International Symposium on NanoPhotonics 2012

Organizer

China-Japan Joint Laboratory on Advanced Photonics, TIPC, CAS

February 12th -14th, 2012

Friendship Hotel, Beijing, China

Committee

Co-Chairs:

Xuan-Ming Duan (Professor, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences)
Satoshi Kawata (Professor, Osaka University)

Local Organizing Committee:

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Organizer

China-Japan Joint Laboratory on Advanced Photonics, TIPC, CAS

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MOST, China
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Symposium Venue

Bejing Friendship Hotel
No.1, Zhongguancunnandajie, Haidian district, Beijing, China
TEL: +86-10-68498888

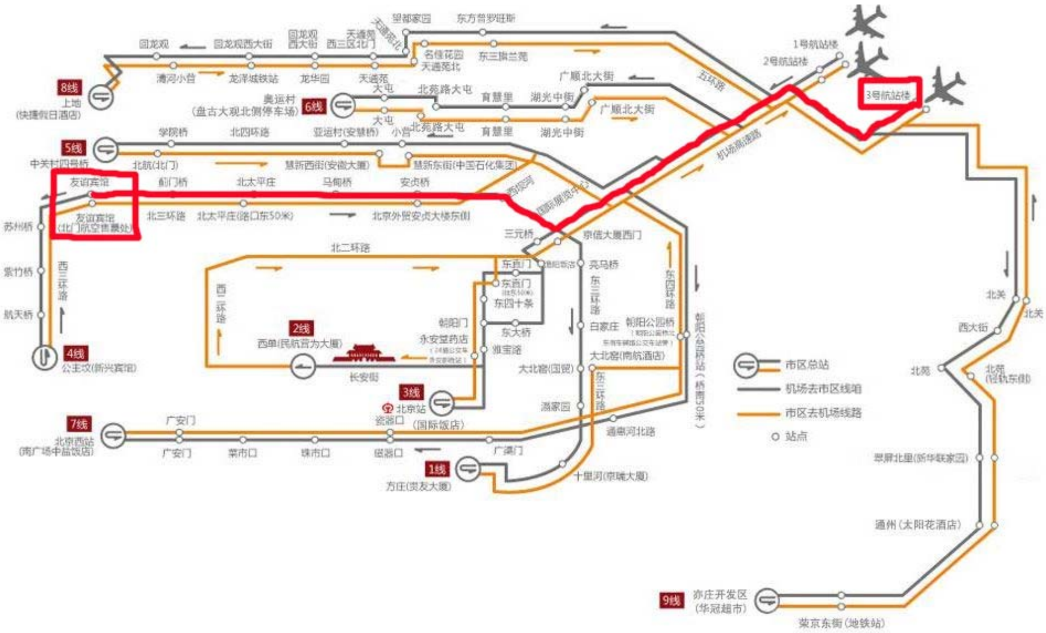
Information

Public Transport and Friendship Hotel for ISONP2012

1. Airport Shuttle

Beijing Capital International Airport (BCIA,首都机场) —Shuttle Bus Line 4 / Gongzhufen 公主坟线→ Beijing Friendship Hotel 北京友谊宾馆

Downtown Shuttle: **RMB 16/person (single trip)**
Tickets Office (From BCIA):
T3: exit of Zone A, opposite of the exit of Zone C on F2; next to Gate5, 7&11 on F1
Available Time: 6:50 – 1:00, fifteen minutes/bus.
Tickets Office (From Beijing Friendship Hotel):
Airplane ticket seller near the north gate of Beijing Friendship Hotel
Available Time: 4:50 – 22: 00, fifteen minutes/bus.



2. Subway

Route 1

Beijing Capital International Airport (BCIA,首都机场) —Airport Express T3→东直门, RMB25→ Sanyuanqiao 三元桥 —Line10 劲松→巴沟, RMB2→ Haidianhuangzhuang 海淀黄庄 —Line4 安河桥北→公益西桥→ Renmin University 人民大学

Route 2

Beijing Capital International Airport (BCIA,首都机场) → Airport Express T3 → 东直门, RMB 25 → Dong Zhimen 东直门 → Line2 东直门 → 西直门, RMB2 → Xizhimen 西直门 → Line4 公益西桥 → 安河桥北 → Renmin University 人民大学

For More information, please see http://en.bcia.com.cn/traffic/

3. Beijing Friendship Hotel (北京友谊宾馆)

Program

Feb. 12th	
14:00-20:00	Registration (Beijing Friendship Hotel, Building No.2)
18:00-20:00	**Dinner**

Feb. 13th		
8:00-9:00	Registration (Beijing Friendship Hotel, Building No.8)	
Opening ceremony Chairman: Xuan-Ming Duan		
9:00-9:15	Zhen-Sheng Zhao (*Technical Institute of Physics and Chemistry, CAS*) Satoshi Kawata (*Osaka University*)	
Section 1 Scientific Talk Chairman: Xuan-Ming Duan		
9:15-9:45	Plasmonic Polaritons in Symmetry Broken Nanostructures Xing Zhu (*Peking University*)	I01
9:45-10:15	Nanophotonics and Plasmonics Satoshi Kawata (*Osaka University*)	I02
10:15-10:45	Plasmon-based Interferometric Logic and Plasmon-assisted Chemical Reactions Hong-Xing Xu (*Institute of Physics, CAS*)	I03
10:45-11:05	**Coffee break**	
Section 2 Scientific Talk Chairman: Satoshi Kawata		
11:05-11:35	From Nano Bumps to Vertical u-shape Three-Dimensional Gold Nano-rings and Toroidal Metamaterials in Optical Region Din-Ping Tsai (*National Taiwan University*)	I04
11:35-12:05	Design, Synthesis and Biological Application of in Vivo Imaging Probes with Tunable Chemical Switches Kazuya Kikuchi (*Osaka University*)	I05
12:05-13:30	**Lunch (聚祥園)**	
Section 3 Scientific Talk Chairman: Din-Ping Tsai		
13:30-14:00	Fluorescing Platinum Nanocluster and Its Application to Bio-imaging Yasushi Inouye (*Osaka University*)	I06
14:00-14:30	Transformation Plasmonics: Plasmonic Bloch Oscillations in a	I07

	Concentrically Cylindrical Metal-Dielectric Waveguide Arrays and Plasmonic Roche Limit in Metal-dielectric-metal Structure Yung-Chiang Lan (*National Cheng Kung University*)	
14:30-15:00	Measurement of Nanometer Spin Separation of Light Yan Li (*Peking University*)	I08
15:00-15:20	Advanced imaging tools for bio-photonics: introduction to Nikon super resolution and multi-photon microscope systems Chun-Yuan Zhou: *Nikon Instruments(SHANGHAI)CO.,LTD*	I09
15:20-15:30	**Group photo**	
Section 4 Poster section (with drinking)		
15:30-17:00	**Poster section**	
18:00-20:00	**Banquet (Nikon Evening, 聚祥園)**	

Feb. 14th		
Section 5 Scientific Talk Chairman: Masanori Ozaki		
9:00-9:30	Micronanostructured High-Performance Organic Optoelectronic Devices Hong-Bo Sun (*Jilin University*)	I10
9:30-10:00	Surface Plasmon Resonance on the Photocatalytic Water Splitting to Produce Hydrogen Chi-Sheng Wu (*National Taiwan University*)	I11
10:00-10:30	Printable Small-molecule Solar Cell with Nano-scale Self-organized Bulk-heterojuncion Masanori Ozaki (*Osaka University*)	I12
10:30-10:50	**Coffee break**	
Section 6 Scientific Talk Chairman: Hong-Bo Sun		
10:50-11:20	Nano-imaging with Optical Antennas Prabhat Verma (*Osaka University*)	I13
11:20-11:50	A Novel Surface Structure Micro/nanofabrication Qian Liu (*National Center for Nanoscience and Technology*)	I14
11:50-12:00	**Closing ceremony** Chairman: Zhang-Gui Hu	
12:00-13:30	**Lunch (聚祥園)**	
13:30-17:00	**Lab tour**	

Poster Titles

P-01 **Multiphoton Direct-writing of Positive Photoresist for Two-dimensional Air-hole Array**/ Hong-Zhong CAO, Xian-Zi DONG, Feng JIN, Zhen-Sheng ZHAO, and Xuan-Ming DUAN/ *Laboratory of Organic NanoPhotonics and Key Laboratory of Functional Crystals and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, P. R. China*

P-02 **Three Dimensional Split-ring Resonators Fabricated by Stress-driven Assembly Method**/ Che-Chin CHEN, Chih-Ting HSIAO, Shu-Lin SUN, Kuang-Yu YANG,Pin-Chieh WU, Guang-Yu GUO, Wei-Ting CHEN, Yu-Hsiang TANG, Ming-Hua SHIAO, Eric PLUM, Nikolay I. ZHELUDEV, and Din-Ping TSAI/ *Instrument Technology Research Center, National Applied Research Laboratory, Hsinchu, Taiwan*

P-03 **Non-degenerate Two-photon Polymerization and 13-nm Feature Size on SOI Substrate**/ Shu CHEN, Xian-Zi DONG, Zhen-Sheng ZHAO, and Xuan-Ming DUAN/ *Laboratory of Organic NanoPhotonics and Key Laboratory of Functional Crystals and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, P. R. China*

P-04 **Surface Wave Holography for Manipulation of Electromagnetic Wave Scattering and Transport**/ Yu-Hui CHEN, Jin-Xin FU, and Zhi-Yuan LI/ *Laboratory of Optical physics, Institute of Physics, Chinese Academy of Science, Beijing, P. R. China*

P-05 **Mesogenic Phthalocyanine Derivative Based Organic Solar Cell**/ QuangDuy DAO, Tetsuro HORI, Tetsuya MASUDA, Kaoru FUKUMURA, Takeshi HAYASHI, Toshiya KAMIKADO, Fabien NEKELSON, Hiroyuki YOSHIDA, Akihiko FUJII, Yo SHIMIZU, and Masanori OZAKI/ *Division of Electrical, Electronic and Information Engineering, Osaka University, Japan*

P-06 **Local Temperature Measurement of Laser-irradiated Single Gold Nanoparticles**/ Mitsuhiro HONDA, Yuika SAITO, Nicholas I SMITH, Katsumasa FUJITA, and Satoshi KAWATA/ *Department of applied physics, Osaka university, Osaka, Japan*

P-07 **Fabrication of Three Dimensional Silver Micro/Nanostructures by Multiphoton Photoreduction**/ Yan-Peng JIA, Xian-Zi DONG, Zhen-Sheng ZHAO, and Xuan-Ming DUAN/ *Laboratory of Organic NanoPhotonics and Key Laboratory of Functional Crystals and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, P. R. China*

P-08 **Flexible Quantum Dot/Polymer Composite Film Based on Thiol-ene Click Reaction**/ Feng JIN, Xian-Zi DONG, Mei-Ling ZHENG, Zhen-Sheng ZHAO, and Xuan-Ming DUAN/ *Laboratory of Organic NanoPhotonics and Key Laboratory of Functional Crystals and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, P. R. China*

P-09 **New Type Positive Molecular Glass Resists for Two-photon Lithography**/ Hao LI, Feng JIN, Wei-Qiang CHEN, Zhen-Sheng ZHAO, and Xuan-Ming DUAN/ *Laboratory of Organic Nanophotonics, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, P. R. China*

P-10 **Surface Plasmon Focusing by Semicircular Slits Filled with Different Dielectric Mediums**/ Jie LI, Zhong-Bo YAN, and Xing ZHU/ *School of Physics, State Key Laboratory for Mesoscopic Physics, Peking University, Beijing, P. R. China*

P-11 **Plasmon Propagation Characteristics of Ag Nanowires with Grating Structure**/ Jing LI, Hong WEI, Shun-Ping ZHANG, Xiao-Rui TIAN, Hong-Xing XU, Zhen-Sheng ZHAO, Xuan-Ming DUAN/ *Laboratory of Organic NanoPhotonics and Key Laboratory of Functional Crystals and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, P. R. China*

P-12 **3D Site-specific Functionalization of Matrices Via Multi-photon Grafting and Subsequent Click Reaction**/ Zhiquan LIA, Aleksandr OVSIANIKOV, Jan TORGERSEN, Jürgen STAMPFL, and Robert LISKA/ *Vienna University of Technology, Institute of Applied Synthetic Chemistry, Austria*

P-13 **Adjustment of Light Enhancement for Silver Bowtie Nanoantennas Arrays**/ Feng LIN, Chao-Jie YANG, Shan HUANG, Meng YANG, Jie LI, Pei-Pei WANG, Jia-Ming LI, Xing ZHU/ *School of Physics, State Key Laboratory for Mesoscopic Physics, Peking University, Beijing, P. R. China*

P-14 **Effects of KrF (248nm) Excimer Laser Irradiation on Structural and Optical Properties of ZnO Single Crystal**/ Jie LIU/ *Laboratory of Organic NanoPhotonics and Key Laboratory of Functional Crystals and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, P. R. China*

P-15 **High-Performance Whispering Gallery Microcavities Fabricated by Direct Laser Writing**/ Zhao-Pei LIU/ *Institute of Modern Optics, School of Physics, Peking University, P. R. China*

P-16 **Preparation of Gold Nanostructures by Multiphoton Laser Direct Writing**/

Wei-Er LU, Mei-Ling ZHENG, Xian-Zi DONG, Zhen-Sheng ZHAO, and Xuan-Ming DUAN/ *Laboratory of Organic NanoPhotonics and Key Laboratory of Functional Crystals and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, P. R. China*

P-17 **Nano-observation of Biomolecular Dynamics Using Au Nanoparticle Dimers**/ Hiroyuki MORIMURA, Shin-ichi TANAKA, Hidekazu ISHITOBI, Tomoyuki MIKAMI, Kamachi YUSUKE, Hisato KONDOH, Yasushi INOUYE/ *Department of Applied Physics, Osaka University, Osaka, Japan*

P-18 **Planar Lens Based on Tapered Metallic Nano-slits**/ Jun-Jie MIAO, Yong-Sheng WANG, Qian LIU, and Zhi-Ping ZHOU/ *National Center for Nanoscience and Technology, Beijing, P. R. China*

P-19 **Observation of the In-plane Spin Separation of Light**/ Yi QIN/ Peking University/ *Peking University, Beijing, P. R. China*

P-20 **In-vitro Cardiotoxicity Diagnosis Based on Quantitative Imaging Analysis**/ Eiichi SHIMIZU, Tomohiko IKEUCHI, Masato SAITO, Yoshinori YAMAGUCHI, and Eiichi TAMIYA/ *Department of Applied Physics, Graduate School of Engineering, Osaka University, Osaka, Japan*

P-21 **Photoreduction for the Fabrication of A Finite-size Near-field Tip for Tip-enhanced Raman Spectroscopy**/ Takayuki UMAKOSHI, Taka-aki YANO, Taro ICHIMURA, Yuika SAITO, and Prabhat VERMA/ *Department of Applied Physics, Osaka University, Osaka, Japan*

P-22 **Femtosecond Laser Lithography Technique for Submicron T-gate AlGaN/GaN HEMTs**/ Yan-Dong DU, Wei YAN, Wei-Hua HAN, Yan-Bo ZHANG, Fu-Hua YANG, Hong-Zhong CAO, and Xuan-Ming DUAN/ *Engineering Research Center for Semiconductor Integrated Technology, Institute of Semiconductors, Chinese Academy of Sciences, Beijing, P. R. China*

P-23 **Electro-optical Applications of Nanoparticle Doped Blue Phase**/ Shuhei YABU, Yuma TANAKA, Kenta INOUE, Hiroyuki YOSHIDA, Akihiko FUJII, and Masanori OZAKI/ *Division of Electrical, Electronic and Information Engineering, Osaka University, Osaka, Japan*

P-24 **Annealing Temperature on the Performance of Quantum Dot Sensitized Solar Cell**/ Mei-Lin ZHANG, Feng JIN, Mei-Ling ZHENG, Zhen-Sheng ZHAO, and Xuan-Ming DUAN/ *Laboratory of Organic NanoPhotonics and Key Laboratory of Functional Crystals and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, P. R. China*

P-25 **Incident Angle Dependence of Reflection Spectrum of Gold Nanoparticle Plasmonic Sensors**/ Hidetaka YAMAMOTO, Hiroyuki YOSHIKAWA, and Eiichi TAMIYA/ *Department of Applied Physics, Graduate School of Engineering, Osaka University, Osaka, Japan*

P-26 **Enhanced Light Absorption in Silicon Solar Cell Using Plasmonic Nanoparticles**/ Meng YANG, Jie LI, Feng LIN, and Xing ZHU/ *School of Physics, State Key Laboratory for Mesoscopic Physics, Peking University, Beijing, P. R. China*

P-27 **On-chip Optical Diode Based on Silicon Photonic Crystal Heterojunctions**/ Chen WANG and Zhi-Yuan LI/ *Laboratory of Optical Physics, Institute of Physics, Chinese Academy of Sciences, Beijing, P. R. China*

