G Plasmonics and Applications

ICMAT 2009

International Conference on Materials for Advanced Technologies 2009

AND

INTERNATIONAL UNION OF MATERIALS RESEARCH SOCIETIES

IUMRS - ICA 2009

International Union of Materials Research Societies- International Conference in Asia 2009

28 June - 3 July 2009, Singapore

Suntec Singapore International Convention & Exhibition Centre

www.mrs.org.sg

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Symposium G

Plasmonics and Applications

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Scope of Symposium

There is a growing interest in the sub-wavelength control and manipulation of electromagnetic energy at optical frequencies (nano-photonics). A rapidly expanding branch of this field, plasmonics, aims at harnessing the unique properties of surface plasmon polaritons (SPPs) to miniaturize optical components to the nanoscopic dimensions of their electronic counterparts. Metallic nanostructures can also be fabricated to concentrate and locally enhance the electromagnetic fields by orders of magnitude. This effect is achieved by either engineering the metallic nanostructures to function as optical antennas or by controlling the illumination conditions to launch SPPs at a metal-vacuum or metal-dielectric interface. The potential applications of these phenomena span many disciplines and include high speed nano-scale interconnects, meta-materials, chemical and biological sensing, sub-wavelength optics and waveguides, near-field optical trapping, high-density data storage, and the enhancement of non-linear effects.

Symposium Topics

- Surface Plasmon Polaritons
- Imaging techniques of surface plasmon-polaritons
- 2D optics on metallic films
- Non-linear interactions in metals
- Stimulated light or electron emission by surface plasmons
- Computational electromagnetics for plasmonics
- Surface plasmon polariton band-gap structures
- Surface plasmon wave guide structures
- Resonant optical structures: both optical antennas and enhanced transmission apertures
- Applications of surface plasmons in IC interconnects, high density data storage and sensing applications

Contents

Abstracts

A00020-00470

Laser Fabrication of Nonlinear and Metallic Photonic Nanostructures

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We present our investigations into the fabrication by direct laser writing of photonic structures using organic-inorganic hybrid materials that have (i) nonlinear optical properties, (ii) can be selectively covered with metal.

Direct laser writing by two photon polymerization (2PP) is a nonlinear optical technique which allows the fabrication of three-dimensional (3D) structures with a resolution beyond the diffraction limit. The polymerization process is initiated when the beam of an ultra-fast infrared laser is tightly focused into the volume of a transparent, photosensitive material. Two-photon absorption takes place within the focal volume; by moving the focused laser beam in a three-dimensional manner within the resin, fully 3D structures can be fabricated. The technique has been employed successfully in the fabrication of nano-photonic structures and devices.

Here, we present our most recent work into the structuring by two photon polymerization of a series of hybrid organic-inorganic materials. These materials fall into the following two categories:

(i) Silicon oxide-based sol-gels where a nonlinear optical molecule has been chemically bound onto the photopolymer, enabling the dynamic tuning of the optical properties of the fabricated structures. The sol-gels investigated are materials with second and third-order optical nonlinearity. Examples include plasmonic waveguides and three-dimensional photonic crystals incorporating the nonlinear optical molecules N-(4-nitrophenyl)-(L)-prolinol (NPP) and Disperse Red 1, respectively.

(ii) Composite sol-gels with metal binding affinity. These materials contain metal binding groups and can therefore be readily metalized with silver and other metals by simple immersion in a metal bath, without the need to modify the surface of the structures or to use other, complementary techniques. They can be structured accurately with sub-100nm resolution, and the metal coating achieved is uniform and without blemishes.

The combination of direct laser writing with specially designed, functional materials can lead to advanced applications in photonics, plasmonics and metamaterials.

A00058-00108

Making Plasmonic Structures via Lithography and Imprint

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Different lithographical approaches will be discussed for realization of plasmonic components and optical metamaterials. For applications in integrated optical systems, large-scale photolithography-based fabrication of low-loss long-range surface plasmon polariton (SPP) waveguides and waveguide components will be reported. Profiled metal surfaces (V-grooves and wedges) used as plasmonic waveguides with subwavelength confinement will also be discussed. For plasmonic waveguides, nano-imprint-based fabrication techniques that offer mass-production compatibility and wafer-scale parallel fabrication of plasmonic components will be presented. Electron-beam-lithography based fabrication of different arrangements of surface nanoscatterers for efficient in-plane manipulation of SPPs will also be outlined. Controlled fabrication of metal nanoparticles will be discussed for optical nanoanten-nae realization.

