fig3 fluorescence spectra of SiO2: （Tb3 +， Ag）

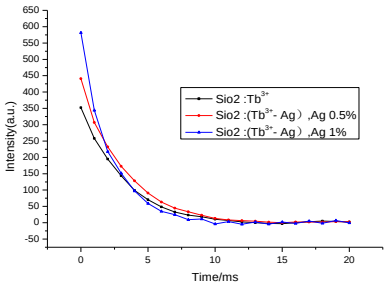

Fig4 fluorescence life of SiO2 (Tb3 +, Ag)

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P-24

Far-field focusing behaviors of subwavelength planar metallic lenses based on non-uniform rings

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A new subwavelength metallic lenses (SMLs) is proposed to realize far-field optical focusing in the visible range based on concentric rings with modulated width in a silver film. The width of each metallic ring is non-uniform so that the radiation fields of surface plasmon polaritons can be controlled and the relevant phase retardations can be modulated to make a beam focus at the desired position in the far-field. The beam properties of SMLs with subwavelength concentric rings are numerically investigated through the three-dimensional finite-difference time-domain method. For comparison, the conventional plasmonic Fresnel zone plate lenses(FZPLs) are analyzed, although with bigger aspect ratio on SML which means it is easy to be fabricated, the computational results show that SMLs can support higher intensity focal spot, narrower full-width half-maximum beam width, and longer depth of focus at the focal region under certain lens thickness. The chromatic dispersion of the SMLs has also been investigated and the intensity distributions around focal spot of the SMLs operating at different wavelengths in the visible range are analyzed and compared. This new kind of SMLs should have a good potential for applications in photonic and plasmonic integrated devices, sensing, and nano-optical manipulations, etc.

P-25

A Facial Synthesis of Branched Silver Nanowire Structure

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Intensive investigations have been devoted to the synthesis of various shaped Ag nanostructures，including spheres,[1] cubes,[2] rice,[3] wires [4] and so on. However, to the best of our knowledge, there is still no chemical synthesis of single branched Ag nanowire structures reported. In this work, we report a facile method of preparing novel branched silver nanowire structures such as Y-shaped, K-shaped and other multi-branched nanowires. These branched nanostructures are synthesized by reducing silver nitrate ($AgNO_3$) in polyethylene glycol (PEG) with polyvinglpyrrolidone (PVP) as capping agent. Statistical data indicate that for the "y" typed branched nanowire, the branches grow out from the side of the trunk nanowire in a preferential orientation with an angle of 55^o between the branch and the trunk. Transmission electron microscopy (TEM) studies indicate that the defects on silver nanowires could support the growth of branched nanowires. Conditions such as the molar ratio of PVP/$AgNO_3$, the reaction temperature, and the degree of polymerization of reducing agent and PVP play important roles in determining the yield of the silver branches.

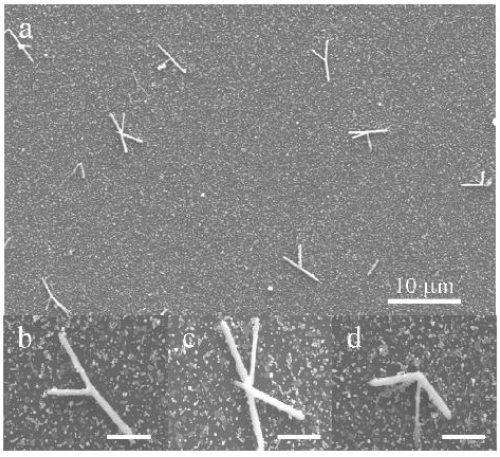

Figure 1. (a) Low- and (b-d) High-magnification SEM images of the as-prepared Y-shaped and other branched Ag nanostructures. The scale bars in (b-d) represent 2 μm.

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P-26

The localized near-field enhancement of metallic periodic bow-tie structure: an oscillating dipoles picture

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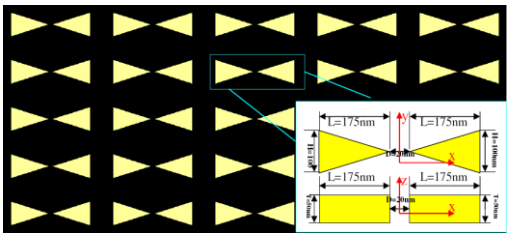
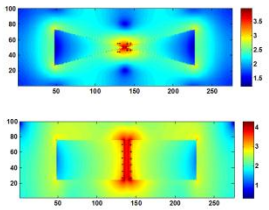
Recently, the delicate-designed metallic structures have been extensively investigated in the visible and infrared frequency range both theoretically and experimentally. The amazing topic is not only its important and unique capacity of coupling the light to the nanometer scale structures, but also its predominant and effective characteristics of enhancing localized field by surface plasmon resonance in the near-field. It has been indicated that the field enhancement near nanoscale metallic structures is attributed to the collective motion of free electrons confined in narrowly localized region, similar to that observed in colloidal nanoparticles exposed to an external electromagnetic field [1]. Some studies have shown that the geometric singularity of sharp-point structures [2] can lead to the electrostatic lightning-rod effect, and the interaction between the particles and the electromagnetic field can be explained by using simple quasi-static approximation provided that the dimensions of the particle are much less than the excitation wavelength.

The bow-tie structure has been investigated as the optical antenna [3] and the alternatives of cavities in the generation of extreme-ultraviolet (EUV) light [4] due to its strong near-field enhancement. Moreover, the localized surface plasmon resonance (LSPR) depends sensitively on the excitation wavelength, the configuration of the structure and the surrounding media environment. The prominent feature offers the LSPR particles as the potential to be evaluated as sensors, which can detect small quantities preferably down to single molecules in all areas mentioned above. However, how to design and optimize the parameters of the bow-tie structure is of great importance to bring the near-field enhancement, and the shift and intensity variations of resonant dips to practical applications in near-field imaging and sensing.

In consideration of the low sensitive factor of single bow-tie structure, we can investigate the bow-tie arrays associating with LSPR conditions to obtain the high sensitive performance when changing the shape of particles and gap distances between them. By using the oscillating dipoles model, it has been shown that the localized field enhancement arises from the accumulation of the oscillating charges on the opposite edges of triangle patches, and the dips shift and intensity variations of transmission spectra are owing to the change of LSPR conditions. Finally, we give the optimized parameters for achieving the strongest enhancement of the localized field.





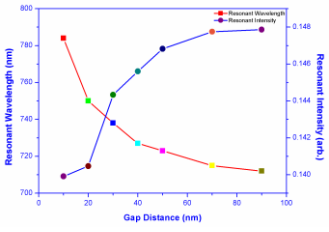


Fig.1 The geometrical shape of the simulated bow-tie arrays and the parameters of the bow-tie unit; Fig.2 The enhanced field distributions of the planes z=0 and y=0 for arrays in our simulations, given T=50nm, L=175nm, D=10nm and Θ=30°; Fig3. The resonant wavelengths and intensities of the transmission spectrum with changing gap distance from 10nm to 90nm.

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P-27

Quantum mechanical study on plasmon resonances in small sodium clusters with ring structure

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Understanding of plasmon excitations in small clusters with ring structure is essential for its applications such as surface enhanced Raman scattering and localized surface plasmon resonance sensing. Using time-dependent density functional theory, we have carried out a systematic study of collective excitations small sodium nanorings. The fragmentation of the photoabsorption strength in nanorings as a function of radius was observed, as found by Broglia et al in the study of the photoabsorption strength in the spherical shape of sodium clusters. Collective excitations were studied along two directions which are respectively perpendicular and parallel to the ring plane. Along the direction parallel to the ring plane, one main resonance peak evolves into two main resonances peaks with the continuous increase of the ring radius as shown in figure 1. These two collective excitation modes are respectively the lower-energy mode and the reverse two-dipole mode. The lower-energy mode is due to the electronic motion along the direction where the electrons can move through a longer distance. For the reverse two-dipole mode, the formations of these two dipoles are due to the external field inducement and the shielding effect. The excitation of the reverse two-dipole mode is mainly due to the coupling effect of the lower-energy mode and the higher-energy mode, and is also affected by the radius of curvature. When the ring radius is much larger, the reverse two-dipole mode is actually the quasi higher-energy mode. Unlike the lower-energy mode, the main resonance point shift of the reverse two-dipole mode is not a continuous process as shown in figure 1. We argue this phenomenon is due to nanoring quantum-size effects. In the cavity inside the ring, we also find the electric field generated by the induced charge should be nearly parallel due to the symmetrical distribution of induced charge. Along the direction perpendicular to the ring plane, there is only one main excitation mode which is the higher-energy mode. This mode is highly collective as a result of equal-strength interactions among energetically degenerate individual electronic states.