P-28 **Multi-resonance Wavelength Using Asymmetric Plasmonic T-shaped Array**/ Chih-Ming WANG/ *Department of Opto-electronic Engineering, National Dong Hwa University, Taiwan*

P-29 **Synthesis and Photoisomerization Properties of Azobenzene-functionalized Polymer Materials**/ Hui WANG, Wei-Qiang CHEN, Feng JIN, Xian-Zi DONG, Zhen-Sheng ZHAO, and Xuan-Ming DUAN/ *Laboratory of Organic NanoPhotonics and Key Laboratory of Functional Crystals and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, P. R. China*

P-30 **Enzyme Triggered Gold Nanoparticle-enhanced Fluorescence of Near Infrared (NIR) Dye**/ Zhang-Hua ZENG/ *Division of Advanced Science and Biotechnology, Graduate School of Engineering, Osaka University, Osaka, Japan*

P-31 **Chiral Surface Plasmon Polaritons on Metallic Nanowires**/ Shun-Ping ZHANG, Hong WEI, Kui BAO, Ulf HAKANSON, Naomi J. HALAS, Peter NORDLANDER, and Hong-Xing XU/ *Beijing National Laboratory for Condensed Matter Physics and Institute of Physics, Chinese Academy of Sciences, Beijing, P. R. China*

P-32 **Tunable Terahertz Optical Antennas Based on Graphene Ring Structures**/ Peng-Hong LIU, Wei CAI, Lei WANG, Xin-Zheng ZHANG, and Jing-Jun XU/ *The Key Laboratory of Weak-Light Nonlinear Photonics, Ministry of Education, School of Physics and TEDA, Applied Physics School, Nankai University, Tianjin, P. R. China*

P-33 **On the Geometry and Dynamics of Transformation Optics**/ Yong-Liang ZHANG, Zhen-Sheng ZHAO, and Xuan-Ming DUAN/ *Laboratory of Organic*

NanoPhotonics and Key Laboratory of Functional Crystals and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Science, Beijing, P. R. China

P-34 **Plasmon-assisted Reaction on Au Film**/ Zheng-Long ZHANG, Meng-Tao SUN, and Hong-Xing XU/ *Beijing National Laboratory for Condensed Matter Physics and Institute of Physics, CAS, Beijing, P. R. China*

P-35 **Molecular Engineering of Carbazole-based Cyanine Probes for Combined Second-harmonic and Two-photon Fluorescence in Cellular Imaging**/ Mei-Ling ZHENG, Katsumasa FUJITA, Wei-Qiang CHEN, Xuan-Ming DUAN, and Satoshi KAWATA/ *Laboratory of Organic NanoPhotonics and Key Laboratory of Functional Crystals and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, P. R. China*

P-36 **Synthesis and Bioimaging of Carbazole Based Cyanine Probes for Living Cells and C. Elegans**/ Yong-Chao ZHENG, Mei-Ling ZHENG, Zhen-Sheng ZHAO, and Xuan-Ming DUAN/ *Laboratory of Organic NanoPhotonics and Key Laboratory of Functional Crystals and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, P. R. China*

P-37 **Plasmon Enhanced Light Amplification in Metal-insulator-metal Waveguides with Gain**/ Xiao-Lan ZHONG and Zhi-Yuan LI/ *Laboratory of Optical Physics, Institute of Physics, Chinese Academy of Sciences, Beijing, P. R. China*

P-38 **Two-photon Photodynamic Activity of Water-soluble Benzylidene Cyclopentanone Dyes**/ Yu-Xia ZHAO, Qian-Li ZOU, Fei-Peng WU, and Ying GU/ *Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, P. R. China*

P-39 **Anisotropic Plasmonic Sensing Ability of Individual or Coupled Gold Nanorods/** Lei HOU/ *Department of Physics，Peking University, Beijing, P. R. China*

P-40 **Plasmonic-Enhanced Molecular Fluorescence within Isolated Bowtie Nano-Apertures/** Wenqiang Li/ *State Key Laboratory for Mesoscopic Physics and Department of Physics, Peking University, Beijing 100871, China*

P-41 **Fluorescence correlation spectroscopy near individual gold nanoparticle/** Qingyan Wang, Guowei Lu, Jie Liu / *State Key Laboratory for Mesoscopic Physics and Department of Physics, Peking University, Beijing 100871, China*

P-42 **Single Molecule Spontaneous Emission in the Vicinity of Individual Gold**

Nanorod/ Tianyue Zhang/ *State Key Laboratory for Mesoscopic Physics and Department of Physics, Peking University, Beijing 100871, China*

Presenter's Profiles and Abstracts

Xing ZHU

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Education

B.S. 1976, Lanzhou University
M.S. 1983, University of Toronto
Ph.D. 1986, University of Saarland
Postdoctoral Fellow, 1986-1987, University of Saarland
Postdoctoral Fellow, 1987-1989, Peking University
Associate Professor, 1989-1994, Peking University
Professor, 1994-now, Peking Uniersity

Scientific Interests:

Prof. Zhu's research areas involves the early pioneer work on nanocrystalline materials; the structure analysis of nano-materials. In the recent years, his research is focused on the optical properties and spectrum on the nanometer scale, especially in the field of near-field optics. In his group, some new instruments are developed, such as scanning near-field optical microscope (SNOM), cryogenic SNOM and the near-field optical spectroscopy technique. Most recently he is working with the interaction of nanometer scale structures, with surface plasmon polariton(SPPs) phenomenon, the generation, propagation, focusing and trapping of SPP in nanostructures. and the formation and propagation of surface wave, the light scattering of surface; and the properties of fluorescents and light emission and polarization.

Recent papers:

[1] Z. Y. Fang, L. R. Fan, C. F. Lin, D. Zhang, A. J. Meixner, and X. Zhu, ***Nano Letters*** **11**, 1676 (2011).
[2] Z. Y. Fang, Q. Peng, W. T. Song, F. H. Hao, J. Wang, P. Nordlander, and X. Zhu, ***Nano Letters*** **11**, 893 (2011).
[3] Z. Y. Fang, J.Y. Cai, Z. B. Yan, P. Nordlander, N. J. Halas, and Xing Zhu, ***Nano Letters*** **11**, 4475 (2011).

Plasmonic Polaritons in Symmetry Broken Nanostructures

***Zheyu FANG*[1], *Feng LIN* [1], *and* <u>*Xing Zhu*</u>[1,2]**

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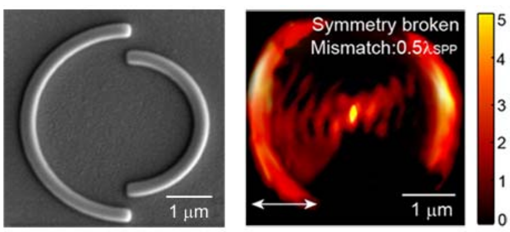
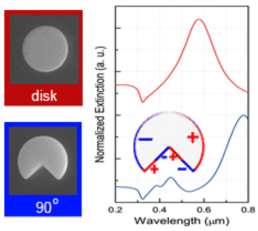
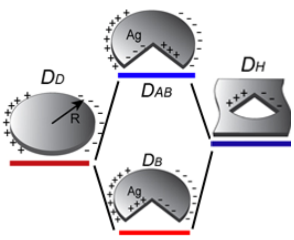
Surface plasmon polariton (SPP) as the collective vibration of electro-magnetic field at the interface between metallic and dielectric media, has unique properties in the propagation, focusing and waveguiding, it has found applications in nano-optics and nano-phononic devices. In this contribution, we will show our latest results of Plasmonics properties in symmetry broken nanostructures, such as the subwavelength focusing of SPP in unsymmetrical metallic rings, and the Fano resonance in Ag nanodisks. Combing Scanning Near-field Optical Microscopy (SNOM) and spectroscopy technique, we characterized such unique properties and numerical simulations. The other properties of SPP will be also discussed, such as the conversion and detection of plasmon polariton (SPP), plasmonic propagation, field enhancement, coupling between devices, as well as the design of new plasmonic nanostructures and their characterization.

In this lecture, we will demonstrate the characterization of SPP nanostructures by using SNOM and other techniques, such as (1) new Ag nanowire-nanoantenna optical circuits with a single Ag nanowire placed at both feed-gaps of receiving and transmitting bowtie-antennas pairs has been designed. This design offers significant plasmon coupling and emission enhancement over previous designs. Finite-difference time-domain simulations consist with the experiments which suggest an effective approach to control the SPP coupling with the nanoribbon dielectric waveguide. (2) Plasmonic focusing is an important topic in near-field imaging, superlensing, nanolithography and magnetic recording. We propose a radically new design consisting of a phase-matched symmetry-broken plasmonic corral that provides highly efficient subwavelength single focal spot focusing using simple linearly polarized incident light. This design offers significant practical advantages over previous designs; and multiple plasmonic lenses can be fabricated on a substrate, enabling simultaneous focusing in several spots. (3) our new experimental and theoretical results on Fano resonance in a single symmetry broken Ag nanodisk at a normal incidence will also be discussed, which originates from the overlap between the broad hybridized dipole and a narrow quadrupole.

Keywords: surface plasmon polariton, near-field optical microscopy, symmetry broken.
Work supported by 973 Program of China, 2007CB936800, and NSFC 61176120.







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Education:

B.S.c in Applied Physics 1974, Osaka University
M.S.c in Applied Physics 1976, Osaka University
Ph.D. in Applied Physics 1979, Osaka University
Postdoctoral Fellow, 1979, Japan Society for the Promotion of Science
Research Associate, 1979-1981, University of California, Irvine
Assistant Professor, 1981, Osaka University
Associate Professor, 1992, Osaka University
Professor, 1993-, Osaka University
Chief Scientist, 2002-, RIKEN

Scientific Interests:

Nanophotonics, Plasmonics, Nano-fabrication and Spetroscopy.

Recent papers:

[1] Miyu Ozaki, Jun-ichi Kato, and Satoshi Kawata, “Surface-Plasmon Holography with White-Light Illumination”, ***Science***, Vol.**332**, pp. 218-220 (2011).

[2] Prabhat Verma, Taro Ichimura, Taka-aki Yano, Yuika Saito, and Satoshi Kawata, “Nano-imaging through tip-enhanced Raman spectroscopy: Stepping beyond the classical limits,” ***Laser & Photon. Rev***., Vol. **4**, pp. 548-561 (2010).

[3] Yao-Yu Cao, Nobuyuki Takeyasu, Takuo Tanaka, Xuan-Ming Duan, and Satoshi Kawata,"3D Metallic Nano-Structure Fabrication By Surfactant-Assisted Multi-Photon-Induced Reduction," ***Small***, Vol. **5**, pp. 1144-1148 (2009).

Nanophotonics and Plasmonics

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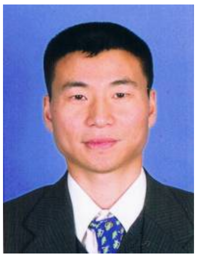
Photonics at nano-scale has given new dimensions to several aspects of nanoscience, such as nano-imaging, nano-analysis, nano-manipulation, and nano-function of several kinds of materials ranging from semiconductors to biomolecules. The interaction volume between light and sample is classically restricted by diffraction limit of light, which is about half of the wavelength of probing light. We have crossed this classical barrier in several nanophotonics technologies, such as in fabrication, in analysis and in imaging of samples at nanoscale, and have shown how light can be manipulated to interact with materials in a volume much smaller than the diffraction limits. In particular, we use surface plasmons localized on the surface of nanostructured metal. I will review the science of nanophotonics and the mechanism and functions of plasmonics for going beyond the limit in conventional photonics.

Hong-Xing XU



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Education

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1992 B.A. (Physics) Peking University, China

POSITIONS: 2009 - Present Director of Nanoscale Physics & Devices, Institute of Physics, Chinese Academy of Sciences, China
2005 - Present Professor, Institute of Physics, Chinese Academy of Sciences, China
2005 - Present Visiting Professor, Department of Physics, Lund University, Sweden
2002 - 2004 Assistant Professor, Department of Physics, Lund University, Sweden

Scientific Interests:

Surface-enhanced spectroscopy, nanophotonics, nanooptics, plasmonics and those devices

Recent papers:

[1] Zhang SP, Wei H, Bao K, Hakanson U, Halas NJ, Nordlander P, and Xu HX, "Chiral Surface Plasmon Polaritons on Metallic Nanowires", ***Phys. Rev. Lett.*** **107**, 096801 (2011).
[2] Wei H, Wang ZX, Tian XR, Kall M, and Xu HX, "Cascaded logic gates in nanophotonic plasmon networks", ***Nature Communications*** **2**, 387, DOI: 10.1038/ncomms1388 (2011).
[3] Wei H, Li ZP, Tian XR, Wang ZX, Cong FZ, Liu N, Zhang SP, Nordlander P, Halas NJ, Xu HX, "Quantum Dot-Based Local Field Imaging Reveals Plasmon-Based Interferometric Logic in Silver Nanowire Networks", ***Nano Lett.*** **11**, 471-475 (2011).

Plasmon-based Interferometric Logic and Plasmon-assisted Chemical Reactions

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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 electronic devices, 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.

It is interesting to note that all the plasmonic devices demonstrated here are based on the same principle: interference of plasmons in a primary wire with those introduced by a secondary, adjacent nanowire, or in a reverse way routing plasmons from the primary wire to the adjacent wire. This primary wire can thus be viewed as the plasmonic equivalent of a bus in a central processing unit. By loading the primary wire with plasmons launched with specific input properties at the secondary input NWs, the resulting plasmonic interference enables routing and out-coupling to specific output NWs. We believe this concept can be further generalized and expanded to more complex structures that can combine optical signals in various ways, and that a multiple-input, multiple-output plasmonic bus may serve as an efficient splitter, router, switcher and/or multiplexer in future complex plasmonic networks designed for computation and information processing functions. It worthwhile to note that the phase sensitivity of the plasmon structures presented here presents significant challenges for cascaded devices, as one would find in information processing applications. Precise design and fabrication criteria with specific plasmon propagating lengths for phase control would be a necessary requirement for practical plasmon-based interferometric logic. Such cascaded devices will be also discussed.

We also investigate plasmon-assisted chemical reactions, where the electrons needed in the chemical reaction contributed from "hot" electrons decayed by plasmons. Furthermore, the Raman-active and IR-active (Raman-inactive) modes and the corresponding Fermi resonance phenomena in HV-TERS can be experimentally observed simultaneously.

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Scientific Interests:

My current research interests are nanophotonics, near-field optics, plasmonics, metamaterials and bio-photonics. Applications of my R&D are focused on plasmonic nanophotonics, photocatalytic chemical reactor, nanolithography, near-field optical storage and image, plasmonic enhancement of light harvesting and emission, plasmonic waveguides and integrated circuits, nano antennas and sensors.

Recent papers:

[1] T. Kaelberer, V. A. Fedotov, N. Papasmakis, D. P. Tsai, and N. I. Zheludev, "Toroidal Dipolar Response in a Metamaterial", ***Science*** **330**, 1510 (2010).

[2] Y. H. Fu, A. Q. Liu, W. M. Zhu, X. M. Zhang, D. P. Tsai, J. B. Zhang, T. Mei, J. F. Tao, H. C. Guo, X. H. Zhang, J. H. Teng, N. I. Zheludev, G. Q. Lo, and D. L. Kwong, "A micromachined reconfigurable metamaterial via reconfiguration of asymmetric split-ring resonators", ***Advanced Functional Materials*** **21**(18), 3589-3594 (2011).

[3] W. M. Zhu, A. Q. Liu, X. M. Zhang, D. P. Tsai, T. Bourouina, J. H. Teng, X. H. Zhang, H. C. Guo, H. Tanoto, T. Mei, G. Q. Lo, and D. L. Kwong, "Switchable Magnetic Metamaterials Using Micromachining Processes", ***Advanced Materials*** **23**, 1792 (2011).

From Nano Bumps to Vertical U-Shape Three-Dimensional Gold Nano-rings and Toroidal Metamaterials in Optical Region

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Fabrication of nano bumps and vertical U-shape nano gold rings (110 nm x 60 nm x 40 nm) on a fused silica substrate has been successfully implemented by laser and e-beam lithography double exposure process. Plasmonic resonance modes of such particles are investigated by finite-element simulations and optical measurements, which are in excellent agreement with each other. Results show the manipulation of the light, and electromagnetic field solely depends on the resonance mode either enhanced between two prongs of vertical U-shape nano ring or enhanced around two prongs of vertical U-shape gold ring. The electromagnetic interaction between three dimensional meta-molecules also results in extraordinary electromagnetic properties, such as plasmon induced transparency (PIT) and toroidal dipole response. By the magnetic dipole interaction of each meta-molecule in near-field region, we find the toroidal dipole response can be excited at optical region. The toroidal metamaterials provide a compelling evidence of a resonant response attributed to a toroidal dipole excitation. These research results have potential to be applied in the area such as integrated photonic circuit, plasmonic biosensor and toroidal lasing spaser in optical frequency region.