A00114-00716

Long-range Surface Plasmon on Thin Plasma Film with Launching Current Flows

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Surface plasmas waves (SPWs) are the coherent fluctuations of the electron charges at the plasma-dielectric interface. SPWs can be excited by the incident light through the attenuated total reflection (ATR) configurations. In this work, the surface plasma waves (SPWs) on thin plasma film with launching constant current flows are investigated via computer simulation and theoretic analysis. The long-range SPWs in the plasma film are excited by ATR setup. The particle-in-cell finite-difference time-domain (PIC-FDTD) model is utilized to simulate the motion of the plasma with constant currents and its response to incident radiation. The dispersion relations of SPWs in the plasma

film with constant currents are also derived and analyzed. Our simulation results exhibit that the SPWs will cause the electron bunch and then modulate the DC current in the plasma. With proper output designing, the modulated current will re-emit amplified electromagnetic radiation with the same frequency as the incident light. The power of amplified EM radiation is extracted from the DC current beam in the plasma. These phenomena will be useful for designing new active plasmonics devices.

A00114-00717

Plasmonic Transistor Based on Resonant Tunneling Effects Caused by Surface Plasmon Excitations

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Surface plasmons (SPs) are the coherent fluctuations of the electron charges at the metal-dielectric interface. The phenomenon of resonant tunneling through thin metal films with periodic grooves is attributed to excitation of standing waves of coupled SPs in the grooves on two opposite surfaces. In this work, the plasmonic transistor based on the resonant tunneling in the main groove by adjusting the relative permittivity of the material filling in the side grooves is proposed and studied via computer simulation and theoretic analysis. A p-polarized plane wave is normally incident into a silver film with periodic grooves on film's both surfaces. The finite-difference time-domain method with the Drude dispersion model is utilized in this simulation.

Our simulation results exhibit that the local near-field emitted power is increased as relative permittivity in the side grooves increases and approximates to a saturated value finally. The increase in distance between two adjacent grooves and numbers of filled side grooves also increases the value of enhancement. The observed local emitted power enhancement is attributed to the enhancement of entranced power in the main groove and re-emits to the other side. These phenomena will be useful for designing new plasmonic transistor.

A00162-00354

Surface Plasmon Differential Imaging for Sensing Applications

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Surface Plasmon Resonance (SPR) has been utilised in various forms in sensors for many years. It is usually based on angular or wavelength interrogation of the reflectivity minimum found with Transverse Magnetic (TM) light. However for a flat metal surface the SPR is traversed there is also a very rapid change in the phase of only the reflected TM light; there being no such change in the Transverse Electric (TE) light. Recently a new SPR sensor has been developed that exploits this rapid change in optical phase difference.

Linearly polarised light of mixed TM and TE polarisation, from a high intensity LED is passed through a polarization modulator, which adds a small amplitude 47 kHz modulation to the polarisation. This modulated light is incident on a gold film ~50 nm thick evaporated onto the base of a SF2 prism in the Kretschmann-Raether, configuration. The coupling of the TM polarised light to the SPR is dependant on the properties of the dielectric medium adjacent to the gold film. The SPR shifts when this sensed medium undergoes a change in refractive index (or if it is a bound analyte layer index or thickness). This in turn causes a change in the reflected elliptically polarised light. The change of the resultant modulated polarisation 'dither' is interrogated through the use of a phase sensitive camera (64 by 64 pixels) fabricated with the equivalent of a lock in amplifier on each of the 4096 pixels. The spatial map of the modulation amplitude gives an optical phase differential image. By imaging the SPR in this way it is possible to produce a multi channel differential sensor capable of analysing changes within a large bio-addressable array. An number of pixels on the camera may also be used as reference pixels to allow compensation for the effects of pressure and temperature variations which change the index of the sensed media and which may otherwise mask the desired signals.

A00210-00498

Surface Plasmon Resonance Sensing of Two-dimensional Metallic Nanoparticle Arrays

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We demonstrate the fabrication of two-dimensional (2D) structures of metal nanoparticles for surface plasmon resonance (SPR) detection. Resonance peak modes for different polarized incident light have been observed. The extraordinary optical transmission (EOT) phenomenon through nanohole arrays was first studied a decade ago. The transmission peak of the EOT of sub-wavelength metal structures corresponds to the resonant frequency of the surface plasmon polaritons (SPPs). SPPs are electromagnetic excitations generated by strong interaction between electromagnetic field and free electron oscillations at a metal-dielectric interface. Furthermore, the excitation and radiation of SPPs are highly geometry dependent, which means different sizes and shapes lead to different resonances. They have attracted considerable attention because of their potential applications in photonics, wave guiding and biochemical sensing. The transmission of light can be improved dramatically by introducing grooves or hole arrays into metallic films. Surface plasmon modes will interact on both sides of the metal film when it is thin enough.