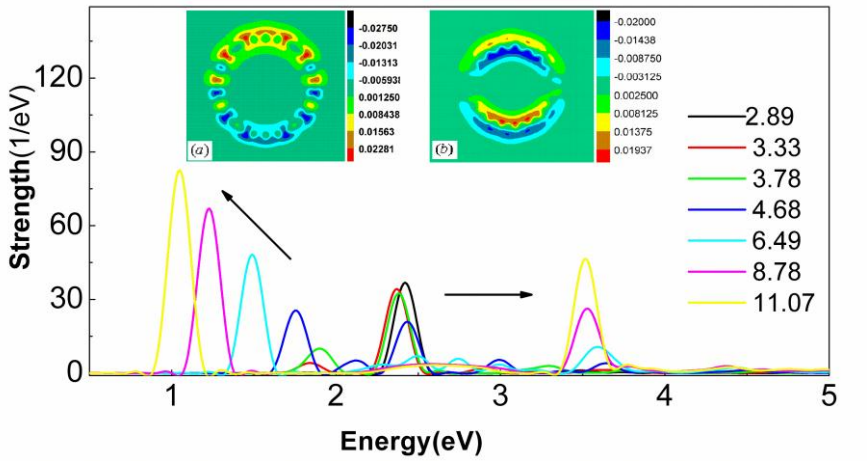

Figure 1. Optical absorption along the direction parallel to the ring plane . The numbers of the figure denote the radius of the ring. The unit is angstrom. The inset (a) is Fourier transform of the induced density at the energy resonance point 1.05 eV, and the inset (b) is Fourier transform of the induced density at the energy resonance point 3.52 eV.

P-28

Localized Surface Plasmon Resonance Modes at Edges of Gold Film Patterns

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We report on a study of localized surface plasmon resonance (LSPR) modes at edges of microscale Au film patterns. With the aid of conventional photolithography, Au micro-squares with a size of 100 × 100 μm^2 and thicknesses of 10 to 60 nm have been fabricated. Although these patterns are confined in only one spatial direction, the edge effect allows the occurrence of LSPR similar to that in metal nanoparticles or nanowires [1]. In the dark-field scattering spectra obtained at pattern edges, LSPR modes have been observed. Figure 1a is a dark-field optical image of a 40 nm thick Au pattern and it is apparent that the edges scatter the incident light strongly. The dark-field scattering spectrum at an edge is shown in Figure 1b and three peaks at around 517, 588, and 646 nm are observed. For comparison, the spectrum obtained at the center is also plotted and the signal is negligible as expected. To understand the origin of the modes, a cross-sectional transmission electron microscopy (TEM) image of the edge has been acquired and is shown in Figure 1c. The inset is a magnified image of the edge and three arrows are marked on the curved edge surface. The three LSPR modes are likely to originate from collective electronic oscillations along these three directions. Similar measurements have been carried out and LSPR modes have been observed on other samples. It has been found that the peak wavelength of the first mode increases as the film thickness is increased, whereas the other two peak wavelengths decrease slightly. By spin-coating a thin layer of PMMA on the Au patterns, chemical sensing capability of the three modes has been investigated. Red-shifts of the three peak wavelengths are observed as expected. A maximum refractive index sensitivity of 104 nm R.I.U.$^{-1}$ has been obtained for the 60 nm Au pattern. The sensitivity is close to that of single Au nanowires [1] and indicates the usefulness of these structurally simple Au patterns for chemical sensing.

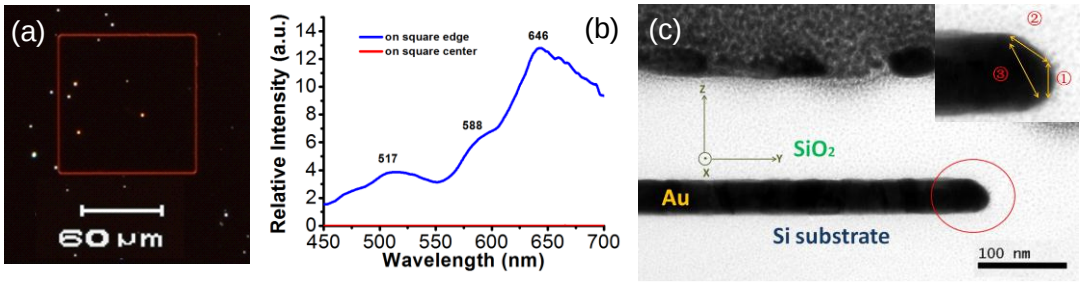

Figure 1. (a) Dark-field optical image of a 40 nm thick Au film pattern. (b) Scattering spectra obtained at an edge and the center of the pattern. Three LSPR modes are observed at 517, 588, and 646 nm. (c) Cross-sectional TEM image of the edge. The inset is a magnified image of the edge and indicates possible directions of the three modes.

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P-29

Plasmonic characteristics of hybrid Au/GaAs QW structure under electrical injection

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Plasmonic circuit is thought as a promising candidate for future information technology because it can be much faster than its electronic counterparts and break the diffraction-limited size of photonic circuits due to the surface plasmon polaritons (SPPs). Combining plasmonic structures with photonic devices and systems provide a possible avenue for the realization of plasmonic integrated circuits. Recently there are some studies focused on the active elements aimed at the excitation, amplification and detection of SPPs, especially the electrical SPP sources. However, the organic emitting material and Si nanocrystal with low quantum efficiency are hard to be applied to future integrated circuits. So electrical SPP source based on high gain compound semiconductor need to be developed.

Here the plasmonic characteristics of Au grating structure integrated with GaAs quantum well (QW) are investigated. In the device, QW layer is very close to the metal electrode layer with 30-nm-thick p-type GaAs layer between them, which results in efficient exciton-plasmon coupling. A big Au electrode region nearby the grating structure is obtained by metal deposition and lift-off process after pattern created. SPPs generated under electrode region propagate along GaAs/Au interface and then couple out by the grating structure. The spectra and images are collected by a 50 ×objective of long working distance. As shown in Fig.1, the intensity of the spectra increases with the increase of injection current, with two peaks at 755 nm and 870 nm due to the special epitaxial material structure. Under the injection current of about 0.7 mA, the images of the emission light at the stronger peak of 755 nm are recorded for different polarizations. For the image obtained with no polarizer used for the detection, the emission intensity at both the grating region and the bare epitaxial region is strong. At the grating region, the intensity of the light polarized perpendicular to the grating is much stronger than that polarized parallel (Fig.2 (b) and Fig. 2 (c)). Whereas, for the bare epitaxial region, the intensity under perpendicular polarization is weaker. Although part of the emission light comes from the direct QW emission because of current spread, SPPs are electrically generated and coupled out at the grating region, which is confirmed by finite-domain time-difference (FDTD) simulation. This device could be integrated with other plasmonic structures, such as Ag nanowire waveguide.

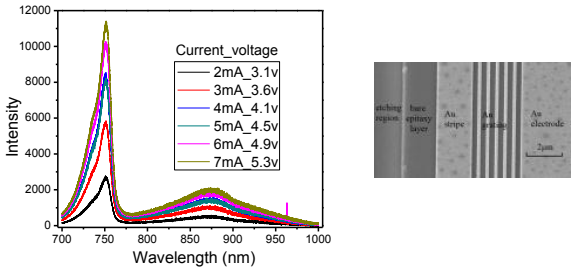

Fig.1 Spectra

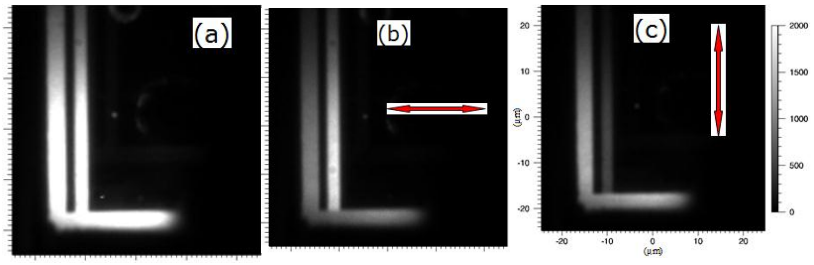

Fig.2 Image with different polarizations (red arrow: polarization direction)

P-30

Photocatalytic Activity of TiO2 Nanotube Array Enhanced by Surface Plasmon Resonance

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TiO2 nanotube array(TiO2 NTs) was prepared by anodic oxidation, and then Ag was assembled in TiO2 nanotube array (Ag/TiO2) by microwave-assisted chemical reduction. Ag/TiO2 sample was characterized by X-ray diffraction, scanning electron microscope, fluorescence spectrum, UV-visible absorption spectrum and Raman spectrum, respectively. The results showed that Ag nanoparticles (Ag NPs) was well dispersed on the surface of TiO2 NTs with Ag0 state. The surface plasmon resonance(SPR) effect of Ag NPs could not only improve the photoresponse of TiO2 NTs, but also enhance its Raman activity. Furthermore, Ag NPs restrained the recombination of photogenerated electron-hole pairs of TiO2 NTs efficiently. According to the experiments of photodegradation on methylene blue and photocatalytic water splitting, Ag/TiO2 had better photocatalytic performance than pure TiO2 NTs. The corresponding degradation rate and hydrogen evolution rate was 1.9 fold and 3.4 fold increase in the certain condition.