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Scientific Interests:

Biophotonics, Molecular Imaging, Fluorescent Probes, MRI Probes

Recent papers :

[1] S. Mizukami, S. Watanabe, Y. Akimoto, & *K. Kikuchi, "No-Wash Protein Labeling with Designed Fluorogenic Probes and Application to Real-Time Pulse-Chase Analysis", ***J. Am. Chem. Soc.***, **134,** in press (2012).

[2] T. Kowada, J. Kikuta, A. Kubo, M. Ishii, H. Maeda, S. Mizukami & *K. Kikuchi, "*In Vivo* Fluorescence Imaging of Bone-Resorbing Osteoclasts", ***J. Am. Chem. Soc.***, **133,** 17772-17776 (2011).

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Design, Synthesis and Biological Application of in Vivo Imaging Probes with Tunable Chemical Switches

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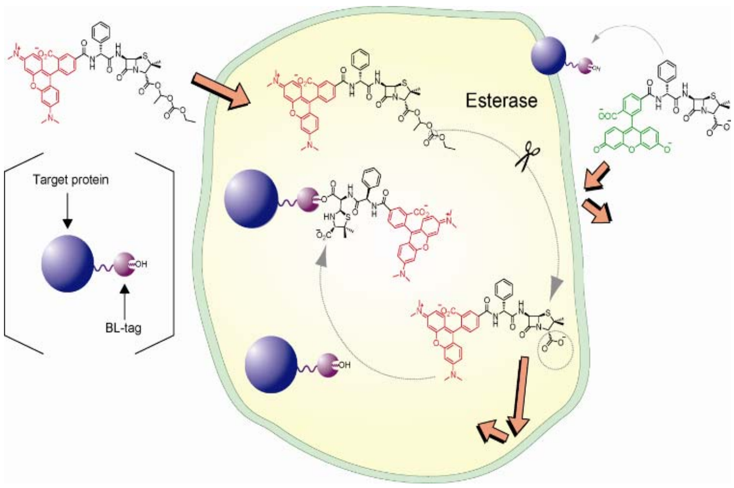
One of the great challenges in the post-genome era is to clarify the biological significance of intracellular molecules directly in living cells. If we can visualize a molecule in action, it is possible to acquire biological information, which is unavailable if we deal with cell homogenates. One possible approach is to design and synthesize chemical probes that can convert biological information to optical output.

Protein fluorescent labeling provides an attractive approach to study the localization and function of proteins in living cells. Recently, a specific pair of a protein tag and its ligand has been utilized to visualize a protein of interest (POI). In this method, a POI is fused with a protein tag and the tag is labeled with the ligand connected to a fluorescent molecule. The advantage of this protein labeling system is that a variety of fluorescent molecules are potentially available as labeling reagents, and that the protein tag is conditionally labeled with its fluorescent ligand. However, in the existing labeling systems, there are some problems with the size of a protein tag, the specificity of the labeling or fluorogenicity of labeling reagents. Protein tags for labeling proteins of interest (POIs) with small molecule based probes have become important technique as practical alternatives to the fluorescent proteins (FPs) for live cell imaging. We have designed a protein labeling system that allows fluorophores to be linked to POI. The protein tag (BL-tag) is a mutant class A β-lactamase (TEM-1) modified to be covalently bound to the designed specific labeling probes and the labeling probes is consisted with a β-lactam ring (ampicillin, cephalosporin) attached to various fluorophores. A fluorogenetic labeling system can be designed using the unique property of cephalosporin, which release leaving group by subsequent reaction after opening the lactam ring. For further sophisticated application, multicolor imaging was done by adopting the colorful fluorophores.



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Scientific Interests:

Nanophotonics, Plasmonics, Biophotonics, Vibrational Spectroscopy

Recent papers:

[1] S. Tanaka, J. Miyazaki, D.K. Tiwari, T. Jin, and Y. Inouye, "Fluorescent Platinum Nanoclusters: their synthesis, purification, characterization and application to bio-imaging", ***Angew. Chem. Int. Ed***., **50**, 431-435 (2011).

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Fluorescing Platinum Nanocluster and Its Application to Bio-imaging

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Noble metal, e.g. gold and silver, exhibts a remarkable optical property of localized surface plasmon when its size becomes smaller than 100 nm. Hence, scattering light from nano-metal shows a variety of colours which are characterized by resonant wavelength of plasmon [1]. As the size of nano-metal is reduced to 1 nm or less (so-called nanocluster), a band gap emerges in electronic structures of the nano-metal and it obtains fluorescent capability [2]. In this presentation, we will show our platinum nanocluster emitting blue photons and its application to bio-imaging. We have synthesized platinum nanoclusters by mixing hexachloroplatinic(IV) (H_2PtCl_6) acid and PAMAM (polyamidoamine) dendrimers in pure water and reducing platinum ions with sodium tetrahydroborate ($NaBH_4$). Then, the PAMAM dendrimers were exchanged with mercapto acetic acid and the products were purified with high performance liquid chromatography. Figure 1 illustrates a mass spectrum of the purified nanoclusters obtained with electro-spray ionization mass spectrometry, which shows that the nanoclusters have composed of 5 platinum atoms. We investigated capability of platinum nanocluster to act as fluorescent probes for live cell imaging by using an immunostaining technique. Figure 2 shows a confocal fluorescent image of HeLa cells stained with the platinum nanoclusters. Details of optical properties of the nanclusters will be shown in the presentation.

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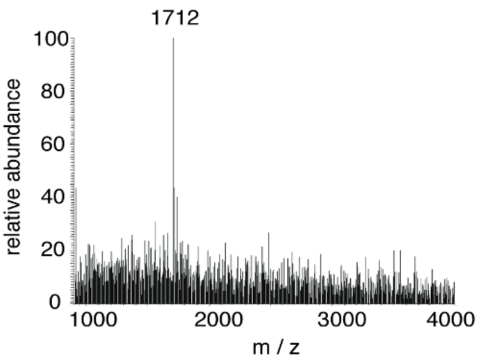

Fig. 1 Mass spectrum of purified products

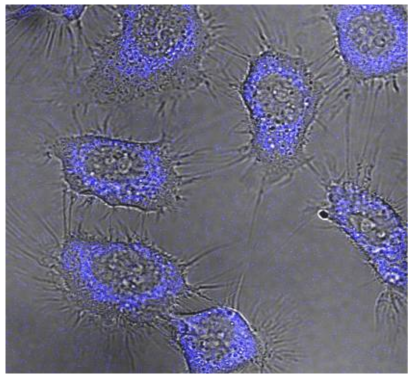

Fig. 2 Confocal fluorescent image of HeLa cells

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Scientific Interests:

Plasmonics, Transformation optics, Metamaterial, Plasma physics

Recent papers :

[1] Y. C. Lan* and C. M. Chen, "Long-range Surface Magnetoplasmon on thin Plasmon Films in the Voigt Configuration", ***Opt. Express*** **18**, 12470-12481 (2010).

[2] R. C. Shiu, Y. C. Lan* and C. M. Chen, "Plasmonic Bloch Oscillations in Cylindrical Metal-Dielectric Waveguide Arrays", ***Opt. Lett***. **35**, 4012-4014 (2010).

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Transformation Plasmonics: Plasmonic Bloch Oscillations in A Concentrically Cylindrical Metal-dielectric Waveguide Arrays and Plasmonic Roche Limit in Metal-dielectric-metal Structure

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In the first part of this work, we investigate the plasmonic Bloch oscillations (PBOs) in a concentrically cylindrical metal-dielectric waveguide arrays (MDWAs) with a Gaussian beam incidence using the 2D finite-difference time-domain (FDTD) simulations and theoretical analyses. Optical Bloch oscillations are the phenomena of periodic oscillations of optical beams propagating in waveguide arrays, caused by alternately total internal reflection and Bragg reflection between two boundaries of the waveguide arrays. Optical conformal mapping is used to transform cylindrical MDWAs into equivalent chirped structures with permittivity and permeability gradients across the waveguide arrays, which is caused by the curvature of the cylindrical waveguide. The PBOs are attributed to the transformed structure. The period of oscillation increases with the wavelength of the incident Gaussian beam. However, the amplitude of oscillation is almost independent of wavelength. In the second part, the plasmonic Roche limit (RL) is proposed and explored. RL, an astronomy phenomenon observed in a two-star system, defines the trajectories within which a celestial body will be disintegrated by the gravitational fields of the two stars. RL can be mimicked by the coupled surface plasmon that propagates in a designed MDM structure. When the MDM structure contains two neighboring circle regions in which the refraction index of dielectric layer has the same function form as the gravity potential (i.e. $n(r) \propto 1/r$), a Gaussian beam that moves in the plasmonic RL will also be disintegrated by the optical force. Plasmonic RL is investigated by using both FDTD simulations and theoretical analyses. The simulation results exhibit that two parameters strongly modulate the motion of the incident beam: the relative magnitude of the refraction index gradients between the first and second circles and the beam's incident position that is within or outside the plasmonic RL. The beam's trajectories forecasted by ray optics method and Newton's law of motion closely correspond to the simulation results.

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Scientific Interests:

Femtosecond laser 3D nanofabrication, Ultrafast dynamics of spins, Spin Hall effect of light

Recent papers :

[1] Yi Qin, <u>Yan Li</u>, Xiaobo Feng, Yun-Feng Xiao, Hong Yang, and Qihuang Gong, "Observation of the in-plane spin separation of light", ***OPTICS EXPRESS***, **19**: 9636-9645 (2011)

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[3] Zhao-Pei Liu, <u>Yan Li</u>, Yun-Feng Xiao, Bei-Bei Li, Xue-Feng Jiang,Yi Qin, Xiaobo Feng, Hong Yang, and Qihuang Gong, "Direct laser writing of whispering gallery microcavities by two-photon polymerization", ***APPLIED PHYSICS LETTERS***, **97**: 211105 (2010)

Measurement of Nanometer Spin Separation of Light

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Amazing shifts of a physical light beam at a planar dielectric interface have been investigated for a long time. Among them, the in-plane Goos-Hänchen (GH) shift in the plane of incidence and the transverse Imbert-Fedorov (IF) shift perpendicular to the plane of incidence are well-known. While the (linear) GH shift or the (linear) IF shift exhibits a linear positional shift of the beam center, the angular GH shift or the angular IF shift manifests the angular deviation of the beam axis, which can be considered as the shift in the wave vector space. Recently, the spin Hall effect of light (SHEL) has attracted much attention because it offer a promising tool in quantum and classical optical information processing applications As a result of an effective spin-orbit interaction, the reflected or transmitted beam slightly splits into its two spin components that acquire opposite transverse displacements perpendicular to the plane of incidence. This effect is also referred to as the optical Magnus effect of spinning particles. SHEL has been studied at non-planar interfaces and applied to probe the spatial distributions of electron spin states in semiconductors at the nanometer scale.

We have measured the spin-dependent nanometer-sized displacements of the SHEL of the reflected light from a planar air-glass interface. In the case of the vertical polarization, the displacement is found to increase with the incident angle and subsequently decrease after ~ 48 degrees; while in the case of the horizontal polarization, it changes rapidly near the Brewster angle. For a fixed incident angle of 30 degrees, the displacement decreases to zero as the polarization angle approaches ~39 degrees from 0 degree (the horizontal polarization) and then increases in the opposite direction till 90 degrees (the vertical polarization).

We have also observed the spin separation of light in the plane of incidence when a linearly polarized beam is reflected or refracted at a planar dielectric interface. Remarkably, the in-plane spin separation reaches hundreds of nanometers, comparable with the transverse spin separation induced by the well-known SHEL. The observation is properly explained by considering the in-plane spread of wave-vectors. This study thus offers new insights on the spinoptics and may provide a potential method to control light in optical nanodevices.

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Scientific Interests:

Laser micronanofabrication, Ultrafast spectroscopy

Recent papers:

[1] Hong-Hua Fang, Ran Ding, Shi-Yang Lu, Jie Yang, Xu-Lin Zhang, Rui Yang, Jing Feng, Qi-Dai Chen, Jun-Feng Song, and Hong-Bo Sun, "Distributed feedback lasers based on thiophene/phenylene co-oligomer single crystals", ***Adv. Funct. Mater.*** **22**, 33 (2012).

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Micronanostructured High-Performance Organic Optoelectronic Devices

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Organic materials is known difficult to be processed by standard lithographic technologies since the they subject to severe degradation when they are immersed to organic solvents that were used to remove photoresists. This fact poses a serious problem when high performance organic optoelectronic devices are desired, which require generally complicated micronanostructures to confine distribution of light field or transportation of carriers. In order to solve this problem, we propose to process the organic thin films in either amorphous or crystalline forms with laser technologies. Both direct laser writing or interference ablation are found effective to produce the desired functional structures. Aided with these technologies, high-performance light-emitting devices such as micro-disk lasers, distributed feedback (DFB) lasers, and OLEDs (organic light-emission devices), and photovoltaic devices are enabled.

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Scientific Interests:

(1) Photoreduction of CO_2 with H_2O to fuel.
(2) Photocatalytic water splitting for H_2 production.
(3) Photocatalytic selective catalytic reduction of NOx air pollutant.
(4) Biodiesel synthesis using solid acidic catalysts.

Recent papers :

[1] Jiun-Jen Chen, Jeffrey C.S. Wu, Pin Chieh Wu, and Din Ping Tsai, "Plasmonic Photocatalyst for H_2 Evolution in Photocatalytic Water Splitting", ***Journal of Physical Chemistry-C***, **115**(1), 210-216 (2011).

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Surface Plasmon Resonance on the Photocatalytic Water Splitting to Produce Hydrogen

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The effect of surface plasmon resonance (SPR) on the photocatalytic water splitting was studied by employing the photocatalyst, Au/TiO_2. It is well known that metal particles on TiO_2 can behave as electron traps, retarding the recombination of electron-hole pairs, thereby improving reaction activity. However, the electron trap is not the only mechanism responsible for the photoreaction enhancement. The photocatalytic water splitting was performed on Au/TiO_2 prepared by photo deposition method. The production of hydrogen was significantly increased because Au particles not only acted as electron traps as well as active sites but also played an important role of the SPR enhancement as shown in Figure. The intensified electric field at the interface between Au particle and the sub-domain on the TiO_2 was illustrated by finite element method (FEM) electromagnetic simulation.

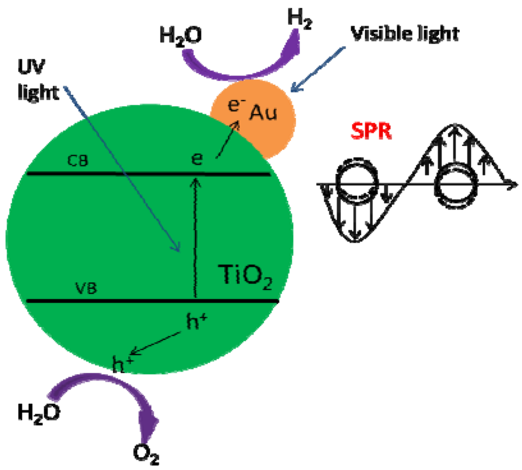

Figure: Schematic of SPR induced by visible light irradiation can boost the energy intensity of trapped electrons resulting in the photocatalytic activity enhancement

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Scientific Interests:

Organic Photonics and Electronics, Photonic crystals, Plasmonics,Nonlinear optics, Liquid crystals, Photovoltaic materials and devices, Electrooptic devices

Recent papers:

[1] T. Hori, Y. Miyake, N. Yamasaki, H. Yoshida, A. Fujii, Y. Shimizu, and M. Ozaki, "Solution Processable Organic Solar Cell Based on Bulk Heterojunction Utilizing Phthalocyanine Derivative", ***Appl. Phys. Express***, **3**, 101602 (2010).

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Printable Small-molecule Solar Cell with Nano-scale Self-organized Bulk-heterojuncion

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Low cost and high efficient solar cell has earnestly been desired for a sustainable world. The use of self-assembling characteristics is one of the most potential candidates for the realization of a prevailing solar cell. We have demonstrated a high-efficient bulk-heterojunction solar cell based on liquid crystalline phthalocyanine $C6PcH_2$ exhibiting a high carrier drift mobility in excess of 1 cm^2/Vs. The device can be fabricated through a spin-coating process from the blend solution of $C6PcH_2$ and 1-(3-methoxy-carbonyl)-propyl-1-1-phenyl-(6,6)C_{61} (PCBM). For the formation of the optimally phase-separated nano-structure for efficient carrier generation and transportation, the mesogenic properties should play an important role. Solar cells have demonstrated a high external quantum efficiency above 70% in the Q-band absorption region of $C6PcH_2$ and a high energy conversion efficiency of 3.1%. By inserting MoO_3 hole transport buffer layer between the positive electrode and active layer, the fill factor FF and energy conversion efficiency were improved to be 0.50 and 3.2%, respectively. The tandem organic thin-film solar cell has also been studied by utilizing active layer materials of $C6PcH_2$ and poly(3-hexylthiophene) (P3HT) and the interlayer of LiF/Al/MoO_3 structure, and a high V_{oc} of 1.27 V has been achieved. $C6PcH_2$ is also available as a dopant for conventional organic thin-film solar cells with an bulk hetero-junction active layer composed of P3HT and PCBM. The improvement of long-wavelength sensitivity in P3HT:PCBM bulk hetero-junction solar cells by doping $C6PcH_2$ has been succeeded.