In this work, the metallic arrays were obtained by coating thin Au or Ag metal films by electron-beam evaporation on 2D dielectric arrays patterned by laser holography. All arrays have square structure with period a=260 nm and radius r=65 nm. The thickness t varies from 30 nm to 100 nm. To characterize the fabricated nanostructures, the transmission spectra of white light through different patterns were measured. The shift in the SPR is associated with the changes in metal thickness and pattern shape. The intensity changes could be separated from the changes coming from the SPR shift provoked by surface modification. In particular, the resonance energy and field pattern can be manipulated independently by changing the geometry of arrays.

A00213-02230

Surface Plasmon Enhancement of Thin-Film Amorphous Silicon Solar Cells

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At the present, thin-film solar cells are considered as a main and low-cost alternative to conventional wafer-based cells. However, due to relatively poor light absorption of thin-films, they require more efficient mechanisms of light trapping for high performance. Usual methods like surface texturing used in wafer-based cells for light trapping cannot be applied to thin-film cells: micron texturing has a relatively large size, while submicron surface texturing inevitably increases the surface area and hence the minority carrier recombination on the surface. A promising way, which emerged recently, is to make use of the plasmonic behavior of metals.

Recent experimental studies on both organic and inorganic solar cells have shown that performance of thin-film cells can be improved significantly by metallic nanoparticles deposited onto the photoactive layer. The enhanced scattering from the metallic nanoparticles caused by excitation of surface plasmons can strongly influence the light trapping changing the optical absorption in thin-film cells. It makes plasmonic nanoparticles a very efficient and flexible tool for solar cell application to manipulate the light trapping and thus, enhance power conversion efficiency.

In this work, we conduct a systematic research on the plasmonic enhancement of thin-film amorphous silicon cells. Based on predictive numerical modeling, we discuss how the surface charges induced on metallic nanoparticles, as well as dispersive effects, contribute to the enhanced optical absorption in the photoactive layer. Finally, we summarize how one can optimize optical absorption (with the proper adjustment of the nanoparticle parameters) and make plasmon-enhanced thin-film amorphous silicon solar cells a cheap and efficient source of renewable energy.

A00218-00707

Self-Assembled, Nanoscaled Metal Structures for Surface Enhanced Raman Spectroscopy

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The wealth of molecular information provided by surface enhanced Raman spectroscopy (SERS) makes it ideally suited for advanced sensing and detection applications. Under proper conditions, SERS enhancements can be on the order of 1015 and in many cases begin to approach sensitivity of single molecule level. Recent approaches to fabricating SERS active substrates include nanoparticle aggregates, lithographically defined particle arrays, as well as electrochemically roughened electrodes, among others. While the exact mechanism responsible for efficient SERS enhancement is convoluted between several factors (electromagnetic, chemical, etc.), a common trait among these systems is the need for a well defined plasmon response that is associated with their nanoscale metallic surface features. Achieving this level of control over the SERS surface is often a compromise between easily fabricated regular arrays that have marginal enhancements and randomly generated surfaces that have large enhancements but very little synthetic control. For example, aggregated metallic nanoparticles produce extremely large SERS enhancements. However, the reproducibility from aggregate to aggregate is often suspect and the dynamic nature of individual aggregate architectures has limited their applicability in biosensing applications. Our work involves expanding the field of effective SERS substrates through a variety of surface based self assembly and nanoparticle synthetic techniques. This talk will focus on our recent advances in polyaniline based silver substrates which can be used to generate a wide variety of nanostructured silver features that are shown to be highly SERS active. This conducting polymer is capable of reducing aqueous silver ion solutions over large areas and gives a highly reproducible homogeneous SERS signal. Using these nanostructured substrates as a template, we engineer higher order nanoparticle and nanoshell based assemblies to produce 3-D SERS substrates with enhanced and tunable capabilities afforded by the plasmon resonance of the adsorbed particles. These materials are demonstrated in model biosensing applications to have potential for next generation sensor capacities.