Keywords: anodic oxidation; microwave; Ag/TiO2; surface plasmon resonance; photocatalysis

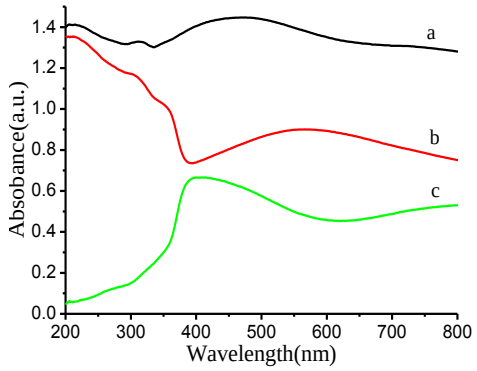

Figure 1. UV-vis absorption spectrum:a. Ag/TiO2 NTs b. TiO2 NTs c.Ag NPs(curve a substracted curve b)

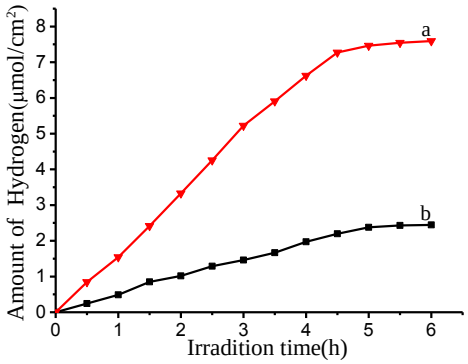

Figure 2. Amount of Hydrogen evolution by a. Ag/TiO2 NTs b. TiO2 NTs

P-31

Focusing light using spiral plasmonic lens

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We investigate the focusing properties of a plasmonic lens with spiral nano-structures, and analyze its field enhancement effect based on the experiments and finite-difference time-domain simulation. The simulation result demonstrates that a left-hand spiral plasmonic lens can concentrate an incident right-hand circular polarization light into a focal spot with a high focal depth. The intensity of the focal spot could be controlled by altering the number of turns, the radius and the width of the spiral slot. And the focal spot is smaller and has a higher intensity compared to the incident linearly polarized light.

And this spot can be focused into far field due to constructive interference of the scattered light by an annular groove. The focal properties can be adjusted by changing the groove radius and number of grooves within a certain range. This design can also eliminate the requirement of centering the incident beam to the plasmonic lens, making it possible to be used in plasmonic lens array, optical data storage, detection and other applications.

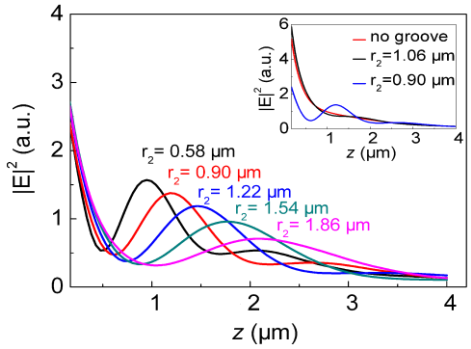

Fig.1. $|E|^2$ distributions on the optical axis for the left-hand spiral plasmonic lens with different groove radiuses.

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P-32

The Relationship between Scattering Spectra and SERS Effect in SHINERS

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Shell-isolated nanoparticle-enhanced Raman spectroscopy (SHINERS), in which the Raman signal amplification is provided by metal nanoparticles with an ultrathin shell (such as dielectrics, transition metals), is a powerful approach to study single-crystal surfaces. In this work, surface plasmon resonance (SPR) based scattering spectra and SERS effect in Au@SiO_2 SHINERS system was simulated by the three dimensional finite difference time domain (3D-FDTD) method.

The dependence of the scattering efficiency and the maximum SERS enhancement factor at the hot spot on the excitation wavelength in SHINERS is shown in the figure. Note that the two curves in the fig.(b) are normalized. Our calculation results show that the profile of the electric field intensity enhancement is clearly different from that of the scattering spectra, regarding the relative values or positions of their peaks. The interparticle SPR coupling effect (including dipole-dipole and quadrupole-quadrupole coupling) between the particle and substrate plays a dominant role in SHINERS enhancement.

Acknowledgement(s) Financial supports from NSF of China (Nos. 11074210 and 21173171) and National Basic Research Programs (2009CB930703) are gratefully acknowledged.

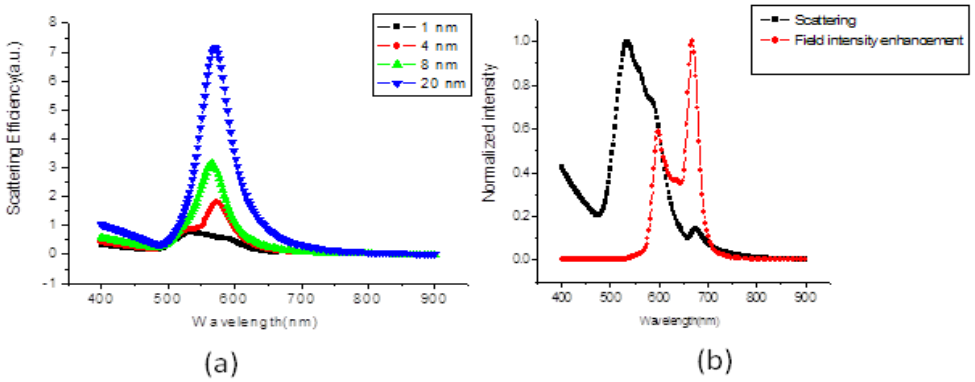

Figure 1_(a) Incident wavelength dependent spectra of Au@SiO_2 particle lying on Au single-crystal surface with D=80nm and various h. (b) Incident wavelength dependent spectra of Au@SiO_2 particle lying on Au single-crystal surface with D=80nm and h=1nm.

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P-33

Sub-attomolar sensitivity through directed pre-concentration on super-hydrophobic surface using an SERS optrode

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SERS optrode is a recently developed sensor[1, 2] in whichthe SERS substrate is built on the distal end of a fiber optic, while the proximal end of the fiber is used to couple in the excitation laser. Both the laser excitation and the scattered signal travel through the same fiber. Such kind of sensor is well suited for field work and remote analysis.

The solutes in a droplet recedes along with the contact line on the surface of certain type (Cassie type) of superhydrophobic materials. Unlike the common coffee ring effect, this phenomenon allows analytes to precipitate on a very small area after the solvent evapoartes. This effect has been used for preconcentration of trace analytes[3, 4]. Near single-molecule sensitivity SERS analysis of the model analyte R6G has been established, based on superhydrophobic-SERS dual functional substrate.[4]

In this report, SERS optrodes will be used in combination with superhydrophobic materials to develop a new type of analytical device for trace analysis. The superhydrophobic material was constructed by coating a sandpaper with Tefflon® NPs. The SERS optrode was fabricated according to our former report[2]. 10 μL of sample solution containinig trace amounts of nile bule A was dropped on the superhydrophobic surface, then the SERS optrode was inserted, as shown in Fig. 1. The solution droplet was allowed to dry. Instead of random precipitation on the dual functional substrates reported by others[3, 4], in our configuration the solutes in the sample droplet is naturally directed to the optrode during evaporation. In another words, the SERS optrode acts as both the sensing element as well as the preconcentration platform. Preliminary results showed that ppt level (10's attomole) limit of quantification can be easily achieved using this device. This LOQ is 3 oders of magnitude lower than previous reported using optrodes without pre-concentration.