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Photonics, Plasmonics, Nano-spectroscopy, metamaterials

Recent papers:

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Nano-imaging with Optical Antennas

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Nature has many interesting things to offer - one of them is the fact that visible light (from near-UV to near-IR) contains an energy that is comparable to the electronic or vibrational energies of most of the naturally existing materials that we interact with in our day-to-day lives. Visible light can therefore interact directly with the electronic or vibronic system of a sample, and can extract rich information related to the intrinsic properties of the sample. That is probably the reason why optical imaging has been an inseparable part of human life for centuries, which has gradually improved over the time as scientist developed various kinds of microscopes and telescopes that enabled us to see tiny objects, such as a bacteria, or distant objects, such as a planet. Even then, observing a sample at nanoscale resolution with optical microscope always remained a dream of scientists, because the wave nature of light prevents it to get focused into a volume smaller than half of its wavelength, a phenomenon known as the diffraction limit. The diffraction limit for visible light is about 200~300 nm, which is much larger than the nano-sized samples one usually wants to study. Therefore, one of the most important requirements for optical nano-imaging is to confine the light into a nano-scale region, so that it can efficiently interact with nano-samples.

Another important issue about optical imaging is related to the strength of light-matter interaction, which is usually a weak phenomenon. For example, when a sample is illuminated with a particular light source, only one in a million photons undergoes Raman scattering. This is particularly important for nanomaterials with extremely small sample volumes, where the strength of optical scattering becomes very weak. Hence, another important requirement for optical nano-imaging is to enhance the scattering, so that even weak scattering can become observable under usual experimental conditions. Both confinement and enhancement of light field can be achieved by utilizing optical antennas, which are nothing but metallic nanostructures with specific shapes and sizes. Here, we will discuss about optimization of the antenna for better confinement and enhancement of light, and will show some results of enhanced and confined spectroscopy at nanoscale. We will also show some examples of nano-imaging through optical antennas, where we can achieve very high spatial resolution, far beyond the diffraction limit.

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Recent papers:

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A Novel Surface Structure Micro/Nanofabrication

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With the rapid development of micro/nanofabrication technology, unconventional fabrication methods, especially those inspired by natural phenomena have attracted much more attentions. Wrinkles are widely existed in nature from landforms to animals and plants. Artificial wrinkles have enormous potential in the applications of optics, flexible electronics, force sensors, microfluidic system, particle alignment and advanced metrology, and many advantages such as simple process, low cost and realizability of large-area fabrication. Since Bowden *et al*. utilized wrinkling to fabricate ordered surface structures via spontaneous formation of wrinkles in a stiff/soft bilayer, scientists have been trying to seek effective ways to better align wrinkles. However, it is still unable to satisfy simultaneously the requirements of highly ordered, defect-free and devisable wrinkles; such barriers have been hindering wrinkling from becoming a true micro/nanofabrication method. Here we show an effective way to meet all requirements mentioned above, for the first time, by laser direct writing (LDW) of guide path to control wrinkling. We also show diverse morphologies and good controllability of wrinkle height and pitch, as well as practical devices made up of wrinkles. Moreover, we present a brand-new concept of *unit-wrinkle*, the basic unit of wrinkles, and found that the interaction among unit-wrinkles is governed by a superposition effect of their height profiles, thus the accurate location and configuration of the surface structures can be described by a function of surface profile, $H(x,y)$. The breakthrough opens a new way for making controllable, complexly patterned, functional/structural wrinkle structures and devices in high-quality for both scientific research and practical application.

Abstracts for Poster Presentations

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Multi-photon Direct-writing of Positive Photoresist for Two-dimensional Air-hole Array

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In the past decade, multi-photon direct-writing has been a very powerful and important means for high resolution and intrinsic 3D fabrication. The spatial resolution of multi-photon direct-writing with cross-linkable negative photoresists has reached 50 nm. Compared with negative photoresists, positive photoresists are used more extensively in semiconductor fabrication. However, there are only very few reports on multi-photon fabrication of positive photoresists.

In this study, we present multi-photon direct-writing of positive photoresist for two-dimensional air-hole array on glass substrate. During the experiment, the substrate spin-coated with 180 nm AZ4620 photoresist was placed at 3D piezostage and written by multi-photon absorption of focused 780 nm femtosecond laser. With the input power of 1.94 mw, two-dimensional array composed of 350 nm hole was direct-written. The distance between holes was 600 nm and the exposure time for each hole was 10 ms. Different diameter hole can also be easily written by changing the input laser power or exposure time, and the smallest hole with diameter of less than 100 nm was obtained. We analyzed the influence factors of the spatial resolution. The spatial resolution is greatly influenced by standing wave interference of the incident light and reflected light. Therefore, the spatial resolution can be improved by reducing the reflection.

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Three Dimensional Split-ring Resonators Fabricated by Stress-driven Assembly Method

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Recently, metamaterials have attracted intense interests for a wide range of advanced applications. The metamaterials are the artificial structures which exhibiting unconventional engineered responses, such as artificial magnetism, negative index of refraction, field enhancement, and toroidal response. These tailored metamaterials reveal their specific optical properties which are primarily dependent on the dimensions and configurations. The split ring resonators (SRRs) are the most common meta-molecule adopted in constructing the sub-wavelength structures. In previous works, most of the SRR structures were focused on the planar types, i.e. the SRRs plane is lay on the substrate, due to the limited fabrication methods and the LC resonance mainly obtained through capacitance response. The induction response in planar SRRs can be performed only with the applied external light having an off-normal direction with respect to the SRRs plane, which thus lowers the coupling efficiency.

In this study, we demonstrate a relative simple method by adopting metal stress driven assembly strategy to fabricate the 3D SRRs. This strategy is simply combined with electron beam lithography (EBL) and reactive ion etching (RIE) processes, providing a promising way for the applications of 3D SRRs. The intrinsic stresses in thin films result from the lattice mismatch, grain boundaries, thermal expansion coefficient difference, impurities in the thin film, and deposition methods during film deposition. The 3D structure could be constructed by means of well arranging the material and dimensions of the deposited thin films.

By ultilizing Al as the metal material, we found that the bending results manifest that, with the same arm length, the radii of curvature are increased with increased arm width. In contrast, with the same arm width, the curving structures exhibit similar radii of curvature. Besides, the bending effect is studied by varying the thickness of thin film. The radii of curvature are strongly dependent on the film thickness. The thinner metal thickness reveals smaller radii of curvature. Transmittance spectra and magnetic field patterns of the fabricated 3D SRRs are calculated by FEM simulation which demonstrates that both electric and magnetic resonance modes can be excited with x-polarized normal incident wave. Moreover, a blue-shift of the resonance modes with increasing gap width is investigated in the case of reconfigurable application. Details of this study will be presented later.

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Non-degenerate Two-photon Polymerization and 13-nm Feature Size on SOI Substrate

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Two-photon absorption (TPA) has been proved to be an effective approach to break the optical diffraction limit and was utilized for micro-fabrication. The optical nonlinear effect takes place by absorbing two identical photons from a laser beam, which is also named as degenerate TPA (D-TPA). In this paper, we report a novel polymerization technology for photolithography based on non-degenerate two-photon absorption (Nd-TPA). In this technique, two laser beams with different wavelengths are employed to initiate the absorption process, so it is the general case of D-TPA. It is estimated by electromagnetic focusing theory that Nd-TPA can excite smaller regions than D-TPA, and polarization directions contribute to the focal volume. Experimentally, we proved the polarization dependence and obtained an 84-nm polymerized line on glass slice with lower light intensity than that by D-TPA, which was attributed to the effect of intermediate state resonance enhancement (ISRE) in Nd-TPA, i. e. the photon with high energy provided stronger transition strength. Furthermore, we successfully applied this technique into SOI (Silicon-On-Insulator) substrate and achieved a 13-nm feature size. This study provides a new super-resolution photolithography approach and marks an entrance into on-chip nanofabrication by laser direct writing.

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Recent papers:

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Surface Wave Holography for Manipulation of Electromagnetic Wave Scattering and Transport

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We present a novel 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 (3D) space. The method allows for direct determination of the metallic surface structure morphology for a given transport functionality, by means of writing desirable object information on the metallic surface via interference with a reference surface wave. We have employed the analytical approach to design and build metallic surface structures that realize arbitrary single-point focusing, arbitrary single-direction beam collimation, and simultaneous two-point focusing of electromagnetic wave in 3D space. Good agreement between numerical simulations and microwave experimental measurements has been found and confirms the power of the method in conceptually understanding and exploiting the surface electromagnetic wave on subwavelength metal structures.

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Recent papers:

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Mesogenic Phthalocyanine Derivative Based Organic Solar Cell

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Organic thin-film photovoltaic devices with great properties such as flexibility, low cost, etc. recently have attracted many attentions. However, the organic semiconductors, which possessing both of the high crystallinity and excellent solubility in conventional organic solvent are still being requested, especially for the bulk heterojunction based devices. In this poster, we introduced the mesogenic phthalocyanine derivative, 1,4,8,11,15,18,22,25-octahexylphthalocyanine ($C6PcH_2$) with the high hole mobility and electron drift mobility of 1.4 cm^2/Vs and 0.5 cm^2/Vs in the crystalline phase, respectively [1] as one potential semiconductor for bulk heterojunction solar cell. The $C6PcH_2$ further indicated the ability to dissolve in the various solvent such as chloroform, toluene, etc. In the beginning, The organic solar cells with bulk heterojunction of $C6PcH_2$ and 1-(3-methoxy-carbonyl)-propyl-1-1-phenyl-(6,6)C61, fabricated by spin-coating have demonstrated the high energy conversion efficiency of 3.1% and external quantum efficiency (EQE) higher than 70% at the Q-band region [2]. The results exhibited the potentials of $C6PcH_2$ to apply for photovoltaic devices in future.

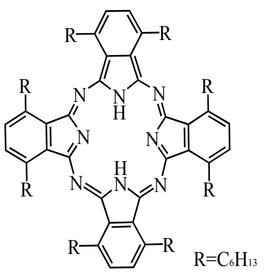

Fig. 1 Molecular structure of $C6PcH_2$.

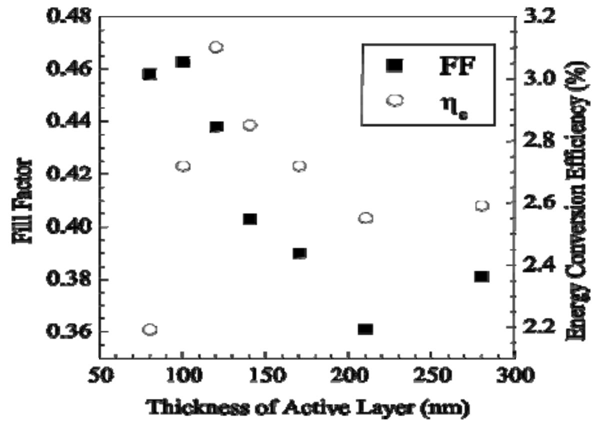

Fig. 2 The dependence of FF and efficiency of the mesogenic phthalocyanine based solar cells on the active

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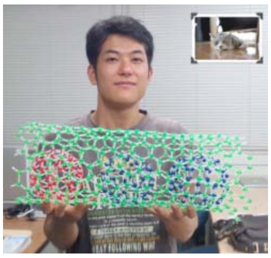

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Recent papers:

[1] Yuika Saito, Mitsuhiro Honda, Yoshikiyo Moriguchi, Prabhat Verma, "Temporally dynamic photopolymerization of C_{60} molecules encapsulated in single-walled carbon nanotubes", ***Phys. Rev. B***, Vol. **81**, No. 245416 (2010),

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Local Temperature Measurement of Laser-irradiated Single Gold Nanoparticles

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Metal nanoparticles exposed to incident laser at wavelengths close to surface plasmon resonance efficiently absorb optical energy and generate heat. The heat is considered to be localized near the nanoparticles. Localized heat induced by gold nanoparticles is widely used in biological field due to their biocompatible nature. [1, 2]

We have investigated the local temperature of a laser-irradiated single gold nanoparticle through surface plasmon peak shift due to the refractive index change of surrounding medium. To make surrounding medium sensitive to temperature, gold nanoparticles (40 nm diameter) were coated by thermo-responsive polymer, poly(N-isopropylacrylamide). [3] To investigate the effect of laser heating, scattering spectra of a single gold nanoparticle were measured with 532/488 nm laser irradiation at different laser power. Figure 1(a) and (b) show relationship between peak wavelengths and laser power with 532 nm and 488 nm. All curves were obtained from different particles. With 532 nm laser, scattering peak shift of around 7 nm was observed with laser power increment. This shift corresponds to temperature rise of around 10 degrees c. On the other hand, with 488 nm, scattering peak wavelengths exhibit almost no shifts. These results indicate that heating is dominated by absorption of light at the surface plasmon resonance wavelength. We found that 5 different heating effect with 532 nm laser irradiation, which should derive from different particle sizes, shapes or polymer thickness. In this research, high sensitivity temperature measurement for nanoparticles at room temperature range has been achieved. This method will be useful to estimate the local temperature effect of laser-irradiated nanoparticles.

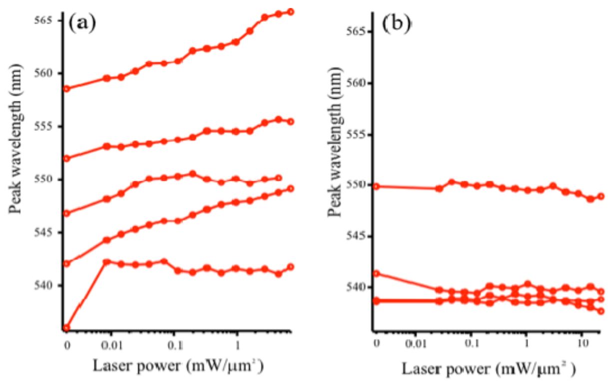

Figure 1 Relationship between scattering peak wavelengths

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Scientific Interests:

NanoPhotonics, Multiphoton lithography

Fabrication of Three Dimensional Silver Micro/Nanostructures by Multiphoton Photoreduction

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Three-dimensional metallic structures with micro/nanosized features are of great interest in various research fields because of the unique properties and extensive applications. But fabrication techniques of these structures are still being developed. Owing to its three dimensional and high resolution fabrication ability, femtosecond laser direct writing technique employing multiphoton induced photoreduction processes becomes a promising tool in metallic structures fabrication on micro/nano scale.

In this report, we have demonstrated the fabrication of three dimensional micro/nanostructures by multiphoton photoreduction (MPR) of metal ion aqueous solutions containing diammine silver ions (DSI) with 0.05 M silver ions as the silver resource and 0.099 M n-decanoylsarcosine sodium (NDSS) as the surfactant. A mode-locked femtosecond laser (Ti: sapphire laser with an operating wavelength of 780 nm, a pulse width of 100 fs, and a repetition rate of 80 MHz) with an extremely low power of 1.55 mW was introduced to irradiate the aqueous solutions dropped on a cover slip. By scanning the focused laser spot along the direction normal to the plane of the cover slip with a speed of 1 μm/s, free-standing silver pillars with smooth surface were fabricated. In conclusion, we present a simple way to build three dimensional micro/nanostructures, which would provide a feasible method for creating arbitrary three dimensional silver micro/nanostructures and lay a substantial foundation for their functions exploration.

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Scientific Interests:

Multi-photon photopolymerization; Inorganic/Organic composites

Recent papers:

[1] Lanting Shi, Feng Jin, Meiling Zheng, Xianzi Dong, Weiqiang Chen, Zhensheng Zhao, Xianming Duan*, "Threshold optimization of polymeric opal photonic crystal cavity as organic solid-state dye-doped laser", ***Appl. Phys. Lett.***, **98**, 093304 (2011).

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[3] Xiaomei Wang*, Feng Jin, Zhigang Chen, Shouqing Liu, Xiaohong Wang, Xuanming Duan*, Xutang Tao*, Minhua Jiang, "A new family of dendrimers with naphthaline core and triphenylamine branching as a two-photon polymerization initiator", ***J. Phys. Chem. C***, **115**, 776-784 (2011).

Flexible Quantum Dot/Polymer Composite Film Based on Thiol-ene Click Reaction

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Quantum dot(QD)/polymer composites, which combine the high photoluminescence quantum yield and high optical stability of QD and the flexibility of polymer, are of great importance in constructing active devices. Numerous methods have been demonstrated to construct QD/polymer composite, including layer-by-layer assembly, incoporation by van der waals interaction, and so on.[1-2] However, these methods either need to be carried out in polar media, or require special solvent or functional monomer, which usually decreased the photoluminescence quantum yield of QD and deteriorate the fluorescent property of the QD/polymer composite. Thiol-ene click reactions provide an effective way to make polymer containing thiol group, which is readily to anchor nanoparticles.[3] In this paper, we demonstrate the construction of flexible QD/polymer composite based on the thiol-ene click reaction.