A00237-00436

Plasma for Plasmonics

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This contribution highlights the intrinsic links between the plasma and the rapidly emerging field of plasmonics, in particular, nanoplasmonics. The most obvious link is commonly understood through the plasmon resonances that are widely used to control the interaction of electromagnetic waves with the surface. These interactions make it possible to bridge the photonic and micro/nanoelectronic device platforms. Given that low-temperature plasma-based nanofabrication is the key, multi-billion-dollar manufacturing platform in micro/nanoelectronics, would not that sound reasonable to base the production of nanoplasmonic functionalities and devices on the merged, nanoplasmonic-nanoelectronic platform and use the existing pool of plasma-based facilities? This common nanofabrication platform may eventually enable a reliable and commercially-viable synergy of the two fields. This presentation discusses the main advances, challenges and unresolved issues related to this possibility. It gives an overview of fundamental and applied research within the International Research Network on Deterministic Plasma-Aided Nanofabrication, which is relevant to the synthesis and applications of various micro/nanoscale systems for applications in plasmonics and related fields. The main focus of this presentation is on the various possibilities offered by the plasma-assisted nanofabrication techniques to create ordered arrays of nanoparticles of various sizes, shapes and dimensionalities that can be used to control the interaction of light with the underlying functional layers. One of the greatest challenges in present-day nanofabrication is to enable highly-controlled synthesis of self-organized arrays of quantum dots and nanoparticles with precisely tailored spatial arrangements, without the use of any pattern delineation and templates. Here we show various approaches to achieve this goal by capitalizing on numerous electric field/charge and other effects intrinsic to the synthesis processes that involve ionized gas environments or ion fluxes. We also show the applications of such nanostructure arrays in solar cell devices of the third generation and nanoparticle-enhanced solar cells and discuss the results related to the optimization of light absorption in the functional layers of the solar cells through the fabrication-related adjustment of the resonance plasmonic effects in the nanoparticles. Finally, we summarize why various plasma-related approaches and effects are very critical to meet the continuously rising demands of nanoplasmonics and related fields.

A00404-00785

Surface Enhanced Raman Scattering Observation on Metal Nanobowls

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Surface-enhanced Raman scattering (SERS) has gained much attentions owing to the remarkable capability of single molecule SERS detection and the explosion of interest in nanophotonics and plasmonics. Many attempts have been made to fabricate reproducible and cheap SERS-active metallic substrates, including fabrication of periodic arrays of metal nanoparticles, nanoring structures and crescent moon structures via nanosphere lithography (NSL), individual nanocube and nanorice via galvanic replacement reaction. In this study, we report on the SERS observation from both Au and Ag nanobowls which can be promising candidates for efficient SERS-active metallic substrates as well as for applications in nanophotonics and plasmonics.

Interconnected metal nanobowl arrays were fabricated by the NSL method. One-micron-thick photoresist was inserted between metal coated PS monolayer and original substrate to facilitate the flip-over and transform the metal coated PS monolayer onto a new substrate. After removing the PS via ultrasonication in chloroform, the half-spherically free standing metal bowls are formed, with the bowl mouth size of about 1 um and wall thickness of 30 nm.

A green laser (532 nm) was used as excitation source to induce the amplified scattering field on Au and Ag nanobowls. Broad photoluminescence (PL) intensity varies with the bowl morphology. The strongest PL occurs at the rim of nanobowls. The bowl rim has the features of both ring-shaped nanostructure and nanotips of 30 nm (in cross sectional view) leading to the local electromagnetic field enhancement. The experimental results indicate that the orientations of enhancement are parallel to incident laser polarizations for both individual and arrays of Au nanobowl, which agrees well with the simulation results. Therefore we can control the locality of electromagnetic enhancement on nanobowls by tuning incident laser polarization.

SERS activity of crystal violet (CV) molecules, rhodamine 6G (R6G) molecules and brilliant cresyl blue (BCB) molecules were detected on both Ag and Au nanobowl substrates. The detected SERS signals at bowl rims are much stronger than at inner bowl areas, which confirm that localized surface plasmon resonance (LSPR) mainly originates from electromagnetic coupling of inner and outer surfaces of bowl walls.

In conclusion, metal nanobowls have shown their SERS capability to detect different species of molecules. Such method makes the detection of molecules more efficient and easier, and can be extended to fabricate versatile SERS-active substrates by accurately tuning the size, shape, wall thickness and interspacing of the nanobowls.

A00413-00794

Transforming Light and Cloaking with Photonic Metamaterials

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We review recent progress in developing metamaterials for the optical part of the spectrum as well as the new emerging field of transformation optics. A new paradigm of engineering space for light with transformation optics and its applications for cloaking and "super-imaging" will be also discussed.