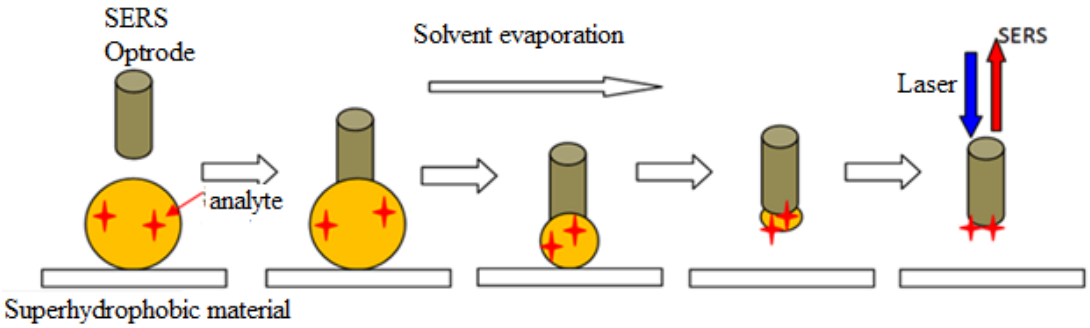

Figure 1 schematic representation of the experiment set-up

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P-34

Fabrication of Ag nanostructure substrate using the femto-second laser for broadband and tunable plasmonic enhancements

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Using a femto-second laser, we have transformed the laser-direct-writing technique into a highly efficient method that can rapidly process glass substrate into aggregates of Ag nanoparticles that provide plasmonic enhancement. The processed AgOx thin films showed enhanced optical absorption over a broad spectral range. Blinking of dyed polymer beads has been observed as they randomly drift in and out of the plasmonic hotspots in the Ag nanostructures. The treated AgOx thin film can effectively function as an active substrate for surface enhanced Raman scattering measurement. Degree of Raman enhancement can be tuned by controlling the processing laser power. The large pulse power delivered by the femto-second laser allows for a continuous scan across the sample surface at the fast processing rate of more than 300μm2/min, which is at least two orders of magnitude faster than other reported laser-direct-writing techniques with either continuous or nano-second lasers. In addition, the hotspots are found to be uniformly distributed over the treated area. This technique offers an efficient and cost effective approach to develop large area active substrates from AgOx thin films for plasmonic enhancement applications.

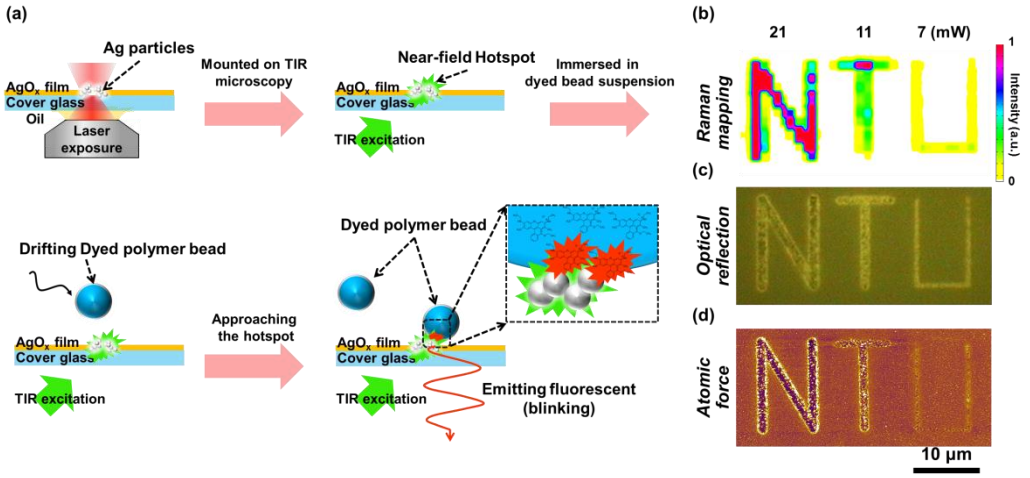

Figure 1. (a) Schematics of LDW processing 15-nm-thick AgO_x thin film being mounted on a TIR microscopy, immersed in dyed polymer bead solution, excitation of drifting beads at hotspots, and blinking of dye molecules embedded in the beads. (b)-(d) Raman, optical reflection, AFM images of "NTU" pattern written on AgO_x thin film by the femto-second laser. Letter "N" is written with laser power of 21 mW, "T" with 11 mW, and "U" with 7 mW. The Raman image is obtained from R6G (10^{-5} M) adsorbed on the laser-patterned AgOx thin film by integrating the spectral intensity over their identified Raman peaks ranging from 568-623 cm^{-1}.

P-35

Tip-enhanced Raman spectroscopy: from monolayer to single molecules

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Tip-enhanced Raman spectroscopy (TERS) has been a promising method in surface science due to its high spatial resolution and sensitivity since it was discovered in 2000s. An important issue in surface science is the molecular self-assemble process on metal surface, which actually closely relate to surface chemistry and molecular electronics. As the topography images and chemical information can be simultaneously obtained by TERS, it could be a preponderant tool. We will show our resent works on the investigations about self-assemble process and single-molecule detection on the surface of gold single crystal.

We firstly immersed the gold single crystal in the solution of probe molecules (see the structure in fig.1a) for varied time. After an immersion time of 2 hours, the STM images were unable to give detectable difference. Yet, we could observe evident changes of TERS spectra, which implied strong interactions between molecules in the monolayer. Thus we could not only further investigate the detailed process during self assembling, but also demonstrate the great advantages of TERS in studying this kind of surface process.

In order to know more about the behavior of molecules on surface and exclude the influence of interactions between molecules, we isolated the probe molecules with molecular template formed by thiols. Due to the high sensitivity of TERS, we could observe the vibrations of the isolated single molecules. In addition, fluctuations in intensity and frequency were also obtained, which was believed to be a character of single-molecule phenomenon. We have obtained single-molecule TERS for both resonance and non-resonance molecules, and the latter is particular important because the resonant effect can be neglected.

The present study points to a promising future of TERS in surface science.

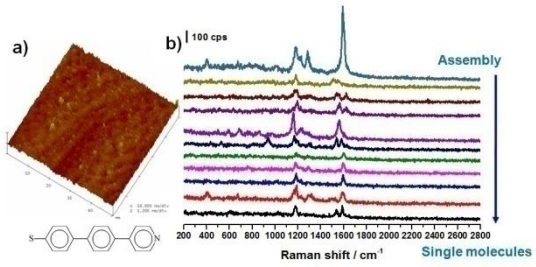

Fig. 1 a) STM image for single probe molecules captured in the holes of self-assemble layer of hexanethiol. b) TERS spectra of saturated monolayer molecules (the top one) and single molecules.

Acknowledgement Financial supports from NSFC (20825313, 21021002 and 21021120456) and 973 program (2011YQ03012406 and 2009CB930703) are highly acknowledged.

P-36

The Raman spectroscopy studies on the oxygen ion implanted ultrananocrsytalline diamond films

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Ultrananocrystalline diamond (UNCD) films were implanted by 10^{14} cm^{-2} oxygen ion and annealed at different temperatures. Visible and uv Raman spectroscopy measurements were performed on the samples. The results of uv Raman spectroscopy measurements show that the amorphous carbon phase transits to diamond phase with annealing temperature increasing from 500 ˚C to 800-900 ˚C, and diamond phase transits to amorphous carbon phase again at 1000 ˚C annealing. Visible Raman spectroscopy measurements reveal that the phase transition has a close relation to the hydrogen diffusion in the films under different annealing temperatures.