Flexible quantum dot/polymer composite was prepared by selectively absorbing CdSe-CdS QD using thiol-containing polymer, which was obtained by radical-mediated thiol-ene click reaction. Polymer film containing thiol group was polymerized by thiol-ene click reaction, and dipped in the CdSe-CdS QD toluene solution. CdSe-CdS QD were effectively absorbed on the surface of polymer film because of the strong interaction between thiol groups and CdSe-CdS QDs. Thickness of the CdSe-CdS/polymer composite film was varied by changing the cycle of spin-coating and QD deposition. The CdSe-CdS QD/polymer composite film showed good fluorescent property, and was expected to have perspective in fabricating active devices.

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Scientific Interests:

Two-photon lithography, positive-tone resist, molecular glasses

Recent papers :

李浩[1,2]，金峰[1]，陈卫强[1]，赵震声[1]，段宣明[1*] 双光子用小分子正性光刻胶的合成与评价, 中国感光学会 2011 学术年会

New Type Positive Molecular Glass Resists for Two-photon Lithography

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Femtosecond laser 3D Micro-nano Fabrication technology is hyperfine fabrication technology, with high accuracy, good resolution and true three-dimensional microfabrication capability[1-2]. Photoresists, the critical materials of lithography, have great influence on the LERs, resolution. Compared to traditional polymer resist, molecular glasses resist possesses small molecular size, small LERs and high fabrication resolution[3]. Tert-BOC protected calix[4]resorcinarene derivatives have been designed and synthesized as positive-tone resist.Triphenysulfonium triflate was used as photoacid generator and its quantum yield upon 250nm exposure was investigated. Positive-tone molecular glass resist build by these compounds was used in two-photon lithography, resulting to line/space and 2D patterns with 350nm line width.

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Scientific Interests:

Plasmonics

Surface Plasmon Focusing by Semicircular Slits Filled with Different Dielectric Mediums

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A novel method is proposed to focus surface plasmon through a metallic film with semicircular nano-slits filled with different dielectric mediums under linearly polarized illumination. The slits transport electro-magnetic energy in the form of surface plasmon polaritons (SPPs) in nanometric waveguides and provide desired phase shifts which are controlled by the SPPs' optical paths due to different refractivities of the slits. In addition, plasmonic focusing can also be realized by varying the incident angle of light which can change the initial phase of the excited SPPs. Numerical simulations of illustrative design examples are performed through finite-difference timedomain (FDTD) method and show agreement with our analysis.

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Scientific Interests:

Photonics: semiconductor microcavity laser

Plasmonics: active plasmonics, plasmonics cavity, plasmonics waveguide

Laser technology: laser direct writing technology

Recent papers :

[1] Jing Li, Yuedeng Yang, and Yongzhen Huang, "Design of Quantum Cascade Microcaivty Lasers Based on Q Factor versus Etching Depth", ***Jouranl Optical Society of America B***, **26**, 1484-1491 (2009).

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Plasmon Propagation Characteristics of Ag Nanowires with Grating Structure

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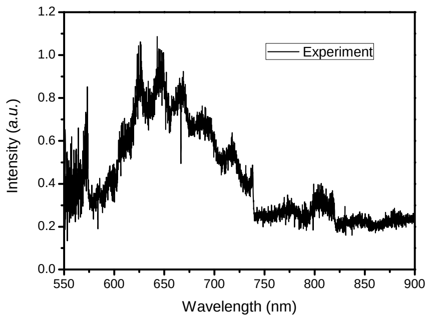
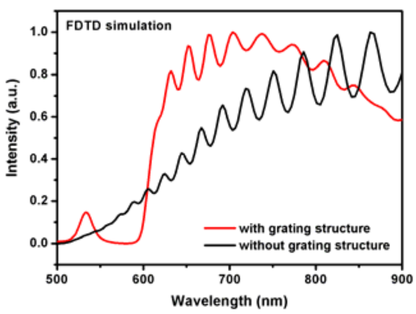
Plasmonic structure combining with conventional photonic devices will be fundmental components for future integrated nanophotonic circuits. Chemically synthesized metal nanowires used as subwavelength plasmonics waveguide because of relative low loss of energy maybe a solution for the interconnect of components in the circuits. Recently there are many studies focused on the excitation and propagation of surface plasmon polaritons (SPPs) along the Ag nanowires, especially the light-plasmon in/out-coupling and splitting. For the plasmon propagation along Ag nanowires, the in-coupling efficiency of light into nanowires plasmons and plasmon damping vary with the distance between Ag nanowires and substrate [1]. Combining Ag nanowires and grating structure is an easy and common integrated method. However, there are few reports about the Ag nanowires plasmonics characteristics for the Ag nanowires-grating integrated structure.

Here Ag nanowires integrated with the grating structure is investigated by experiment and finite-difference time-domain (FDTD) simulation method. For Ag nanowires put on substrate with photoresist grating structure (period of 200 nm), the propagation of plasmon along Ag nanowire is modulated because there is conversion between plasmon of Ag nanowires and photon of grating substrate. For the near-field optical transmittance spectra of Ag nanowire on the substrate with grating structure, there is good agreement between experiment result and FDTD simulation. And this transmittance spectrum is different from one of Ag nanowires on the substrate without grating structure. The Fabry-Pérot cavity effect is enhanced for Ag nanowires with grating on both ends as resulting from an increasing reflection of plasmon on the nanowire ends.





Reference:

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Scientific Interests:

Multi-photon photopolymerization; Multi-photon photografting.

Recent papers:

[1] Zhiquan Li, Marton Siklos, Niklas Pucher, Klaus Cicha, Aliasghar Ajami, Wolfgang Husinsky, Arnulf Rosspeintner, Eric Vauthey, Georg Gescheidt, Jürgen Stampfl, Robert Liska* [J] ***Journal of Polymer Science Part A: Polymer Chemistry***, **49**, 3688-3699 (2011).

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3D Site-specific Functionalization of Matrices Via Multi-photon Grafting and Subsequent Click Reaction

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Photografting has been widely applied as a simple and versatile method for tailoring physical-chemical properties of surfaces, such as wettability, adhesiveness, biocompatibility, antifouling, etc. Multiphoton grafting provides additional advantages of spatial and temporal control of the process. Since multiphoton-induced reactions are restricted only in a confined area within the focal spot, more accurate functionalization with high resolution in a 3D volume is possible. Here, the commercially availuble aromatic azide 2,6-bis(4-azidobenzylidene)-4-methylcyclohexanone (BAC-M), which exhibits a large three-photon absorption cross section of 4.8×10^{-78} ($cm^6\ s^2$) at 800 nm, was firstly selected as a suitable chromophore for the multiphoton grafting. After writing with the focused laser beams, 3D grafting patterns within the PEG matrix was obtained with a lateral resolution of around 4 μm. As the grafting products contain the ketocyanine chromophore with strong fluorescence, the produced grafting patterns could be directly observed via confocal laser-scanning microscopy (LSM). The post modification was carried out via copper catalyzed azide-alkyne click reaction between the residule azide groups on the matrices and Br-containing alkyne. The succesful imobilization to the patterned areas was verified by Energy-dispersive X-ray spectroscopy (EDX) screening of the Br content on the grafted areas. Such developed 3D site-specific functionalization method is simple and versatile, which reveals great potential applications in microarray-based proteome analysis, biosensors, cell patterning, and drug screening.

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Scientific Interests:

Photonics, Plasmonics, and Near-field optics

Recent papers:

[1] Feng Lin, Xiaoming Huang, Shengchun Qu, Zheyu Fang, Shan Huang, Wentao Song, Xing Zhu, and Zhongfan Liu, "Characteristics of charge density waves on the surfaces of quasi-one-dimensional charge-transfer complex layered organic crystals", ***Phys. Rev. B*** **83**, 125434 (2011)

[2] Meng Yang, Zhenping Fu, Feng Lin, and Xing Zhu, "Incident angle dependence of absorption enhancement in plasmonic solar cells", ***Optics Express*** **19**, A763 (2011)

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Adjustment of Light Enhancement for Silver Bowtie Nanoantennas 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.

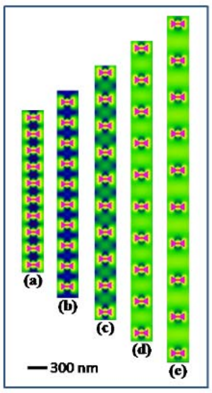

Figure 1. The transverse array of silver bowtie nanoantennae. With the array periodicity increasing (a)-(e), the light enhancement at the bowtie gap is significantly reduced.

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Scientific Interests:

Semiconductor, Raman spectroscopy

Recent papers:

[1] Liu Jie, Zhao Yan, Jiang Yijian, Lee Chakman, Liu Yulong, and G. G. Siu, "Identification of zinc and oxygen vacancy states in nonpolar ZnO single crystal using polarized photoluminescence", ***Applied Physics Letters***, **97**(23), 231907 (2010).

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Effects of KrF (248nm) Excimer Laser Irradiation on Structural and Optical Properties of ZnO Single Crystal

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ZnO single crystals irradiated at different laser energy densities are systematically investigated using x-ray diffraction(XRD) and photoluminescence (PL) spectroscopy. Our results show both the structure and PL properties of the strongly depend on laser energy densities. A critical laser energy density that divides respective predominance is determined to be about 200 mJ/cm^2. Both the structure and UV PL properties of the ZnO single crystal irradiated at 200 mJ/cm^2 have been improved and the visible emission has been suppressed, compared with that of as grown ZnO crystal. On the contrary, those of the ZnO single crystals irradiated at above the 200 mJ/cm^2 are deteriorated prefect bulk spectra with their spectral-line weakens, broadens and merges, as well as the visible emissions are significantly enhanced. Deteriorated XRD and UV PL spectra are essentially associated with increasing intrinsic defects in the irradiated layer of the ZnO single crystals. The broad visible emission can be resolved into four different emission bands centered at around 490, 525, 566, and 626 nm, together with a violet emission band around 401 nm, besides UV emission band. Based on the irradiation conditions, possible origins are proposed and discussed.

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Scientific Interests:

Photonics, Laser technology

Recent papers:

[1] Zhao-Pei Liu, Yan Li, Yun-Feng Xiao, Bei-Bei Li, *et.al.*, ***Appl. Phys. Lett.*** **97**, 211105 (2010).

[2] Yi Qin, Yan Li, Xiaobo Feng, Zhaopei Liu, *et.al.*, ***Opt. Express*** 18, 16832 (2010).

[3] Xu Yi, Yun-Feng Xiao, Yan Li, Bei-Bei Li, Zhao-Pei Liu, *et.al.*, ***Appl. Phys. Lett.*** 97, 203705 (2010).

High-Performance Whispering Gallery Microcavities Fabricated by Direct Laser Writing

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Whispering gallery microcavities that strongly confine light within small dielectric volumes have found applications in a variety of fields, including quantum electrodynamics, nonlinear optics, biosensing, ultra-small filters, and low-threshold lasers. Due to the low cost and good biocompatibility of polymer materials, polymer microcavities have attracted increasing interest. So far, fabrication of these microcavities has been primarily based on the conventional lithography that is remarkably successful in producing planar devices via multiple steps. With the rapid development of femtosecond laser systems, direct laser writing by two-photon polymerization (TPP) of a photoresist has emerged as a powerful technique for creating fully three-dimensional (3D) micro/nanostructures, such as photonic crystals, metamaterials, waveguide-based devices, and MEMS. Here, we demonstrate that polymer microcavities supporting high-Q whispering gallery modes (WGMs) can be directly written by TPP of zirconium/silicon hybrid sol-gel, resulting from the high resolution and 3D nature of this direct laser writing technique.

Figure 1 depicts a tilted-view scanning electron microscopic (SEM) image of a microdisk which was written by the TPP method. The inset clearly shows the wedge-shaped profile of the microdisk edge. Figure 2 shows a typical transmission spectrum of a fiber taper coupled to a microdisk cavity (Rb=14 μm, Rt=12 μm, and d=2 μm). The observed free spectral range (FSR=19.29 nm) agrees well with the simulation result. The inset of Fig. 2 shows an individual WGM located at 1545.59 nm with a Lorentzian shaped fitting (red curve). After taking coupling loss into account, the cavity Q factor for the mode was found to be 1.48×105, which was significantly better than the most previously reported value (104) for a polymeric microdisk resonator and approached the absorption limit of the polymer material.

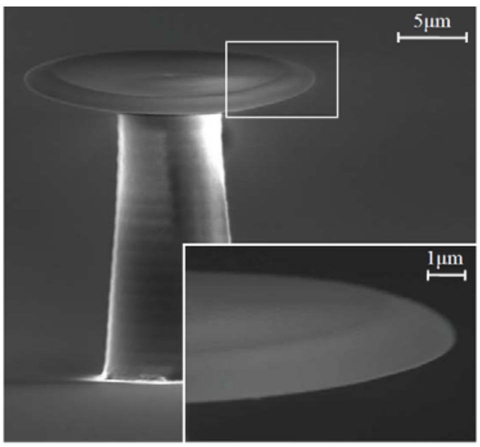

Fig. 1.

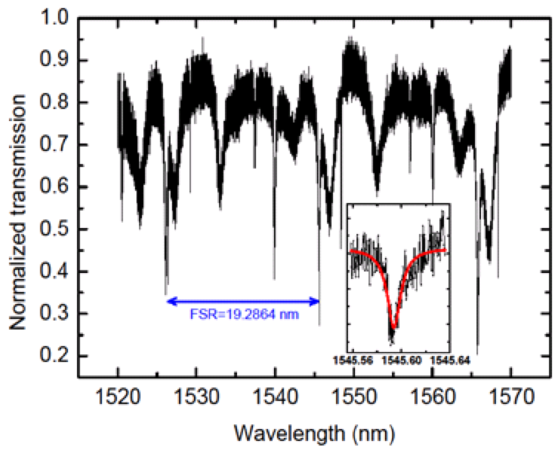

Fig. 2.

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Scientific Interests:

Photonics, Plasmonics, Laser technology

Recent papers:

[1] Wei-Er Lu, Xian-Zi Dong, Zhen-Sheng Zhao, Wei-Qiang Chen* and Xuan-Ming Duan*, "Novel photoinitiator with a radical quenching moiety for confining radical diffusion in two-photon induced photopolymerization", ***Journal of Materials Chemistry.***, **21**, 5650-5659 (2011).

[2] Wei-Er Lu, Wei-Qiang Chen, Mei-Ling Zheng, Zhen-Sheng Zhao, and Xuan-Ming Duan* et al., "Two-Photon Induced Photopolymerization Using Photoinitiator with an Intramolecular Radical Quenching Moiety for Nanolithography", ***Journal of Nanoscience and Nanotechnology.*** (Accepted).

Preparation of Gold Nanostructures by Multiphoton Laser Direct Writing

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Recently, multiphoton photoreduction (MPR) has been explored as a powerful tool for the fabrication of metallic microstructures.[1-3] The silver linewidth of 120 nm was obtained through MPR of aqueous solution of silver ions with the assistance of surfactant.[2] Actually, it was important to note that oxidization and sulfurization of silver microstructures were liable to happen, which greatly affected their application. The ability to fabricate gold nanostructures without the encapsulation of macromolecular polymers was less explored.[1,3] Herein, gold nanostructures were obtained by MPR of an aqueous solution of gold ions with the assistance of a glyciate ionic liquid (IL), (2-hydroxyethyl)trimethylammonium 5-aminopentanoic [HETMA][AP]. The ^{1}HNMR and UV-Vis absorption indicated that gold particles were generated by MPR of [AP]-$AuCl^{4-}$ complex. The IL acted as gold growth inhibitor and a photoreducing agent, which resulted in the photoreduction threshold power as lower as 1.47 mW and a resolution around 200 nm. The gold lines were composed of closely connected smaller gold nanoparticles with the sizes smaller than 5 nm, which contributed to high conductivity that just several times lower than that of bulk gold. Functional gold nanostructures such as split ring resonator, chiral diffraction grating and spiral were fabricated. The experimental results of their optical properties were well agreement with that of the theory simulation. This study demonstrates a simple way to achieve designable gold nanostructures, which would provide a good prospect for wide applications of IL assisted MPR in the realization of arbitrary 2D and 3D metallic nanostructures.