A00433-00817

Transmission Properties in Metamaterials Structures:Zero Equivalent Index and Point Defect Effects

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Metamaterial has been demonstrated and applied in fabricating novel structures such as super lens, invisible cloaking and perfect absorber. The existence of a metamaterial layer in a stack consists of positive index material can result in a zero refractive index stack, which is also interesting in both physics and technology points of view. The stacking of negative index material and positive index material, where the impedances of negative index slab and positive index slab are matched, was manipulated so that the favorable outcome will be a zero equivalent index material with equivalent impedance different from zero. The reflection coefficient was zero at 90 degree incident angle, hence no reflection, and the calculated transmission is unity. Simulation demonstrates that there is no phase change and the wave propagates smoothly through the stack and the interfaces between slabs. Another kind of perfect absorber is also proposed by composing the 3-slab structure into the diffraction multi slits. Simulations show there are no back-scattering wave and transmitted wave.

In the last part, the Double Negative Index (DNG) spheres were employed to investigate the transmission properties. Spheres were laid in air and filled with DNG materials. The full-wave simulation was done to retrieve S-parameter and to confirm the theory. Finally, point defects were introduced into the unit-cell, and its coupling effect was investigated.

A00543-02401

Characterization of Surface Plasmon-Like Modes in Metallic Photonic Crystals

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The author investigates surface plasmon-like modes in metallic photonic crystals made of periodic arrays of perfect metal cylinders. A certain number of rectangular grooves, basically on the subwavelength scale, are milled on the cylinder surface. In this configuration, the subwavelength grooves are responsible for the existence of surface plasmon-like modes on a perfect metal structure. Basic features of surface plasmon-like modes are either manifest or implied in the dispersion characteristics. For photonic crystals with a delicate substructure, the dispersion relations can be efficiently solved by the inverse iteration method.

The existence of surface plasmon-like modes is manifest on the dispersion characteristics in two aspects. First, a large number of collective modes appear and gather around an asymptotic frequency for TE polarization, which possess similar features of real surface plasmons that occur in plasmonic structures. Second, the typical resonant modes exhibit a highly localized field distribution within the grooves, outside which the field amplitudes are rapidly decayed. This is another distinguished feature of surface plasmons. In particular, the magnetic fields in each groove retain a similar pattern, which is analogous to TE$_{n0}$ mode of an open-ended waveguide. The respective cutoff frequency serves as the role of asymptotic frequency for surface plasmon-like modes.

A00738-01308

Gold Nanoarray on Colloidal Template by Glancing Deposition for Localized Surface Plasmon Resonance

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Metallic nanoparticles and nanostructured metals that support localized electromagnetic resonances or propagating surface plasmons are becoming extremely important structures for subwavelength optics, and this rapidly emerging field is known as plasmonics. Both chemical and mechanical fabrication techniques have been successfully used to create plasmonic nanostructures, and their applications include chemical and biological sensing, plasmonic waveguiding, sub-diffraction-limited focusing for imaging and the development of negative index materials. This paper presents a method to fabricate gold nanoarrays for localized surface plasmon resonance (LSPR), which is a plasmonic chemical or biological sensor yields high sensitivity based on optical refractive index variation. For fabricating the gold nanoarray, a layer of closely packed nanospheres is used as a colloidal template, and the gold is obliquely deposited onto the template at a large angle of 85-89.5°. As the nanospheres shading each other, only a nanotriangle or a nanoband is deposited on each nanosphere and forms a nanoarray for LSPR sensing. The profile of these nanostructures is related to the gold deposition angles and is 3D simulated by software. The profile simulation consists with the fabricated gold nanostructures observed under scanning electron microscope, and can be used to control the gold deposition parameters. Two sensing experiments, liquid media of different refractive indices and layer-by-layer of a few nanometer thick polymer films, are carried out to demonstrate the LSPR sensing of these gold nanostructures, and good sensitivities are achieved in both experiments. This paper for the first time employs the gold nanostructures fabricated by glancing deposition for LSPR sensing; for the first time realized their 3D profile simulation, thus paves the way to fabricating a novel and cost-effective LSPR sensing chip.