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P-37

Giant enhancement of near-ultraviolet light absorption by TiO_2 nanoparticles via designed Al nanostructures

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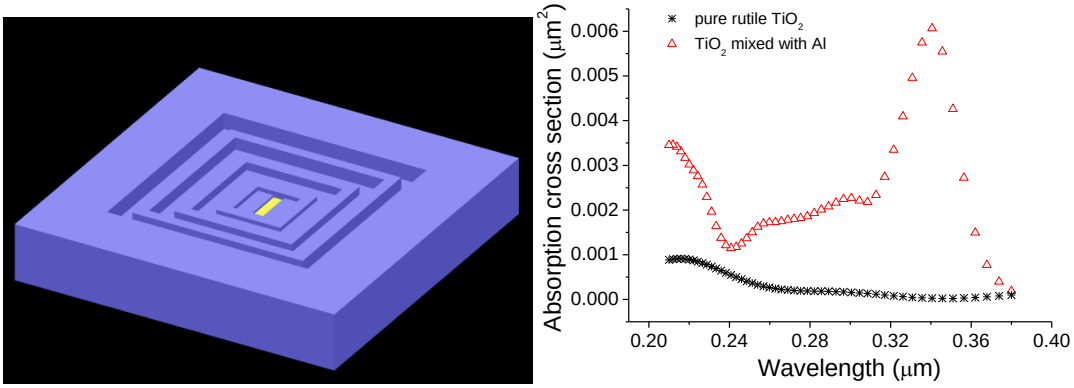
We propose a scheme to enhance near-UV band absorption of a rutile TiO_2 nanoparticle [1] by embedding TiO_2 nanoparticle into designed Al three-dimensional (3D) nanostructures. The 3D finite-difference time-domain (FDTD) method was employed to calculate the absorption spectrum of pure rutile TiO_2 nanoparticle and that of TiO_2 mixed with designed Al nanostructures. Our theoretical study has shown that pure rutile TiO_2 has its maximum absorption located in the deep-UV band of about 210 nm. When we embedded the TiO_2 nanoparticle into Al nanostructure, a significant light harvesting effect occurs, and this maximum shifts to the near-UV band at about 340 nm, which is close to the mercury lamp 365 nm line. The maximum enhancement coefficient is more than two hundreds with an optimized Al nanostructure. The result means that Al nanostructures can play an important role in increasing the absorption of TiO_2 in the near-UV region. This phenomenon is attributed to the strong scattering and local field enhancement of light via designed Al nanostructure in the near-UV region. These designs open up a promising way to boost the photocatalytic activity of TiO_2.



(a) (b)

Figure 1. (a) Schematic configuration of TiO2 mixed with designed Al nanostructure. The yellow part is TiO2 particle and the violet part is designed Al nanostructure. (b) Calculated absorption spectrum of pure rutile TiO2 particles and TiO2 embedded into optimized Al nanostructures.

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P-38

Preparation of 3D network Na2Ti2O4(OH)2 nanotube film and study on light absorption properties

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The 3D network Na2Ti2O4(OH)2 nanotube film was prepared by combining interface chemical reaction with hydrothermal reaction. It can be readily indexed based on an orthorhombic system Na2Ti2O4(OH)2 (JCPDS, 47-0124). The nanotubes are commonly multiwalled with a diameter about 40 nm, and a length more than 2000 nm. The interlamellar space of the nanotubes is about 0.9nm, and the UV-Vis of the specimen loaded with silver by magnetron sputter plating method has a great improvement between 280nm and 630nm, which is due to silver localized surface plasmon resonance with the resonance-absorption peak at 490nm.

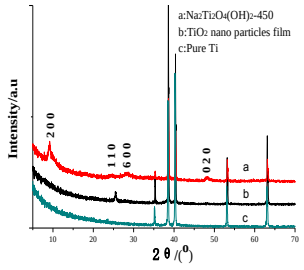

Fig. 1 XRD

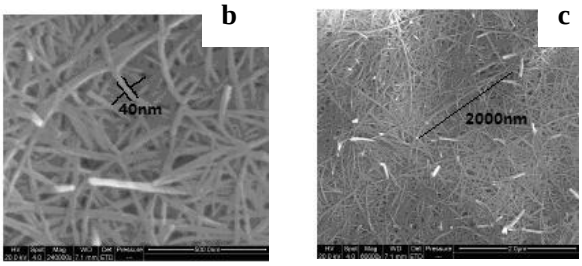

Fig. 2 SEM

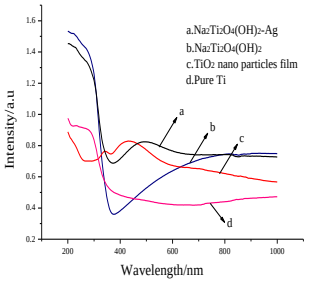

Fig. 3 UV-Vis

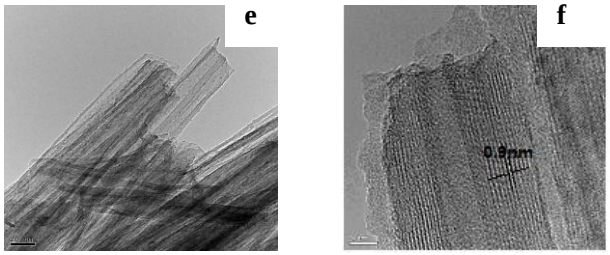

Fig. 4 TEM

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P-39

Study the effect of dielectric layer thicknesses on plasmonic resonance response of a multilayer (metal-dielectric-metal) nanostructure

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Plasmonic resonance frequency and near field intensity enhancement induced by the resonance are important for surface enhanced Raman scattering (SERS) application [1]. In this work, we proposed a SERS-substrate which is a two-dimensional hexagonally nanopillar-array structure with a multilayer (Au-SiO_2-Ag) thin film coating (see figure 1), and investigating the plasmonic resonance response of our SERS-substrate with difference SiO_2 thickness by using three-dimensional finite-difference time-domain (3D-FDTD) simulation tools.

There are two interesting things we found in our simulation results. The one thing is plasmonic resonance frequency can be tuned by varying SiO_2 thickness, because the plasmons interact with each other between two metal films. This phenomenon can be explained by a hybridization model for the plasmon response [2].

Another one is when the resonance frequency caused by the Au-SiO_2-Ag resonator is coincides with the plasmonic resonance frequency for a given SiO_2 thickness, the enhancement of near field intensity is stronger. This can be explained by increasing energy in the cavity (which generated from Au-SiO_2-Ag resonator) can re-excite plasmons. Otherwise, when the cavity resonance frequency is not coincides with the plasmonic resonance frequency, the enhancement of near field intensity is not so strong. Above-mentioned can be illustrated in figure 2, the average near field intensity enhancement for the case of SiO_2=200nm is 1.23 times more than the case of SiO_2=150nm.

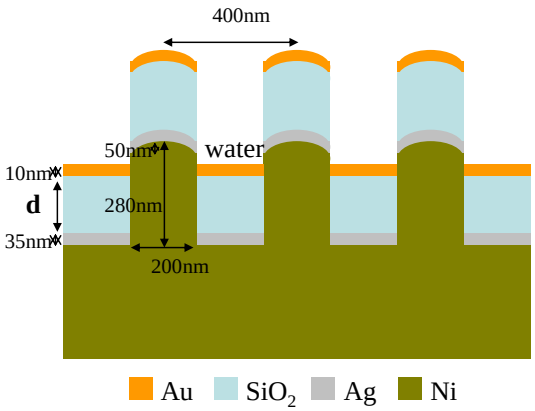

Figure 1. Schematic diagram of our multilayer plasmonic nanostructure

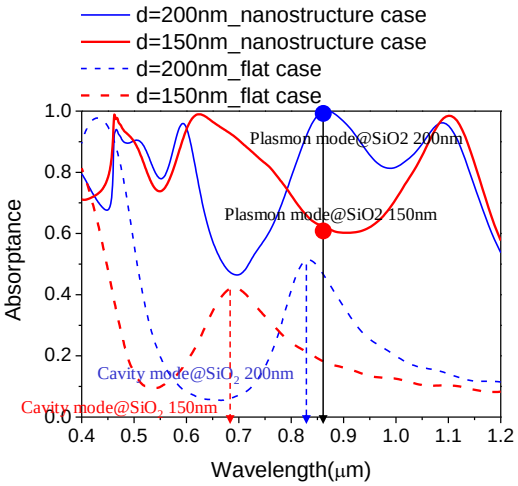

Figure 2. Absorptance spectrum for our multilayer-SERS-substrate (solid line) and multilayer-flat-substrate(dash line). The thickness of SiO_2 are 150nm (red line) and 200nm (blue line). respectively.

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P-40

Au-ITO Multilayer Grating: One-way Absorber at 1550 nm

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An Au-ITO multilayer grating is formed after the Au-ITO multilayer deposition on the ordinary glass grating substrate and simple lift-off. The novel thin metal and transparent dielectric ten-pair multilayer structure absorbs the signal light at 1550 nm by 94.3% along the positive incident direction. While in the negative incident direction, the light is reflected by 91.9%. This nearly one-way absorption or reflection character endows the device with potential application values in the signal procession, optoelectronics integration and military defense.