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Scientific Interests:

Photonics, Plasmonics, Microscopy, Biophotonics, Bioimaging,

Nano-observation of Biomolecular Dynamics Using Au Nanoparticle Dimers

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Plasmonic biosensing, in which a biomolecule is attached to a metallic nanostructure, has attracted attention in biological and biomedical research fields owing to high sensitivity provided by resonant effect and high photostability given by nature of metal. In particular, gold (Au) nanoparticle dimers, whose plasmon resonant wavelength is strongly dependent on inter-particle distance, have a potential to observe dynamic change of conformation, or distance among biomolecules. In this presentation, we report a plasmonic biosensing system of Au nanoparticle dimers for investigation of molecular dynamics of a transcription factor that binds a specific sequence of DNA and induces DNA bending. At first, we optimized the diameter of Au nanoparticles and the synthetic DNA length that defines the inter-particle distance with finite-difference time-domain (FDTD) method. The result shows that the Au nanoparticle dimer consisting of 50 nm Au nanoparticles and 50 base-pairs (bp) DNA (17 nm) provides the largest spectral shift by the DNA bending. After we prepared 50 bp DNA which involves a sequence combinable with transcription factor, and its complementary DNA, we attached the DNA and the complementary DNA on separate Au nanoparticles and hybridized with each other. While Au nanoparticle dimers were illuminated by white light through a dark-field condenser lens (N.A. = 1.20 ~ 1.43), the scattered light was collected by the objective lens (x100, N.A. = 0.8) and then brought to the spectrometer equipped with an EM-CCD camera. We observed that the plasmon resonant peak wavelength shifts 586.9 ± 5.7 nm to 603.9±7.9 nm by introducing the transcription factor. Furthermore, by introducing both the transcription factor and its partner factor, the plasmon resonant peak wavelength shifts to 612.9±10.9 nm. These shifts are due to the DNA conformational change that generates change of the inter-particle distance. From a calibration curve, which we made by measuring several plasmon resonant peak wavelengths while changing DNA length, we inferred that the inter-particle distance of Au dimer was changed to 7.2 nm from 17 nm with the transcription factor, and 5.7 nm with the transcription factor and its partner factor.

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Scientific Interests

Photonics, Plasmonics, Near-filed optics

Recent papers

[1] Junjie Miao, Yongsheng Wang, Chuanfei Guo, Ye Tian, Shengming Guo, Qian Liu and Zhiping Zhou. "Plasmonic Lens with Multiple-Turn Spiral Nano-Structures," ***Plasmonics***, **6**, 235-239, (2011).

[2] Junjie Miao, Yongsheng Wang, Chuanfei Guo, Ye Tian, Jianming Zhang, Qian Liu, Zhiping Zhou, and Hiroaki Misawa, "Far-Field Focusing of Spiral Plasmonic Lens,Plasmonics", 2011. DOI 10.1007/s11468-011-9318-0

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Planar Lens Based on Tapered Metallic Nano-slits

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Slit array is often fabricated by using focused ion beam milling technique, and this results in the trapezoidal slits instead of the ideal rectangular shaped ones in cross-sectional view of the slits. On the other hand, trapezoidal slit array is possible used to focus beam, such as planar lenses.

In this study, we discussed the influence of trapezoidal metallic subwavelength slit array with variant width of slits on beam focus properties. In order to analyze the phenomenon, a finite-difference time-domain (FDTD) numerical algorithm and phase matching theory was adopted for computational numerical simulation of the nano- structures. The structures were flanked with the penetrated slits through a metal (Ag) film coated on a quartz substrate. We found that the phase delay of each slit will grow with the increase of slit width. So by optimizing the slit width of the input and output surfaces, the trapezoidal slit array shows focusing property, and the focal length and the focal intensity can be controlled effectively by regulating the aperture of slits. These results are very encouraging for further study of nano-optics and the applied planar lenses.

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Scientific Interests:

Photonics

Recent papers:

[1] Qin, Y., Li, Y., He, H. Y. & Gong, Q. H. "Measurement of spin Hall effect of reflected light", ***Opt. Lett.*** **34,** 2551-2553 (2009).

[2] Qin, Y., Li, Y., Liu, Z. P., He, H. Y., Xiao Y. F. & Gong, Q. H. "Spin Hall effect of reflected light at the air-uniaxial crystal interface", ***Opt. Express*** **18,** 16832-16839 (2010).

[3] Qin, Y., Li, Y., Xiao, Y. F., Yang H. & Gong, Q. H. "Observation of the in-plane spin separation of light", ***Opt. Express*** **19,** 9636-9645 (2011).

Observation of the In-plane Spin Separation of Light

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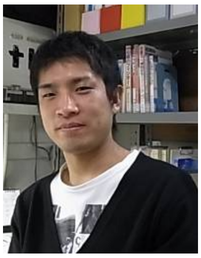
The spin Hall effect of light (SHEL) is a spindependent transverse shift of the wave packet perpendicular to the gradient of the refractive index, which represents a photonic version of the spin Hall effect of electrons by replacing the spin −1/2 charged particles with spin 1 photons and by replacing an electric potential gradient with a refractive index gradient. This effect originates from the geometric phase gradient in the spin states, which arises from rotation of the coordinate frames attached to partial plane waves with different planes of incidence. In fact, the conservation of the total angular momentum of light plays a key role in the phenomenon, and SHEL can be described as the result of the spin-orbit interaction.

We report not only on the SHEL, but also on the observation of the spin separation of light in the plane of incidence when a linearly polarized beam is reflected or refracted at a planar dielectric interface. Remarkably, the in-plane spin separation reaches hundreds of nanometers, comparable with the transverse spin separation induced by the well-known spin Hall effect of light. The observation is properly explained by considering the in-plane spread of wave-vectors. This study thus offers new insights on the spinoptics and may provide a potential method to control light in optical nanodevices.

Eiichi SHIMIZU



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Scientific Interests:

Biological imaging, Micro fluidic chip application, Laman imaging

Recent papers:

[1] M. A. El-Hagrasy, E. Shimizu, M. Saito, Y. Yamaguchi, E.Tamiya, "Discrimination of primitive endoderm in embryoid bodies by Raman microspectroscopy", ***Analytical and Bioanalytical Chemistry***, DOI 10.1007/s00216-011-5554-6, 2011

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In-vitro Cardiotoxicity Diagnosis Based on Quantitative Imaging Analysis

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Introduction

Cardiomyocytes which are derived from Embryonic Stem (ES), or induced pluripotent stem (iPS)-cells have been expected as promising cells for regenerative therapeutics and a pharmaceutical model of drug screening. Althogh characterization of ES- or iPS-derived cardiomyocytes is challanging as well as time and resource consuming, it is cruial in order to deveop uses for them. In this study, we explored a non-invasive imaging method for evaluating in-vitro beating properties of mouse ES-derived cardiomyocytes and applied it to cardiotoxicity diagnosis.

Methods

The method for beating quantification was established by progressive video recording and quantitative imaging processing. In the process, the successive video frames were decomposed into still images, then derivative proceeding of pixel intensity between the still images were conducted and the calculated values were accumulated in every frame. The beating intervals were measured as the frame difference derived from the intensity variation analysis. We applied the method to cardiotoxicity tests using ion channel blockers and sympathetic agents in terms of their beating frequency variation.

Results

The beating of mouse ES-derived cardiomyocytes were quantified. It indicates systolic and diastolic phase of beating as well as beating rhythm and strength. It was also confirmed that the method captured beating at the same rhythm as when using micro electrode array system. In the results of drug testing, beating rhythms got decreased or increased depending on the drug concentration.

Discussion

We developed a non-invasive and handy method in order to quantify beating of ES-derived cardiomyocytes and demonstrated a cardiotoxicity diagnosis. Our method has some advantages in preserving information of beating quantification and physical properties like systolic and diastolic strength and time. We discuss contractile functions along with the conventional methods which reveal intracellular ion movements when it comes to pharmaceutical reactions and maturation of derived cardiomyocytes.

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Scientific Interests:

Photonics, Plasmonics, Tip-enhanced near-field spectroscopy, Raman spectroscopy

Photoreduction for the Fabrication of A Finite-size Near-field Tip for Tip-enhanced Raman Spectroscopy

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Tip-enhanced Raman spectroscopy (TERS) is a powerful method to identify material species at ananoscale spatial resolution [1]. TERS utilizes a metal-coated nano-tip to enhance and confine the lightfield. Instead of complete metal coating, tips having a metal nanostructure attached to the tip apex havepotential of strong enhancement of light field in the visible region due to efficient resonance andconfinement of the surface plasmon at the tip apex such tips are known as finite-size near-field tip [2]. In the past, finite-size tips have been fabricated by attaching a metal nanoparticle to the tip apex coated with glue [3] or by milling a tip which is fully coated with metal by focused ion beam lithography [4]. These methods take long fabrication time, at least a few hours, and need complicated systems such as a focused ion beam lithography system and so on.

In this study, we present photoreduction as a facile fabrication method of finite-size tips. Our photoreduction method needs just one laser without any complicated systems, and takes short fabrication time (about a few minutes). The setup to fabricate finite-size tips is shown in Fig. 1. A silicon cantilever was fixed on aluminum foil in a glass dish with the tip apex facing downward, then solution containing $AgNO_3$ and photosensitizer was filled in the dish. The silicon cantilever was entirely irradiated with an expanded unfocused beam of a laser (λ= 532 nm) to induce photoreduction. As a result, we found that silver particles were deposited dominantly at the tip apex, even though the cantilever was entirely irradiated. We estimate that this result is caused by the lightning rod effect and/or difference of surface energy of the silicon cantilever between sharp corners such as a tip apex and flat surface. As shown in Fig.2, the size of silver nanoparticle (AgNP) grown on the tip apex was changed with the laser exposure time of photoreduction between ~100 nm and ~400 nm. Through an experiment of the TERS imaging of carbon nanotubes, we confirmed that the finite-size tip fabricated by our photoreduction method showed strong enhancement of the Raman scattering compared with near-field tips fully coated with silver fabricated by means of vacuum vapor deposition (most common tip for TERS).

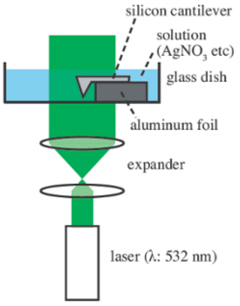

Fig. 1. Setup to fabricate near-filed tips

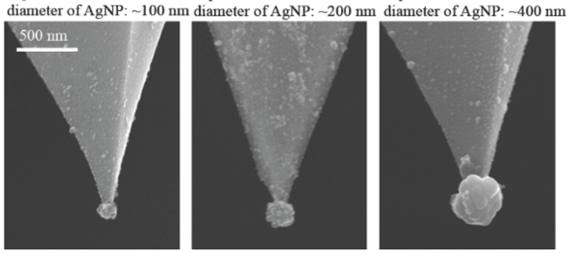

Fig. 2. SEM images of AgNP fabricated by photoreduction at the tip apex
The size of AgNP changes with laser exposure time.

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Femtosecond Laser Lithography Technique for Submicron T-gate AlGaN/GaN HEMTs

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Femtosecond lasers have been found suitable for maskless photolithography with submicron resolution, which is very attractive for solving the problem of high photomask cost. We report direct femtosecond laser writing of lithographic patterns with submicron feature width on thin positive photoresist film. T-shaped gate could be fabricated by two-photon femtosecond laser lithography in two steps, the first exposure defined the foot of the T-shaped gate on the resist using 180 nm-thick AZ4620, the second overlay exposure defined The gate head on AZ4620 photoresist with 500 nm-thick. This work has led to the stable fabrication of sub-300 nm T-gates on GaN on sapphire substrate and AlGaN/GaN on Si substrate. The fabricated AlGaN/GaN HEMT with 380 nm T-gate exhibits good DC performances including a good pinch off behavior, low on-resistance and low knee voltage.

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Scientific Interests: (Times New Roman, 10pt)

Liquid crystals, Optical devices

Recent papers:

[1] Shuhei Yabu, Yuma Tanaka, Kenji Tagashira, Hiroyuki Yoshida, Akihiko Fujii, Hirotsugu Kikuchi and Masanori Ozaki, "Polarization-independent refractive index tuning using gold nanoparticle-stabilized blue phase liquid crystals," ***Optics Letters***, Vol. **36**, Issue 18, pp. 3578-3580 (2011).

[2] Shuhei Yabu, Hiroyuki Yoshida, Gihwan Lim, Kosuke Kaneko, Yasushi Okumura, Noboru Uehara, Hirotsugu Kikuchi, and Masanori Ozaki, "Dual frequency operation of a blue phase liquid crystal," ***Optical Materials Express***, Vol. **1**, Issue 8, pp. 1577-1584 (2011).

Electro-optical Applications of Nanoparticle Doped Blue Phase

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Blue phases (BPs) are types of liquid crystal (LC) phases that appear in chiral LCs. BPs spontaneously form three-dimensional periodical structures comparable to wavelength of visible light, and are classified into BP I and BP II, which possess body centered cubic (bcc) and simple cubic (sc), respectively (Fig. 1). BPs are optically isotropic and exhibit a electro-optical Kerr effect with fast response time. Therefore, BPs are attracting much attention as next-generation photonic materials and have been studied for the applications such as photonic crystals, fast response display and polarization-independent optical devices. However, because of their complex structure, the temperature range of BPs is only a few °C. which is too small to be used in practical applications. Here we present a strategy to expand the BP temperature range based on doping metallic nanoparticles in the LC.

The BPLC prepared in this study is a mixture consisting of two kinds of nematic LCs (46.5 wt% 5CB and 46.5 wt% JC-1041XX) and chiral dopant (7 wt% ISO-$(6OBA)_2$). Gold nanoparticles were dispersed in the material by the sputter-doping method. In this study, sputter-doping of gold was performed under the following conditions: 60 mg of the BP sample was placed in a cylindrical glass container and placed in a sputter deposition apparatus (ULVAC VPS-020). The LC was sputter deposited for various lengths of time (5, 6, 7, 10, 15 minutes) using air plasma at approximately 20 Pa and an applied DC voltage of 1 kV between the electrodes. After sputter-doping, highly dispersed spherical particles with a mean diameter of 3.7 mm were found in the LC by a transmission electron microscope (TEM) observation.

Figure 2 shows the temperature range of the nanoparticle-doped BP during cooling and heating, measured at a rate of 0.1 °C/min. The expansion of the temperature range is found for both cooling and heating, and is larger for samples with higher nanoparticle concentrations. Thus, the BPs are considered to be thermodynamically stabilized by sputter doping method. Furthermore, the samples with more than 7 minutes of sputtering were found to exhibit BP I only. Stabilization of BPs is believed to be caused by the spherical metal nanoparticles being tapped in the disclination lines resulting in the reduction of the volume and the energy associated with the disclination lines being reduced.

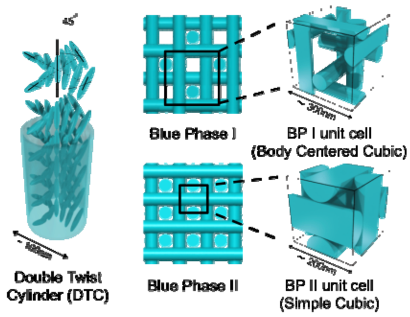

Fig. 1 Three-dimensional structure of blue phases

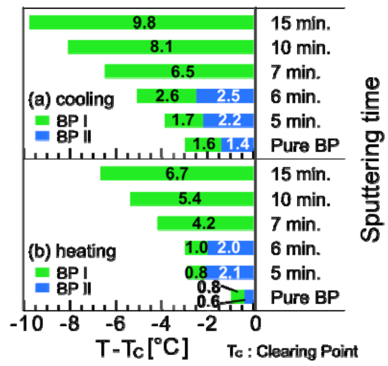

Fig. 2 Sputtering time dependence of the BP temperature range during (a) cooling and (b) heating process.

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Photonics, Photovoltaics

Annealing Temperature on the Performance of Quantum Dot Sensitized Solar Cell

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Nowadays, a series of nano-photovoltaic devices based on one-dimensional nanostructure, including nanowires and nanotubes has been widely studied. One-dimensional nanostructure arrays are beneficial for photovoltaic applications due to their geometrical structure which provides a direct pathway for charge transport. Quantum dots sensitized solar cells (QDSSC) attract many attentions since QDs can absorb light in the visible region and transfer electrons to large band gap semiconductors. in QDSSC Au and Pt are mostly used as counter electrode (CE) and polysulfide solution is used as electrolyte. However, the absorption of sulfur atoms on the surface of Au or Pt CE increases the resistance of CE, imposing performance limitation. To increase the efficiency of QDSSC, new CE need to be developed. Therefore, metal sulfides have been proposed as promising candidates for QDSSC. Recently, a study reported CoS CE behaved better than Pt, CuS and NiS CE[1]. To construct high efficiency solar cell, the influence of annealing temperature need to be discussed.