A00773-01962

Design and Analysis of Voltage Controllable Metal-Insulator-Metal Waveguide Plasmonic Bragg Reflector

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A metal-insulator-metal (MIM) waveguide, in which the insulator has periodic change of dielectric materials, is proposed to realize voltage controllable one-dimensional plasmonic Bragg reflector. $KNbO_3$ is used as portion of the dielectric materials so that the refractive index of the insulator layer can be varied by external applied voltage. In our analysis, transfer matrix method (TMM) is employed to design and optimize the transmission spectra of the MIM waveguide Bragg reflector. With proper design of the MIM waveguides, it can be shown that the corresponding reflectivity at the on- (bias voltage of 100 V) and off- (zero bias voltage) states to be > 90 % and < 7 % respectively for the operating wavelength of 1.5 μm. The results are also verified by finite-difference time-domain method. Furthermore, the modulation response of the MIM waveguide was studied. For the insulator layer with area and average thickness to be 10 μm X 10 μm and 215 nm respectively, the −3dB bandwidth is found to be about 160 GHz. In addition, the turn-on reflectivity of the waveguide is only slightly reduced to 80% at the −3dB point when compared to its steady-state performance.

A00784-02265

Ultrafast Resonant Higher-Order Optical Nonlinearities of Silver Nanoplatelet Colloids

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Materials possessing fast optical nonlinearities are required for limiting, switching and computing applications. Metal nanoparticles show large nonlinearities even though the bulk metal nonlinearity is low. This increase in nonlinearity is due to local field enhancement near the surface plasmon resonance (SPR) of the metal nanoparticle. Higher-order nonlinearities depend on higher powers of local fields enhancement factors, hence are expected to be enhanced much more around the SPR. Additionally nonspherical particles are expected to show higher field enhancements compared to that of spherical nanoparticles. Earlier nonresonant higher-order nonlinearities in silver metal nanospheres were measured using z-scan. We report measurement of the imaginary part of third, fifth and seventh-order susceptibilities of silver nanoplatelets in water. These values were deduced from transient absorption data obtained using conventional pump-probe technique. Silver nanoplatelets in water was prepared using wet chemical technique. The average diameter and average thickness of the nanoplatelets estimated from TEM measurements is 49 nm and 7 nm respectively. The in-plane dipole resonance of the nanoplatelet is at 804 nm. Transient absorption measurements were done using a 190 fs, 82 MHz Ti:Sapphire laser at 778 nm which is close to the in-plane peak of the nanoplatelets. The change in absorption ($\Delta\alpha$) of the colloid was measured as a function of delay between pump and probe at different peak intensities of the pump beam (I_p). The absorption shows an initial fast decrease which recovers almost completely within the next 10 ps. For I_p less than 0.4 MW mm^{-2} the peak value of $\Delta\alpha$ varies linearly with I_p. For intensities higher than 0.4 MW mm^{-2} the peak value of $\Delta\alpha$ is nonlinear with I_p. For the entire range of intensities used in the experiment the value of $\Delta\alpha$ fits well to a third order polynomial in I_p. This dependence of $\Delta\alpha$ on pump peak intensity is used for calculating the imaginary part of third, fifth and seventh-order nonlinear susceptibilities which come out to be -1.3×10^{-21} m^2/V^2, 5×10^{-37} m^4/V^4, and -8×10^{-53} m^6/V^6 respectively. A possible origin of fifth and seventh-order nonlinearities is explained using a two-temperature model. The nonlinear susceptibilities reported here are 2, 4 and 6 orders higher than the reported non-resonant values of silver nanospheres. The possible reasons for such large enhancements of nonlinear susceptibilities are discussed.

Our results show that near the SPR peak the higher order nonlinearities get enhanced to a higher degree compared to the lower order nonlinearities. Since the aspect ratio, hence the SPR position of metal nanoplatelets can be easily tuned to any required wavelength, silver nanoplatelet colloids can be an efficient material for limiting and switching applications in the visible regime.

We thank Dr. S.C. Mehendale and Dr. S. M. Oak for insightful discussions.

A00814-01600

Absorption Properties of Au-$Sn0_2$ Nanoparticles

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One of the major goals behind designing composite nanoparticles is to improve the catalytic properties or to tune the luminescent or sensing properties. The isolation of the core from the surroundings can be used to tailor optical properties of the nanocrystal and to chemically passivate the core. The core-shell nanoparticles are promising for enhanced catalytic and sensing properties as compared to their single component counterparts. Metal-semiconductor Au-SnO_2 is one such multicomponent material system which has attracted considerable attention. The composite Au-SnO_2 nanoparticles can lead to high electronic capacitance and low leakage rates and are potential candidates for information storage element and electronic circuit component. Gold nanoparticles doped SnO_2 based sensors have enhanced selectivity as well as sensitivity as compared to SnO_2 based sensor.