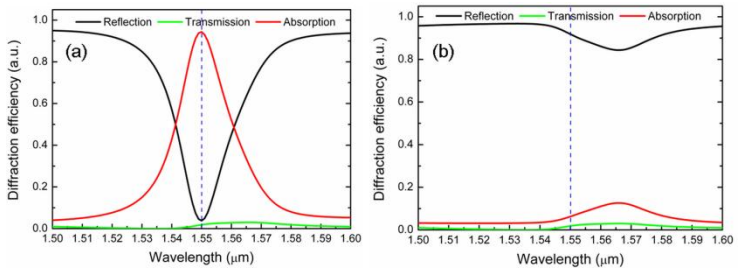

Figure 1. ATR efficiency of the multilayer grating in the positive (a) or negative (b) direction.

P-41

Surface Wave Holography for Wave Manipulation

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Subwavelength structures on a metallic surface have attracted much interest over years. It is shown that when a subwavelength aperture is surrounded by periodic corrugations, the transmitted light can emerges as a beam with a small angular divergence, instead of diffracting in all directions [1]. This finding has opened a path of manipulating wave front by designing periodic subwavlength structures. It is believed that the interaction between surface electromagnetic wave and subwavelength metallic structures plays a key role in the phenomenon [2].

So far, an analytical tool that allows for easy conceptual understanding of the numerical or experimental results of metallic surface periodic structures is absent, and this becomes a big obstacle for expanding these structures to have more complicated functionalities. In this work, by introducing the concept of surface wave holography [3, 4], we find that the extensively studied focusing and beaming structures, metallic films with a hole surrounding by grooves etc., are essentially a plane hologram [4]. We present a method in the framework of surface wave holography to manipulate the electromagnetic wave on the metallic surface for realizing complicated electromagnetic wave transport functionalities in three-dimensional space. For a given electromagnetic wave transportation, one can determine the surface morphology of a metallic plate easily by using the proposed method.

Analytically, we give the morphology equations of a single-point imaging and a plane-wave imaging. Carving grooves on a metallic surface according to these equations, we get numerical and microwave experimental results as predicted. A two-point imaging is also shown, which indicates that two sets of grooves can work together. Furthermore, we demonstrate our idea at 1064 nm wavelength by showing that the light passing through a hole with 180 nm radius can be collected into a letter “L” and a letter “O” at a given position. Good agreement between numerical simulations and experimental measurements con-firms the power of the method in conceptually understanding and functionality exploiting.

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P-42

Direct surface plasmon induced reduction of metal salts

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Xue et al [1] synthesised the gold core with silver nanoprism shell from a mixture of Ag and Au nanoparticles, wherein they argued that SPR of the gold reduces silver from dissolved silver nanoparticle to form the core shell structure, after which further reconstruction takes place to form the silver prism.

Here we show convincingly that silver ions can be directly reduced by SPR excitation of gold nanoparticles to form Au/Ag alloy. From UV-visible spectroscopy analysis, a constant blue shift of the SP peak of AuNP was observed. After 60 minutes of the reaction process, a blue shift of 11 nm was observed in case of illumination with yellow light (λ=589 nm) . Also, decrease in the absorption of AuNP was observed. The blue shift was related to the formation of Au/Ag alloy. Also, the evolution of peak at 395 nm suggested that additional Ag nanoparticles were formed and TEM confirmed that it formed a shell around the gold nanoparticles. After 60 minutes of reaction, core shell and alloy structures were identified from HRTEM and X-ray diffraction analysis.

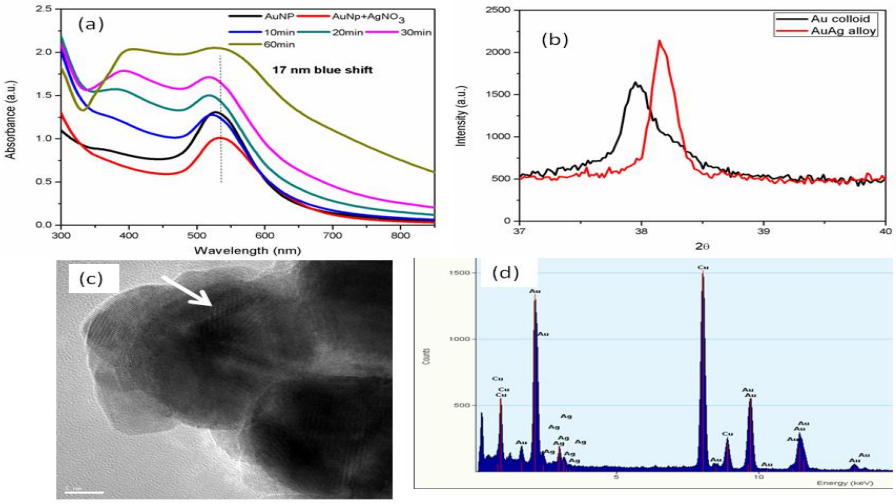

Figure 1(a): UV visible spectra of AuNPs in 5mM $AgNO_3$ solution at various time intervals in presence of 70 W yellow light (589 nm). (b) XRD pattern of Au (111) before and after 60 minutes of reaction. (ICDD Au= 04-0784, Ag/Au= 65-8424) (c) HRTEM image showing the formation of core-shell type structure (d) EDX spectra of TEM sample confirming the presence of both Au and Ag.

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P-43

Simple and Efficient Computational Method to Analyze Cylindrical Plasmonic Nanoantennas with Arbitrary Configuration

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Optical antennas or nanoantennas are devices which can be used to transmit and receive optical fields in the nanoscale domain [1]. Conventional 3D techniques, for example the Green's tensor method, the finite difference time domain method (FDTD), the discrete dipole approximation (DDA) and commercial softwares such as COMSOL and CST, have been used to analyze optical antennas. In general, all these techniques require high computational cost to make a precise analysis. Recently, simplified and efficient methods have been applied to analyze cylindrical nanoplasmonic antennas [2-3]. These methods reduce the original 3D problem in to 1D integral equation.

In this work, we present an efficient and simple alternative technique to analyze metallic cylindrical nanoantennas. In this method, we consider linear current inside the antenna and use 1D integral equation for the electric field with given surface impedance of metal. The solution of this integral equation is obtained approximately by linear Method of Moments (MoM) with sinusoidal basis functions. Some numerical examples are presented and compared with 3D methods (Fig. 1). The results show that the proposed method provides a good efficiency in terms of precision and processing time when compared with general 3D techniques. This method can be used to analyze arbitrary configurations of linear nanoantennas, with different geometries and radius of curvature and different excitation sources.

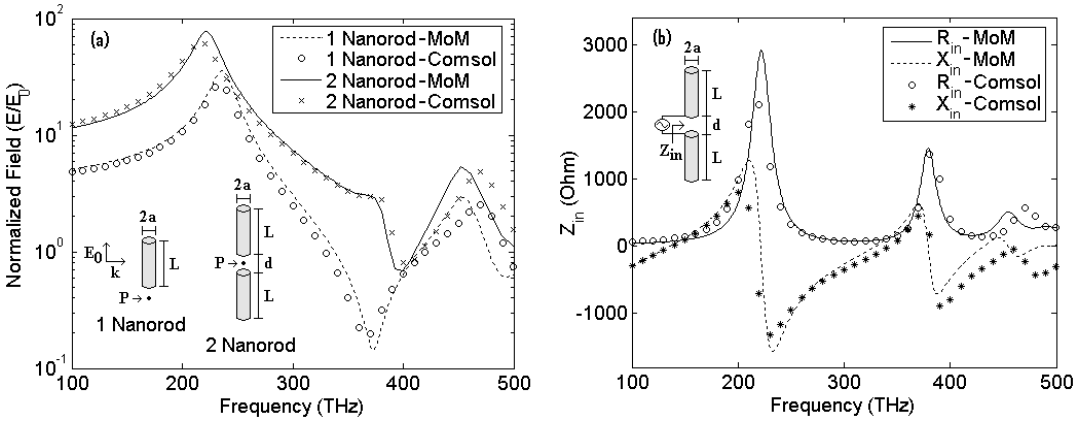

Figure 1. Examples of theory application. (a) Normalized electric field near single and two nanorods, at point P (10nm from the nanorod's edge), scattered by a plane wave with magnitude E_0. (b) Input impedance of a nanodipole center. The nanoantennas are made of Au, background is air, L=220nm, a=10nm and d=20nm.

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P-44

Gold nanorods doped single polymer nanofibers for optical sensing

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Noble metal nanoparticles (NPs) are attractive materials for emerging applications due to their fascinating optical properties originated from localize surface plasmon resonance (LSPR). The incorporation of NPs in one-dimensional optical nanowires or nanofibers (NFs) is highly desired for miniaturized photonic integration. Here we report the waveguiding gold nanorods (GNRs) doped single polymer optical NFs for LSPR-based optical sensing.