Herein, we studied the influence of annealing temperature of working electrode and CE on the performance of CdS/CdSe sensitized ZnO nanowire solar cell. Firstly, ZnO/CdS/CdSe heterojunction nanowire array was fabricated by depositing CdS and CdSe nanoparticles respectively on the surface of ZnO nanowire[2,3]. The ZnO/CdS/CdSe nanowire array with a diameter of 150-200nm had been obtained. Then, CoS CE was prepared by deposing CoS nanoparticles on the ITO glass through chemical bath deposition[1,4]. A thin layer of CoS film had been deposited on the surface of the ITO glass. As the annealing temperature increased, the CoS particles grew up and the CoS film became damaged. Finally, solar cells were constructed with polysulfide electrolyte and their I-V curves were measured. The results showed that the solar cell behaved well with annealing temperature of CE at 150-200℃ and the efficiency increased as the temperature increase from 100℃ to 300℃. As a result, the optimized efficiency achieved was 3.88%.

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[3] M. Seol, H. Kim, Y. Tak, and K. Yong, ***Chem. Commun***., **46**, 5521 (2010).

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Education

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M.S. (expected), 2013, Osaka University

Scientific Interests:

Photonics, Plasmonics, Biophotonics, Biosensor

Incident Angle Dependence of Reflection Spectrum of Gold Nanoparticle Plasmonic Sensors

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Localized surface plasmon resonance (LSPR) is applied to label free photonic biosensors in order to detect antigen-antibody reaction and DNA hybridization etc., because spectroscopic properties due to LSPR in metal nanostructure strongly depend on refractive index near the surface. A variety of nanostructures composed of different size and shape of nanoparticles have been proposed to improve the refractive index sensitivity. Therefore it is necessary to optimize the measurement conditions such as incidence angle and wavelength of light for each nanostracture substrate. In this experiment, gold nanoparticles (diameter :50nm) were immobilized on glass substrate by silane coupling agent, and we examined theoretically and experimentally relationship among refractive index, incident angle, and wavelength in optical reflectance.

By the calculation of Fresnel's formula using effective medium approximation of the complex refractive index of gold nanoparticles substrate, we found that significant reflectivity change is observed toward the change in refractive index at incident angle ~80 degrees (Figure.1). By using the prism coupling optical system shown in Figure 2, the reflection spectra were measured by adjusting the incident angle between 70 and 80 degrees. At an incident angle of total internal reflection, the refractive index sensitivity of the LSPR band (nm/RIU) was found to be better than that at normal incident angle. In addition, we report the refractive index sensitivity and spectral changes for the formation of a SAM film of a nanostructure substrate composed of a gold film (5nm) coated on gold nanoparticles.

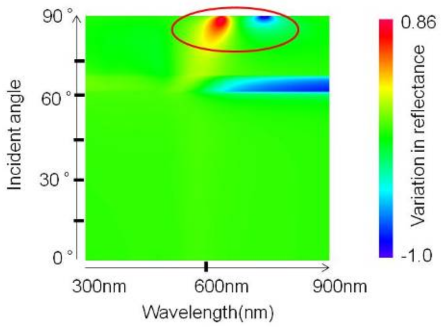

Figure.2 Variation in reflectance toward refractive index change (Gold nanoparticle diameter 50nm, Density 15%, TE mode, Refractive index 1.357→1.425)

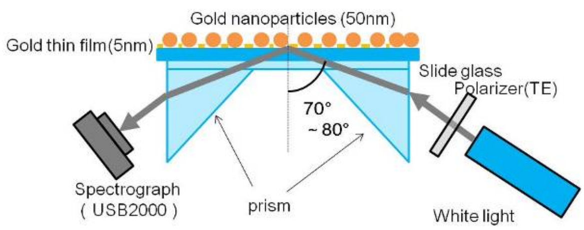

Figure.1 Experimental setup

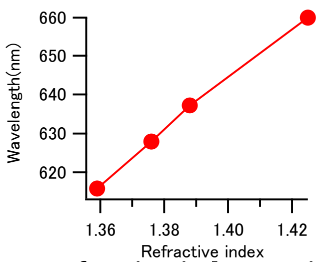

Figure.3 Refractive index sensitivity of the LSPR band

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Photonics, Plasmonics

Recent papers:

[1] M. Yang, Z. P. Fu, F. Lin, and X. Zhu, "Incident angle dependence of absorption enhancement in plasmonic solar cells", ***Opt. Exp.***, **19**, 145889 (2011).

Enhanced Light Absorption in Silicon Solar Cell Using Plasmonic Nanoparticles

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We find that three mechanisms lead to absorption enhancements in a thin-film amorphous silicon solar cell coated with a periodic array of silver nanoparticles on the rear surface through simulation. They are Fabry-Perot (FP) resonant cavity modes, nanoparticle localized surface plasmon (LSP) modes and waveguide effects. The spectral range of the FP enhancement is only dependent on the thickness of the silicon layer. The waveguide enhancement is dependent on both the thickness of the silicon layer and the period of the nanoparticle array. The LSP enhancement is the major enhancing mechanism. It shows strong broadband absorption enhancement which can be tuned in spectrum by changing the nanoparticle size, array period, and the silicon thickness. An average absorption enhancement of up to 57% can be achieved in the AM 1.5G solar spectrum with a 20% nanoparticle coverage.

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Recent papers:

[1] Chen Wang, Chang-Zhu Zhou and Zhi-Yuan Li, ***J. Opt.*** **13**,055101 (2011)

[2] Chen Wang, Chang-Zhu Zhou and Zhi-Yuan Li, ***Optics Express***. **19**, 26948-26955 (2011)

On-chip Optical Diode Based on Silicon Photonic Crystal Heterojunctions

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On-chip high-performance optical diode is a long pursued object with fundamental difficulty in integrated photonics. The need to overcome this difficulty is becoming increasingly urgent with the emergence of silicon nano-photonics, which promises to create on-chip optical systems at an unprecedented large scale of integration. Motivated by this one-way effect, considerable effort has been dedicated to the study of the unidirectional nonreciprocal transmission of electromagnetic waves, showing important promise in optical communications.

Our above manuscript gives a new way to approach this goal in a broader definition of optical diode. We demonstrate the design, fabrication, and characterization of on-chip wavelength-scale optical diodes that are made from the heterojunction between two different silicon two-dimensional square-lattice photonic crystal slabs with directional bandgap mismatch and different mode transitions. The measured transmission spectra show high forward transmission and very low backward transmission of light transport across the heterojunction, in good agreement with numerical simulations. The experimental forward transmissivity approaches 21.3% and the best signal contrast S of the diode structure reaches 0.885 (Fig. 1) at the peak which is near the value of the present electrical diodes.

Our photonic crystal heterojunction diode has advantages of high signal contrast, wavelength-scale small sizes, and being all-dielectric, linear, and passive. The high performance on-chip optical diode realized in silicon without nonlinearity or magnetism will stimulate the exploration of other more complex on-chip optical logical devices with ultra-high stability, integration and much less power consumption. We believe such an optical diode could play the same basic role as the electrical diode in photonic circuit and its large-scale fabrication could be readily achieved by the well-developed CMOS techniques. The realization of high-performance on-chip optical diodes may open up a road toward photonic computers.

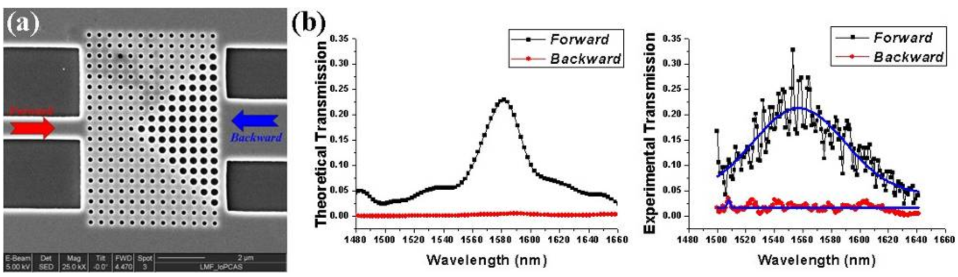

Fig. 1. (a) Scanning electron microscope images of the optimized optical diode system. (b) Theoretical (left) and experimental (right) transmission spectra of the optimized diode structure.

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Recent papers:

[1] C. M. Wang, Y. L. Tsai, S. H. Tu, C. C. Lee, C. H. Kuo, and J. Y. Chang, “Optical properties of light emitting diodes with a cascading plasmonic grating”, ***Opt. Express***, **18**, pp. 25608-25614 (2010)

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Multi-resonance Wavelength Using Asymmetric Plasmonic *T*-shaped Array

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In this study, an asymmetric plasmonic *T*-shaped array is proposed to present dual resonance wavelength. The structure under the *T*-shaped structure forms two metal-insulator-metal (*MIM*) cavities with different cavity length. Each cavity supports a specific resonance wavelength. A notch filter for second-harmonic generation (SHG) Nd:YAG laser is also proposed. The filter offers two resonance dips and low sideband. In addition, the filter properties are based on the localized surface plasmon (LSP). Therefore, the angle tolerance is extremely high. This makes the proposed structure easy to align. The proposed structure can be used in dual wavelength bio-sensing detection and dual wavelength thermal emission applications.

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Polymer chemistry and physics, Two-photon lithography, Photonics

Synthesis and Photoisomerization Properties of Azobenzene-functionalized Polymer Materials

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Due to the prominent photoresponse properties, azobenzene derivatives are demonstrated to have various applications in optical materials and devices, such as optical data storage, optical switching, polarization holography and nonlinear optics. In this study, we have investigated a facile route to prepare azobenzene-functionalized polymer materials and made preliminary attempts to introduce these photoresponse materials to photolithography. A series of polymerizable acryloyloxy-substituted azobenzene derivatives, 3-(*tert*-butyl)-4,4'-bisacryoloxy-azobenzene (tBu-Azo-AO), 3-(*tert*-butyl)-4,4'-bis[3-(acryoloxy)propoxy]-azobenzene (tBu-Azo-AO3) and 3-(*tert*-butyl)-4,4'-bis[6-(acryoloxy)hexyloxy]-azobenzene (tBu-Azo-AO6) were synthesized as monomers employed in the subsequent experiments. The preparation of photoactive polymer films were performed at 75 ℃ in the presence of 1.0 wt% of AIBN as initiator to copolymerize the azobenzene-monomer with dipentaerythritol hexaacrylate (DPE-6A) and methyl methacrylate (MMA) as crosslink agent and dilute monomer, respectively. UV-visible absorption spectra were characterized to monitor the *trans*-to-*cis* photoisomerization of the resultant polymer films. When exposed to a laser beam from Nd:YAG laser at the wavelength of 355 nm, the intensity of π-π* electronic transition absorption band of the polymer films gradually decreased with the prolonged of irradiation time, meanwhile, the intensity of the n-π* electronic transition absorption band increased, indicating the photo-induced *trans*-to-*cis* isomerization of azobenzene chromophores. By measuring the absorption dynamics of the π-π* electronic transition, the photoisomerization kinetics could be well fit by a double exponential function. The fact that the π-π* electronic transition absorbance did not follow a monoexponential decay as a theoretical result was probably caused by the aggregation of azobenzene molecules and complicated photo-induced behaviors of aggregates. These polymerizable azobenzene derivative monomers can also be doped into a photoresist which is appropriate for the fabrication of optical functional polymer micro-structures and devices by combining with two-photon polymerization (TPP) lithography technique.

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Gold nanoparticles surface plasmon resornance (SPR), fluorecence enhancement, enzyme detection

Recent papers:

[1] Z. H. Zeng, A. Torriero, A. M. Bond, and L. Spiccia, ***Chem. Eur. J.***, **16**, 9154 (2010).
[2] Z. H. Zeng, L. Spiccia, ***Chem. Eur. J.***, **15**, 12941 (2009).
[3] Z. H. Zeng, A. Torriero, M. J. Belousoff, A. M. Bond, and L. Spiccia, ***Chem. Eur. J.***, **15**, 10988 (2009).

Enzyme Triggered Gold Nanoparticle-enhanced Fluorescence of Near Infrared (NIR) Dye

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Near infrared (NIR) dyes, as fluorescence imaging, have become promising detection/sensing technology in medical diagnostics and biotechnology due to their deeper penetration and lower background of living system. However, the extensive application of NIR dyes is limited by their low fluorescence quantum yield. There have been recent reports in the use of metal enhanced fluorecence (MEF). Here, we reported that NIR dye (Cy5.5) fluorescence was enhanced using an enzyme (β-galactosidase) triggered modified gold nanoparticles surface plasmon resornance (SPR) change

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Recent papers:

[1] Shunping Zhang, et al. ***Phys. Rev. Lett***. **107**, 096801 (2011).
[2] Shunping Zhang, et al. ***Nano Lett***., **11** (4), 1657-1663 (2011).
[3] Zhipeng Li, et al. ***Small***, **7**(5), 593-596 (2011).

Chiral Surface Plasmon Polaritons on Metallic Nanowires

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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. The handedness and spatial extent of the helical periods of the chiral SPPs depend on the input polarization angle and nanowire diameter as well as the dielectric environment. Chirality is preserved in the free-space output wave, making a metallic nanowire a broad bandwidth subwavelength source of circular polarized photons.

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Recent papers:

[1] Lei Wang, Wei Cai, Yinxiao Xiang, Xinzheng Zhang, Jingjun Xu, and F. Javier Garcia de Abajo, "Reduced radiation losses in electron beam excited propagating plasmons", ***Opt. Exp.*** **19**(19) 18713-18720 (2011)

[2] Xinzheng Zhang, Jun Li, Fan Shi, Yan Xu, Zhenhua Wang, Romano A. Rupp, and Jingjun Xu, "Light-controllable coherent backscattering from water suspension of lithium niobate microcrystal particles", ***Opt. Lett***. **35**(11) 1746-1748 (2010)

[3] Xinzheng Zhang, Junqiao Wang, Baiquan Tang, Xinhui Tan, Romano A. Rupp, Leiting Pan, Yongfa Kong, Qian Sun, and Jingjun Xu, "Optical trapping and manipulation of metallic micro/nanoparticles via photorefractive crystals", ***Opt. Exp.*** **17**(12), 9981 (2009)

Tunable Terahertz Optical Antennas Based on Graphene Ring Structures

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Highly tunable optical antennas in teraherz range based on graphene ring structures are proposed, which employ graphene plasmons instead of traditional metallic plasmons. The plasmon resonances of the perfect graphene ring can be understood with the edge plasmons in graphene ribbons. While in the nonconcentric graphene ring, the multipolar plasmon modes appear and anti-symmetric mode splits due to symmetry breaking. Furthermore, the symmetric dipolar plasmon mode in a perfect graphene ring can concentrate electromagnetic field with an enhancement factor as large as 10^3 in terahertz waveband, which is almost 20 times larger than a gold ring with the same size.

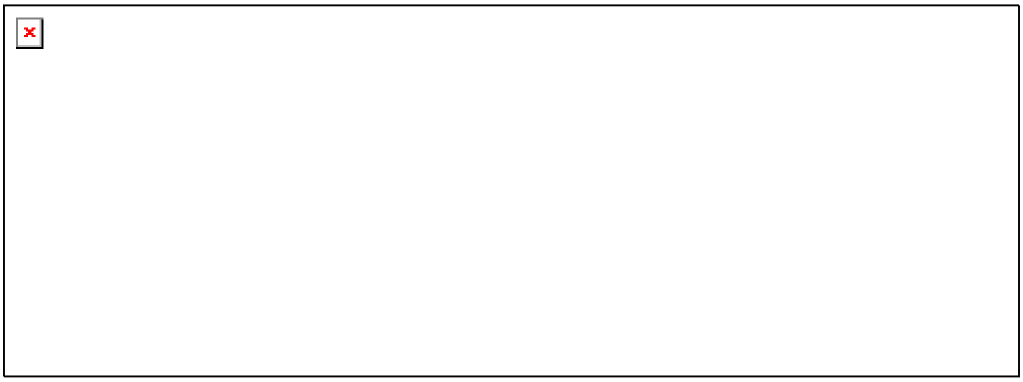

Fig. 1 Plasmon resonance in perfect graphene rings.

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Plasmonics, transformation optics

On the Geometry and Dynamics of Transformation Optics

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Recently the advent of electromagnetic metamaterials has opened up many new ways to control electromagnetic waves. Among various exciting applications with metamaterials, transformation optics [1] has proved a general method to design optical devices with novel properties, such as invisibility cloak and super lenses.

The theory of transformation optics is based on the formal invariance of the Maxwell equations under coordinate transformation. Analogous to the general relativity theory of gravity, the curved space from coordinate transformation in transformation optics is supposed to be a Riemannian manifold. We argue that the most general geometry of transformation optics is Riemann-Cartan geometry [2], where a new geometrical quantity $T^{\lambda}_{\mu\nu}$ arises as the anti-symmetric part of the affine connection. It is shown that nonholonomic coordinate transformation can produce nonzero torsion. Finally, we obtain the dynamical equation of spinning photons in such transformed media, where spin Hall effect of light result from spin-curvature and spin-torsion coupling is derived.

Reference:

[1] U. Leonhardt, and T. Philbin, "Geometry and Light: the Science of Invisibility", (Dover, NewYork, 2010).

[2] M. Nakahara, "Geometry, Topology and Physics", (IOP, 2003).