Here, we investigate surface plasmon resonance in Au-SnO_2 core–shell and composite nanoparticles of average size 3-4 nm prepared by two-step laser ablation in water. The particle size and phase structures are characterized by transmission electron microscopy (TEM). The volumetric ratio of SnO_2 shell was varied by ablating tin target in the presence of gold colloids for different duration. The formation of core-shell nanoparticles was confirmed by TEM micrographs. The composite Au-SnO_2 nanoparticles were prepared by pulse laser heating of mixture of gold and tin oxide colloids. The surface plasmon absorption band of gold nanoparticles is sensitive to a variety of chemical perturbations to the particle surface. In the case of Au-SnO_2 core-shell structure, observed red shift of plasmon resonance band of gold core from 529 nm to 557 nm is due to increased free electron density in the core. We have carried out numerical calculations for core-shell nanoparticles based on Drude model to describe nonlinear dependence of absorption properties on core size and the volumetric ratio of the surrounding SnO_2 shell. We also found improved long term stability of the gold colloidal due to formation of SnO_2 shell around the gold core.

A00835-01457

Multicomponent Loschmidt Echo and Mixing in Quantum Evolution Dynamics of Systems with Discrete Dense Spectra

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We investigate quantum evolution of a system coupled to a reservoir with dense discrete spectrum.

Under assumptions (equidistant spectrum of the reservoir and system-reservoir coupling independent of the reservoir states) proposed long ago by R.Zwanzig we find exact analytic solution of the model, which is a simplified version of the Legget-Caldeira Hamiltonian.

We show that there are possible three dynamic regimes of the evolution:

(I) - almost coherent oscillations governed by transitions from the system to the resonance reservoir state;
(II) - multicomponent Loschmidt echo, when the system is exchanged its energy with many states of the reservoir;
(III) - mixing of recurrence cycles.

In the cycle mixing regime (III) due to inevoidably in any real system coarse graining of time or energy measurements, or initial condition uncertainty, the system loses invariance with respect to time inversion. In such conditions dynamic evolution of the system can not be determined uniquely from the spectrum, and in this sense long time system dynamics looks as a random-like. Our model can be applied to rationalize experiments on femtosecond range vibrational relaxation of a specially selected state (the system) coupled to all other states (the reservoir) of nano-particles.

A00846-01471

Nanoparticles on Nanofiber-polymer Brush Surface: A Novel Composite Material

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Nanoparticles–polymer nanostructures have been extensively studied because of their potential applications, ranging from electronic and optical devices to biosensing and antimicrobial agents. The synthesis of amphiphilic graft copolymer via ambient temperature ATRP such as polystyrene-graft-poly(N,N-dimethylamino-2-ethylmethacrylate),polystyrene-graft poly(methacrylic acid) and polystyrene-graft-poly(acrylic acid) was presented earlier by some research groups. These kinds of graft copolymers have versatile uses due to their "polymer brush" nature. If we can introduce these graft copolymers on the surface of nanofibers we have better understanding of the polymer brush effect in nanoscale region. We also can control the no. of polymer brushes on the surface of nanofiber by controlling the property of nanofiber. In this work, we present a new strategy of embedding nanoparticles using nanofiber-polymer brush as scoffolds. The nanofiber-polymer brush is synthesized using the ''grafting from'' process method, via ambient temperature ATRP. The novel nanofiber grafted copolymers are expected to act as a stabilizer and capping agent for the nanoparticles by steric means through the ''polymer brush effect''. All the synthesized materials are characterized by conventional methods like solid state NMR, IR. The surface modification of the nanofiber is evident from the experimental data from TGA, DSC, SEM and FESEM.

A00848-01517

Nonlinear Optical Studies on Chemically Disordered FePt Nanoparticles Using Z-Scan Technique