GNRs with aspect ratio of 2.5 were synthesized using a seed-mediated method. The polymer used for hosting GNRs and drawing NFs is polyacrylamide (PAM). GNRs/PAM NFs were fabricated using a solution direct drawing method [1]. Figure 1a shows a TEM image of an as-fabricated 390-nm-diameter GNRs/PAM NF, in which the GNRs are aligned in parallel to the NF axis. The unidirectional alignment of GNRs gives rise to strong polarization-dependent scattering along the whole NF.

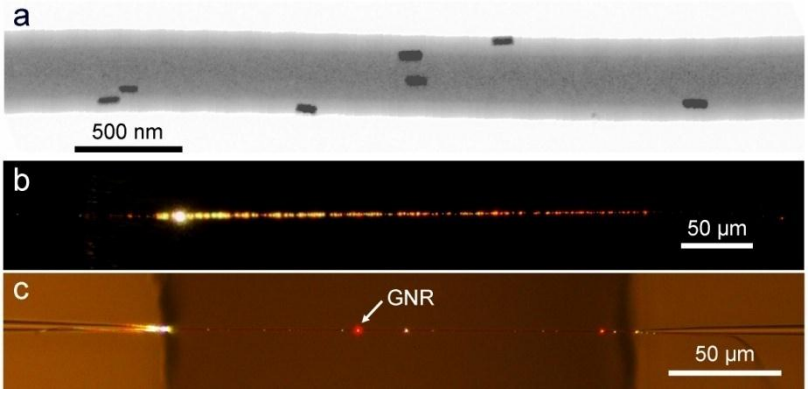

Figure 1. (a) TEM image of a 390-nm-diameter GNRs/PAM NF. (b) Optical microscope image showing the waveguiding excitation of a microchannel-supported 580-nm-diameter GNRs/PAM NF using a fiber taper. (c) Optical microscope image of a 410-nm-diamter single GNR embedded NF waveguided with white light for optical humidity sensing.

Using light in waveguiding modes of the NFs, LSPR in embedded GNRs can be excited with high efficiency and compactness, as shown in Figure 1b. Based on local dielectric environment sensitivity of embedded GNRs, optical humidity sensing using single GNR embedded PAM NF (see Figure 1c) by monitoring LSPR shifts was demonstrated with high sensitivity (~ 12 nm blue shift in plasmon resonance peak in response to 60% RH changes), fast response time (~ 110 ms), low power consumption (~ 5 nW), and small footprint.

In addition, due to the flexibility in host polymer selection, the GNRs embedded polymer NFs can be applied to detect other gases, and may be used for highly efficient and compact Raman spectroscopy.

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P-45

Reflectionless Ultra-thin Microwave wave-plate based on Metamaterial

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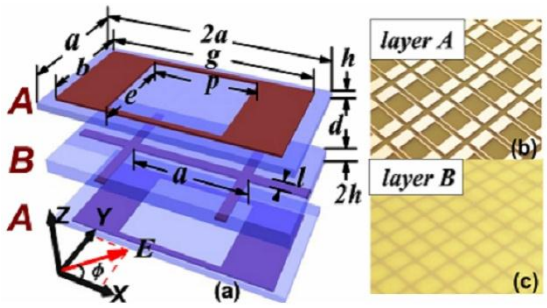
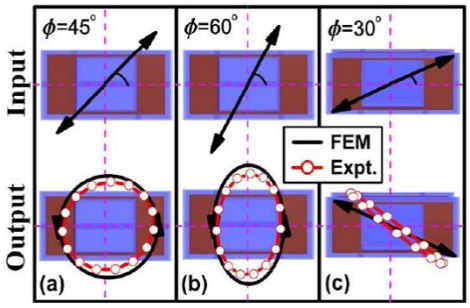
It is highly desirable to efficiently control the polarization of electromagnetic (EM) wave, due to many application requests. Conventional methods to manipulate the polarization of light (based on Faraday, Kerr, birefringence effects, etc.) typically require a system much thicker than wavelength, which are inconvenient for low-frequency applications. Although an optical grating can be very thin, it suffers the energy loss problem since the system is not perfectly transparent.

Metamaterials, artificial materials composed by resonant microstructures to exhibit arbitrary values of effective and , open a new way to manipulate the polarization. Recently, a specifically designed metamaterial reflector can efficiently manipulate EM wave polarizations [1]. The device is much thinner than wavelength and does not suffer the energy loss issue since it is perfectly reflecting for EM waves [1]. However, the reflection geometry makes it inconvenient for practical applications due to the interference between incident and reflected waves. While some newly proposed metamaterial devices [2] can avoid the interference problem, they are typically not perfectly transparent for EM waves so that the energy-loss issues remain unsolved.

Here we design an ultra-thin metamaterial wave-plate (see Fig. 1) to manipulate EM wave polarizations in transmission geometry. The proposed device is much thinner than wavelength, perfectly transparent for EM waves at the working frequency, and can manipulate the EM wave polarizations efficiently. The key idea of the design is to adjust the perfect transmissions for two incident polarizations, which are governed by different mechanisms, to occur at the same frequency. Microwave experiments are performed on realistic samples to demonstrate the polarization manipulation effects, with obtained results agreeing well with numerical simulations (see Fig. 2) [3].





(Left) Fig. 1. Geometry of the device and sample pictures. (Right) Fig. 2. Polarization manipulation effects by our designed device. *

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P-46

Strong coupling in plasmonic cavity combined with QWs at THz wavelengths

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Intersubband polariton are quasiparticles originating from the interaction between plasmonic cavity mode and a two dementional electron gas. Since intersubband polaritons have been observed in 2003[1], several works have been reported for plasmonic cavity with a one-dimensional metallic periodic structure, i.e, metallic rectangular strip gratings, on the top metallic film[2-3].

However, the incident electromagnetic wave in the above reports is TM mode. In our work, we use Au film perforated with two dimensional arrays of cross shaped holes. The incident wave for our novel metal-dielectric-metal microcavity is out of TM mode limit. We believe that our results will devote to the study of new optoelectronic devices.

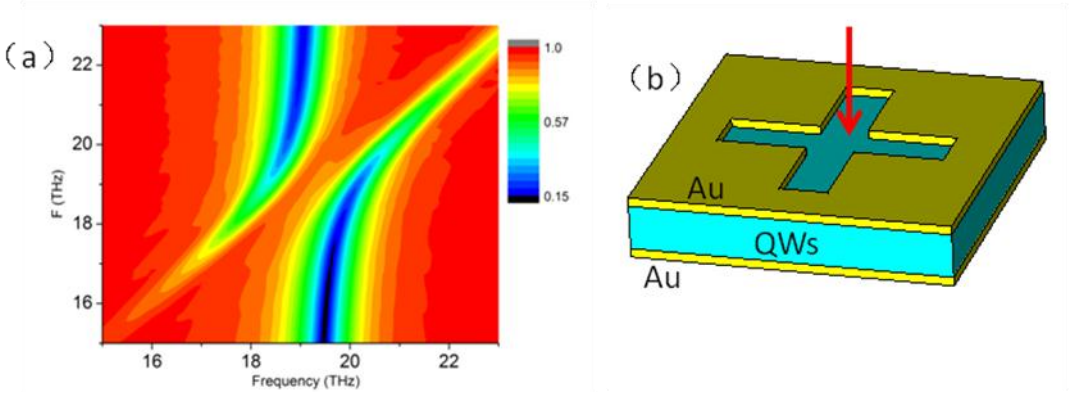

Figure.1. (a)Color contour plot of reflectivity spectra simulated for structure (b) at the QWs' resonance frequency 19THz.(b)A scheme of the unit cell devices in our experiments.

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P-47

Plasmon Controlled Single-Molecule Junctions

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The capability to utilize plasmons to squeeze light into nano-scale metal gaps opens exciting possibilities to gate, control and steer the conductance properties of nano-scale and molecular junctions.
Conductance enhancement is demonstrated for single-molecule junctions in the presence of plasmons. The observed enhancement takes place through a photoassited process, in which plasmonic oscillations are coupled to the junction, bringing a fraction of the tunneling charge into resonance with the molecular levels.
This research is an essential step towards the realization of ultra-fast plasmonic controlled electronic devices.