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[1] Zhenglong Zhang, Hairong Zheng, Meicen Liu, Han Zhang, Baoyin Yin, and Hongjun Zhang, ***J. Nanosci. Nanotechnol***. **11**, 9803-9807 (2011).
[2] Z. L. Zhang, H. R. Zheng, L. M. Xu, M. C. Liu, G. N. Liu, and S. X. Qu, ***Sci. China G***, **40**(3), 1-7 (2010).

Plasmon-assisted Reaction on Au Film

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The plasmon-assisted chemical reaction of 4-NBT dimerizing to DMAB on Au film in home-made instrument of high vacuum tip-enhanced Raman scattering (HV-TERS) is reported experimentally. Not only the Raman-actived modes, but also the IR-actived modes of DMAB were simultaneously observed experimentally, which due to the strong electric field gradient effect. Furthermore, the Fermi resonance was also obverted in HV-TERS.

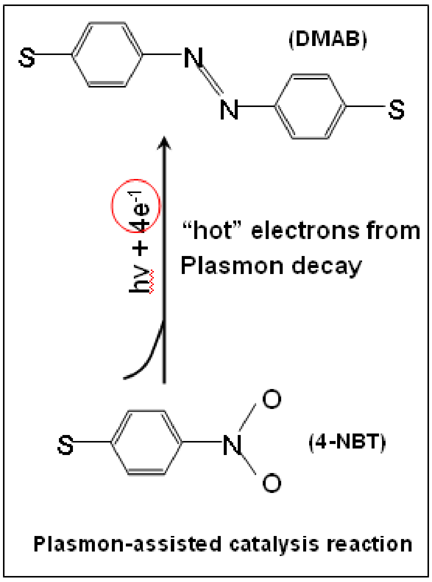

Fig. 1 Mechanism of plasmon-assisted reaction

The required 4e-1 are proposed to be "hot" electrons arising from the surface plasmon. The light quanta stored in the plasmons can be reemitted as light, and can also decay into an electron and a "hole". This hot electrons have high kinetic energy, which can presumably drive the surface-catalyzed reaction.

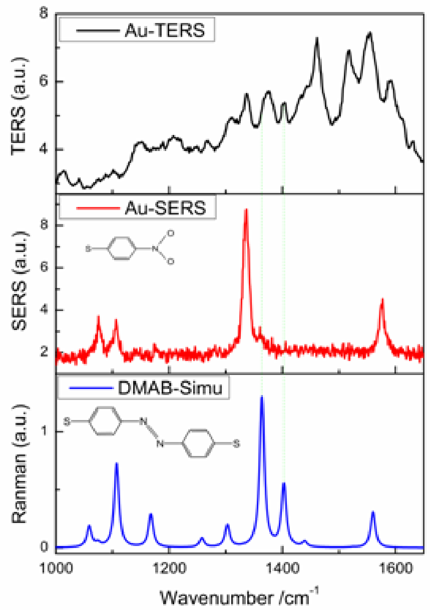

Fig. 2 Experiment and simulation

Figure 2(a) is the measured TERS spectrum of 4-NBT adsorbed on Au film. Compared with the SERS spectrum (b) of 4-NBT adsorbed on Au film and the simulation Raman spectrum (c) of DMAB, it was found that the TERS spectrum is significant different from the SERS spectrum, but is similar with the simulation Raman spectrum of DMAB. So, there may be a chemical reaction of 4-NBT dimerizing to DMAB in HV-TERS.

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Scientific Interests:

Biophotonics, Laser technology

Recent papers:

[1] M.-L. Zheng, K. Fujita*, W.-Q. Chen, X.-M. Duan* and S. Kawata, "Two-photon excited fluorescence and second-harmonic generation of the DAST organic nanocrystals", ***J. Phys. Chem. C***, **115**, 8988-8993 (2011).

[2] M.-L. Zheng*, K. Fujita*, W.-Q. Chen, N. I. Smith, X.-M. Duan and S. Kawata, "Comparison of staining selectivity for subcellular structures by carbazole-based cyanine probes in nonlinear optical microscopy", ***ChemBioChem***, **12**, 52-55 (2011).

[3] M.-L. Zheng, W.-Q. Chen, K. Fujita*, X.-M. Duan* and S. Kawata, "Dendrimer adjusted nanocrystals of DAST: organic crystal with enhanced nonlinear optical properties", ***Nanoscale*** **2**, 913-916 (2010).

Molecular Engineering of Carbazole-based Cyanine Probes for Combined Second-harmonic and Two-photon Fluorescence in Cellular Imaging

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Optical microscopy has been since long a truly enabling visualization technique in biological and biomedical sciences. Nonlinear optical (NLO) microscopy techniques enable us to reduce photodamage and increase the penetration depth due to a decrease in Rayleigh scattering. In addition, the nonlinear excitation is confined to a focused volume, decreasing phototoxicity and out-of-focus photobleaching. NLO microscopy can be based on phenomena like twophoton excited fluorescence (TPEF) and second-harmonic generation (SHG). TPEF is a third-order nonlinear optical effect that results in an opically confined fluorescence emmision. SHG is a second-order nonlinear optical effect only observed in non-centrosymmetric structures. While chromophores in general can be excited through TPEF, non-centrosymmetrical arrangements of non-centrosymmetric chromophores are needed for observing an efficient SHG signal. Design strategies towards chromophores for combined TPEF and SHG should combine function and form requirements.

A series of chromophores with enhanced second- and third-order nonlinear optical properties were engineered for use in combined second-harmonic and two-photon fluorescence microscopy. Electron accepting moieties imparted the nonlinear optical properties of the chromophores. The electron-rich carbazole core served as a template towards one-dimensional or two-dimensional chromophores. More efficient acceptor groups on the carbazole donor core resulted in improved second- and third-order nonlinear optical properties. A selection of these chromophores was tested in a cellular environment with a multimodal multiphoton microscope. The structural differences of the chromophores resulted in high selectivity for mitochondria or the nucleus in two-photon fluorescence and ranging from no signal to high selectivity for mitochondria in the SHG channel. This study provides a good prospect for the applicability of the markers in tissue, as well as in live animal bioimaging.

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B.S. 2010, Chinese Agricultural University

Scientific Interests:

Bioimaging, Organic synthesis, Biophotonics.

Synthesis and Bioimaging of Carbazole Based Cyanine Probes for Living Cells and C. Elegans

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Imaging of chemical and biological systems based on various optical microscopies is a subject of wide interest. Fluorescence probes are powerful tools for investigating molecular behavior in living tissues and cells. Along with the development of fluorescent probes, microscopy techniques are being rapidly developed for imaging biological samples. Cofocal microscopy creates sharp images which have better contrast than that of a conventional microscope of a specimen. However, the development of fluorescence probes for selectively staining in living cells and C. elegans is still challenging. Therefore, it is of significance to design and synthesize the optimized fluorescent probes.

In this study, we have designed and synthesized one and two dimensional (1D and 2D) carbazole based cyanine probes, in which methyl pyridinium used as acceptor group. The chemical structures of the compounds were confirmed by ^{1}H-NMR. The optical properties were characterized by UV/Vis spectrophotometer and fluorescence photometer. Furthermore, we have applied these probes into selective staining of living cells and Caenorhabditis elegans and observed by confocal microscopy.

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Recent papers:

[1] X. L. Zhong, Z. Y. Li, C. Wang, and Y. S. Zhou, ***J. Appl. Phys.***, **109**, 093115 (2011).

[2] X. L. Zhong, and Z. Y. Li. "Plasmon enhanced light amplification in metal-insulator-metal waveguides with gain", (Submitted), 2012.

[3] X. L. Zhong, Z. Y. Li, Z. M. Meng, and Y. S. Zhou. "Mode analysis for periodically modulated metal slits", (Submitted), 2012.

Plasmon Enhanced Light Amplification in Metal-insulator-metal Waveguides with Gain

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We study plasmon enhanced loss compensation and light amplification properties of metal-insulator-metal (MIM) waveguides with gain. An analytical approach based on Maxwell's equations is developed to evaluate quantitatively the influence of gain coefficient on the loss compensation and light amplification efficiencies of the waveguide under different values of the waveguide width and working wavelengths. The analytical results agree excellently with all-numerical calculations that directly solve Maxwell's equations. The results show that the light amplification efficiency obeys a strict linear relationship with the gain coefficient, and MIM waveguides with narrower width and under shorter wavelengths have better efficiencies. In addition, the MIM waveguides have higher light amplification efficiencies than usual dielectric waveguides, which suggests a very positive role of plasmonic structure in enhancing light amplification when gain is introduced. These loss and gain behaviors can be well explained by looking at the modal profile of each transport mode and the corresponding light energy confinement effect and slow light effect.

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Recent papers:

[1] Y. Zhao, W. Wang, F. Wu, Y. Zhou, N. Huang, Y. Gu, Q. Zou, W. Yang, "Polyethylene glycol-functionalized benzylidene cyclopentanone dyes for two-photon excited photodynamic therapy", ***Org. Biomol. Chem.***, **9**, 4168-4175 (2011).

[2] J. Xue, Y. Zhao, F. Wu, D. Fang, "Effect of bridging position on the two-photon polymerization initiating efficiencies of novel coumarin/benzylidene cyclopantanone dyes", ***J. Phys. Chem. A***, **114**, 5171-5179 (2010).

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Two-photon Photodynamic Activity of Water-soluble Benzylidene Cyclopentanone Dyes

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Two-Photon Excited Photodynamic Therapy (TPE-PDT) is a novel phototherapy technology [1-3], which attracts much attention in recent years due to its advantages of deep biological tissue penetration and highly-selective targeting damage. Conventional clinical PDT drugs were used in early TPE-PDT studies. However, their two-photon absorption cross-section (σ) values were too small to be suitable clinically [3, 4]. In last decade, a great number of compounds with large σ values were reported. However, most of them are hydrophobic, can not be used as photosensitizer directly for TPE-PDT [5]. Benzylidene cyclopentanone dyes have high photosensitization activity and large two-photon absorption (TPA) cross-section in near infrared region [6, 7]. To explore their application potentials in TPE-PDT, in this work a series of water-soluble benzylidene cyclopentanone dyes were synthesized by introducing polyethylene glycol (PEG) or carboxylate groups. Their linear and nonlinear photophysical properties, reactive oxygen yields and *in vitro* PDT activity were investigated systematically. The results showed that the TPA capability of dyes could maintain as before while the water solubility of dyes could be significantly enhanced after modified by water-soluble groups. Only dyes exhibiting moderate water-lipid amphipathy presented strong PDT activity to human rectal cancer 1116 cells. Their PDT mechanism involved both Type I (generation of superoxide radical, $O_2^{-\bullet}$) and Type II (generation of singlet oxygen $^1O_2$) processes. These amphiphilic dyes have potential as novel PDT agents.

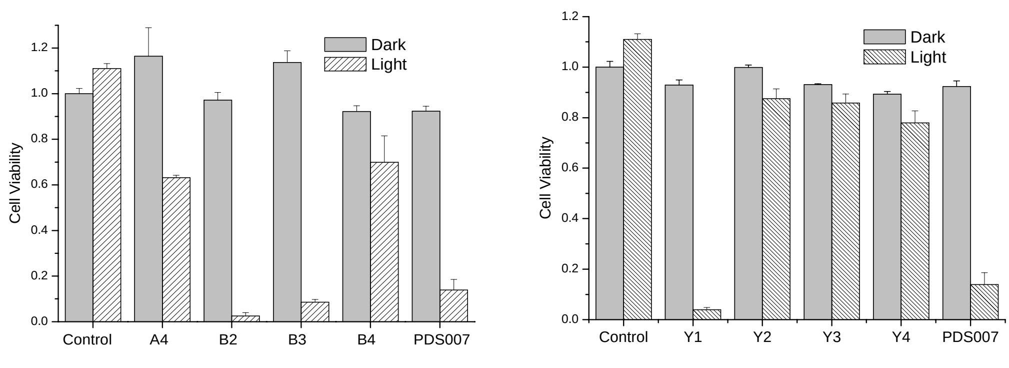

Fig. 1 Dark cytotoxicity (dark) and photocytotoxicity (light) of dyes toward HEC-1116 cells using CCK-8 assay. The error bars denote standard deviation from three replicates. Dyes were dissolved in PBS before injected into culture medium. PDS007 is a clinically available dye.

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<u>Recent papers</u> :

1 "Plasmon Emission Biosensing by a Single Gold Nanorod", submitted to *JACS*;
2 "Anisotropic Plasmonic Sensing of Individual or Coupled Gold Nanorods", *Journal of Physical Chemistry C*;
3 "Fluorescence correlation spectroscopy near individual gold nanoparticle", *Chemical Physics Letter*;

Anisotropic Plasmonic Sensing Ability of Individual or Coupled Gold Nanorods

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ABSTRACT

We perform a theoretical investigation of individual and coupled gold nanorods as plasmonic nanosensors using the finite-difference time-domain method. Key features of single-nanorod sensors are discussed. The sensitivity distribution of an individual nanorod is anisotropic. The characteristic sensitivity decay length of a single-nanorod sensor is comparable to its diameter. Plasmonic sensing abilities are additive, so analyte-detection sensitivity is not affected by substrates or surface treatments; shifts caused by analytes are only determined by their positions relative to the sensor. Coupled nanorods enhance and concentrate plasmonic sensitivities, and the sensitivity within the gap can be over an order of magnitude higher than that at the nanorod cylinder. The sensitivities of coupled nanorods are only higher than those of individual nanorods when the analytes are anchored within the gaps between nanorods. The calculations show that a single biological molecule can be detected by optimizing nanostructure design and surface treatments to anchor analytes locally on high-sensitivity areas of the sensor surface. Our simulation results assist the design and optimization of plasmonic nanosensors, using single or coupled nanorods.

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Plasmonic-Enhanced Molecular Fluorescence within Isolated Bowtie Nano-Apertures

Guowei Lu, Wenqiang Li (ACS nano)

Plasmonic-Enhanced Molecular Fluorescence within Isolated Bowtie Nano-Apertures

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ABSTRACT :

We report experimental behaviors of polarization-dependent, plasmonic-enhanced molecular fluorescence within isolated bowtie nano-apertures (BNAs) milled in aluminum films. BNAs provide efficient control of the fluorescent count rate per molecule and the decay lifetime of the molecules and provide an effective detection volume at the nanometer scale by tuning either the excitation light polarization or the BNA size. Interestingly, large BNAs (>300 nm) present high plasmonic-enhanced fluorescence efficiency and can simultaneously confine the detection volume below the subdiffraction limit. Numerical simulations were performed that agreed qualitatively with the experimental results. The BNAs have potential applications, especially for single-molecule biological analysis.

Fluorescence correlation spectroscopy near individual gold nanoparticle

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ABSTRACT

Dynamic behavior of fluorescent molecules near an individual gold nanoparticle is investigated experimentally by fluorescence correlation spectroscopy method. The gold particle that acts as an optical nano-antenna presents significant near-field volume reduction. The single molecule diffusion behavior is clearly observed within a reduced near-field volume due to a highly localized field enhancement. The near-field volume and fluorescence enhancement are polarization and concentration dependent and strongly depend on the properties of the gold nanoparticle. A simple approximated model is developed to fit the FCS autocorrelation curves. In principle, the single molecule analysis within the near-field volume of nanostructures could be applied to the analysis of biological membranes and intracellular processes.

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Recent papers :

Lu, G.; Zhang, T.; Li, W.; Hou, L.; Liu, J.; Gong, Q. *J. Phys. Chem. C* **2011**, *115*, 15822-15828

Single Molecule Spontaneous Emission in the Vicinity of Individual Gold Nanorod

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ABSTRACT

Individual gold nanorod as an optical antenna to modulate single molecule fluorescence spontaneous emission behaviors is investigated theoretically. Two- and three-dimensional numerical Finite-Difference Timed-Domain method (FDTD) are implemented to investigate the changes of the excitation rates, spontaneous emission rates, quantum efficiency, and emission spectra shape as a function of the separation between the emitter and nanorod. Our simulations reveal that the three-dimensional relative configuration between the gold nanorod and single dipole definitely influences on the quantum efficiency and the emission spectra shape. And the dipole orientation and the excitation light polarization are also investigated to understand the polarization dependence of the plasmonic enhanced fluorescence.

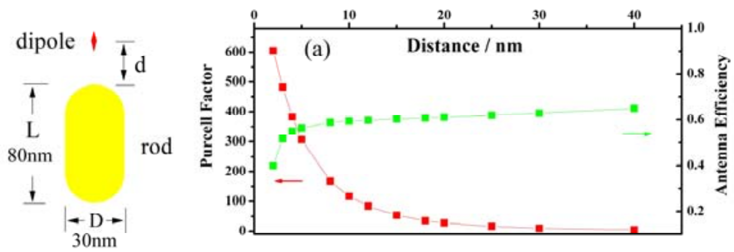

Figure.1 Purcell factor F (red) and Antenna efficiency (green) for an emitter coupled to a nanorod at various distances

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