P-48

Fabrication of M-shaped Nanogratings Nanostructures as Single-Molecule SERS Active-Substrate by Nanoimprint Lithography

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We employ room-temperature nanoimprint lithography (RT-NIL) to fabricate a novel type of three dimensional M-shaped nanostructures with sub-10 nm nanogaps between two adjacent nanostructures. Using such nanostructures as the Surface enhancement Raman Spectroscopy (SERS) active substrate was investigated. A significant enhancement factor (EF) is achieved as approximately 1012 compared with that from a conventional Raman spectroscopy. The preliminary experiments have shown the properties of M-shaped active-substrate with enough sensitivity to single molecule SERS.

The RT-NIL is carried out with bilayer photoresist. The top layer and the bottom layer is hydrogen silsequioxane (HSQ) and ZEP 520 A, respectively. After RT-NIL and releasing, reaction ion etching (RIE) process compositing with O2and CF4 plasma is carried out to cure and remove the residual of HSQ. Subsequently, individual O2 plasma is applied to etch the ZEP resist. Then, mixing with SF6 and Ar plasma is employed to etch the substrate. Finally, we obtain the desirable M-shaped nanostructure after removing the ZEP resist. The Fig.1 shows the morphology of M-shaped nanostructure.The SERS spectra are collected in backscattering mode by a JY LabRAM HR Raman spectroscopy with a laser wavelength of 633 nm. We performed preliminary experiments with varied nanogaps, sub-10 nm, 30 nm and 50 nm, respectively, which results shown in Fig.1 (b) .The SERS EF of single R6G molecule was calculated by the equation:EF = (ISERS/Nads)/(Ibulk/Nbulk). The average SERS enhancement factor achieves up to 1012. To fully reveal the significant enhancement mechanism, we also performed numerical simulation with commercial 3-D finite-difference time-domain (FDTD) software by COMSOLTM 4.2. The simulation results of the fourth order of the local field enhancement versus incident wavelength shows in Fig.1(c), showing that the electrical field of the nanogaps is significantly stronger than other area.

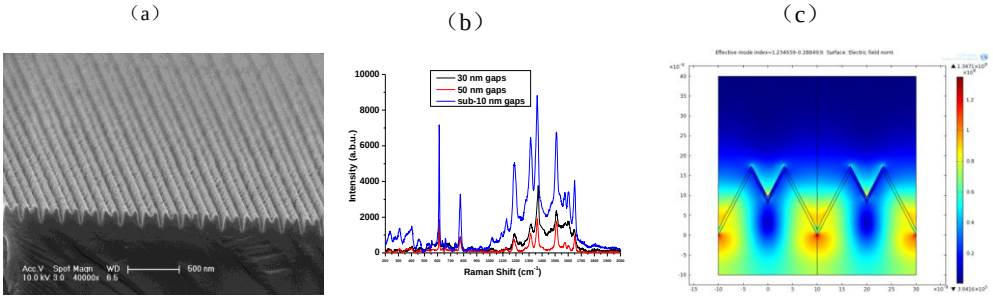

Fig.1(a) M-shaped 3D nanograting with sub-10 nm nanogaps between two adjacent nanostructures.(b) The SERS spectra of M-nanogratings active-substrate with different nanogaps, (c) FDTD simulation shows that the electrical field of the nanogaps is significantly stronger than other area.

P-49

Silver dendrites substrate for surface-enhanced fluorescence

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A new substrate for surface-enhanced fluorescence, which consists of dendrites silver nanostructure on copper surface, was fabricated by modified galvanic displacement process at room temperature. It was found that the fluorescence efficiency of fluorophore Rh6G molecules on the substrate depends on the period of the nanostructure growth, and increases with the enrichment of fine-branches of the dendrites nanostructure. The experimental observations are explained with local field enhancement and surface plasmon resonance theory for metal nanostructures. The results of current study highlight the important of strong EM coupling in surface enhanced fluorescence effect.

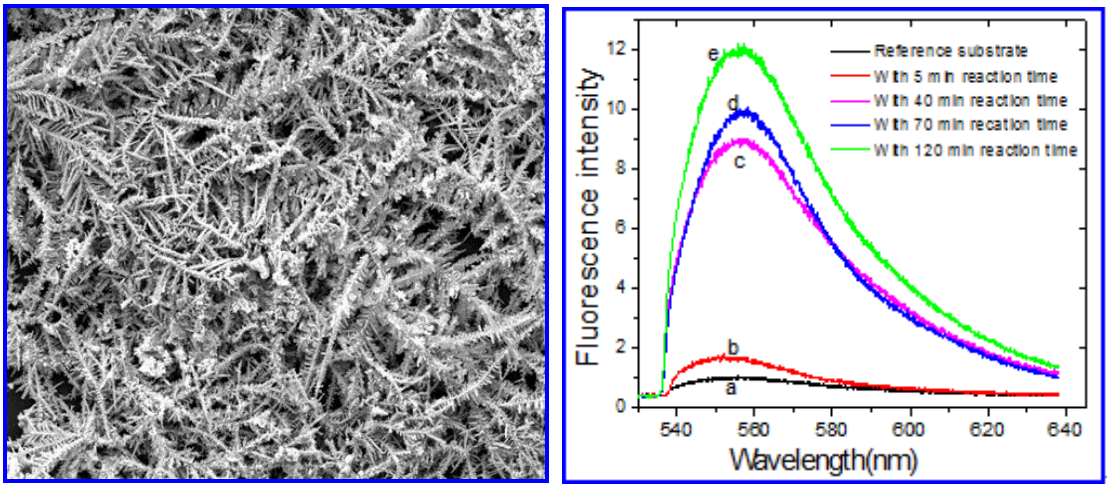

Fig. 1 The SEM picture of silver dendrites nanostructure(a), the fluorescence spectrum of Rh6G molecules on different substrate(b).

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P-50

Giant Raman enhancement on nanoporous gold by conjugating with nanoparticles for single-molecule detection

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Hot spots have the contradictively geometrical requirements for both the narrowest interstices to provide strong near-field coupling, and sufficient space to allow entrance of the analytes. Herein, a two step method is employed to create hot spots within hybrid nanostructures, which consist of self-supported nanoporous gold films with the absorbed probes and subsequent nanoparticle conjugates without surface agents or mechanical motion [see Fig. 1]. The molecules confined into 1 nm interstice exhibit 2.9×10^{7} times enhancement in Raman scattering compared to pure nanoporous gold. Giant enhancement primarily results from strong near-field coupling between nanopore and nanoparticle, which is theoretically confirmed by finite-difference time-domain simulation. Excellent detection limits toward 10^{-11} mol/l offer an opportunity to track spatial orientation of single molecule and engineer hybrid nanostructures as commercial SERS substrates.

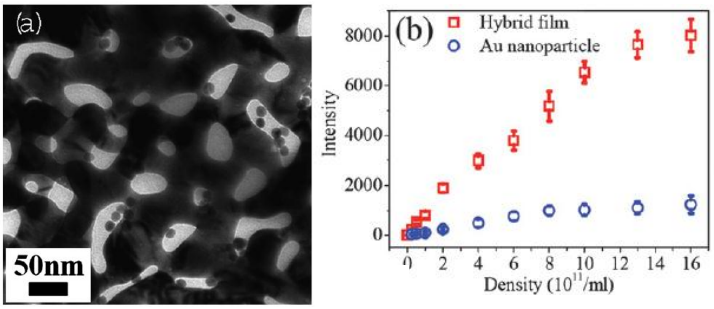

Figure 1. (a) TEM image of pure NPG–nanoparticle conjugates. (b) Variation of Raman intensity at 1097 cm^{-1} with colloidal concentration, measured at ten different spots of the NPG–nanoparticle structures. Raman intensities acquired from monolayer of gold nanoparticles with various concentrations are included for comparison.

P-51

Collective Excitations in Ultrathin Magnesium Films on Silicon

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We present a systematic study of plasmon excitation in ultrathin Mg overlayer on Si(111) substrate. Our numerical results qualitatively reproduce the experimentally observed plasmon spectra of the Mg/Si systems [1]. The underlying physics of the formation of various absorption peaks can be understood using the simple hybridization concept. Based on this concept, the coexistence of surface and bulk plasmons in the experimental observation turns out to be a clear evidence for the existence of multiple surface plasmons due to the quantum confinement in Mg thin films [2]. In addition, we clearly see the plasmon enhanced substrate absorption, which comes from the screening of the substrate to the oscillatory charges.

References:

1. Ao Teng et al. (to be published).
2. Xiaoguang Li et al. (to be published).

Author Index

Organizers

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