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Nonlinear optical measurements in low-dimensional materials continue to draw considerable attention since the nonlinear behavior of the complex refractive indices lead to unique optical phenomena. For example, optical switching, saturable absorption, and optical limiting properties of nanostructures hold considerable promise. Recently, metal & semiconducting nanoparticles, nanowires and other nanostructures like carbon nanotubes, ferrofluids, magnetic colloids etc., are being explored for such potential applications. As observed in most of these materials, we have size dependent quantum confinement effects arising from surface plasmons, excitons etc playing a crucial role in determining their optical properties. In this context, we report here the nonlinear optical properties of FePt nanoparticles using z-scan method. FePt nanoparticles with size distribution less than 20nm are extensively researched as a new avenue for ultrahigh-density magnetic storage devices. Chemically disordered FePt nanoparticles are synthesized using wetchemical route involving the reduction of platinum acetylacetonate and decomposition of iron pentacarbonyl in the presence of oleic acid and oleyl amine acting as stabilizers. Transmission electron microscopy (TEM) images of the as-synthesized nanoparticles show nominal ~7 nm sized nanoparticles. The room temperature X-ray diffractograms of the sample confirmed the fcc structure of chemically disordered FePt nanostructure with the lattice constant a = 3.84 Å. We used laser pulses from a second harmonic of Nd:YAG laser (Quanta system, 7 ns, 10 Hz) at 532 nm as input pulses in the z-scan setup. We performed an open aperture z-scan experiment. In order to study the nonlinear optical properties, FePt nanoparticles were suspended in n-hexane (Merck) having a linear transmission of 70% at 532 nm. As in a conventional z-scan setup, we translated the sample across the focus and recorded the transmission at every step by using a fast photodiode (UDT PIN10D) and the corresponding data was collected using an automated interface. In general, the normalized transmittance as a function of sample position could be used to calculate the intensity dependent nonlinear absorption coefficient like two/three photon absorption, saturable/reverse saturable absorption, etc which are all material dependent. Considering our FePt nanoparticles suspensions, we have found that two photon absorption process to be the effective nonlinear absorption process contributing to the observed nonlinear optical response. The effective two photon absorption coefficient was determined to be 4.5e-10 m/W for an input pulse energy of 40 μJ . The origin of nonlinear absorption could probably be mapped to the excited state absorption arising from intraband absorption or free carrier absorption. Concomitantly, we have observed an increase in scattered light intensity as the sample is translated across the focus. Such occurrence of absorption induced scattering have been reported earlier in many other nanostructures like carbon nanotubes, Au, Ag nanoparticles and metal nanowires. This could be accounted by considering the thermal nonlinearities that arises when the incident pulsewidth is longer than 1ns. In conclusion, as materials with two photon absorption and induced scattering could be an excellent candidate for optical limiting application, FePt nanoparticles could be considered as a potential optical limiter at 532nm.

A00852-01482

Optical Metamaterials: Possibilities and Limitations

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Electromagnetic metamaterials, and particularly negative refractive index materials, have been a subject of exponentially increasing interest in recent years, as they enable the realization of innovative properties, unattainable in naturally existing materials. The attempts to realize and exploit these properties in the optical regime have led to a strong research effort to obtain metamaterials in the sub-micron and nano-scale. This is not a straightforward procedure, as it requires both technological innovations, and novel approaches and designs, taking into account the response of matter in the optical regime.

In this talk we will present our attempts to realize and understand optical metamaterials; we will discuss the main underlying problems, the optical metamaterial designs that have been employed, as well as the main characteristics of the wave propagation in those designs.

A00870-02288

Parametric Oscillatory Instability in Nanoelectromechanical Systems as Detectors of Modulated Terahertz Radiation Exhibiting the Plasma and Mechanical Resonances

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There is a strong need in effective detectors of terahertz (THz) radiation. Recently,a resonant detector of modulated THz radiation based on micromachined high-electron mobility transistor (HEMT) was proposed and evaluated. To detect the THz radiation modulated in the GHz range, the transistor structure with a metalized nanostring (NS) or metallic carbon nanotube (CNT) mechanical oscillators might be used.

As known, in opto-mechanical microsystems due to a parametric coupling between the mechanical and optical resonators, both negative and positive dynamic feedback can be realized. The latter results in parametric instability and self-excitation of mechanical oscillations.

We analyze the effect of parametric coupling between a microcantilever (NS or CNT) and a two-dimensional electron gas in a HEMT (in which such a microcantilever serves as the gate) exhibiting the plasma resonance. We find that in the nanoelectromechanical system under consideration, the parametric oscillatory instability can occur. This instability can lead to the self-excitation of the microcantilever mechanical oscillations.

The instability threshold and the growth rate of mechanical oscillations are calculated for a HEMT with a CNT. The limitations imposed on the parameters determining the operation of the device as the THz detector are found. The obtained results can be extended to other nanoelectromechanical systems in which the coupling between the mechanical and electrical resonators is associated with the electrostatic interaction.

In particular, they can be useful for the development of atomic force microscopes utilizing microcantilevers controlled by LC circuits.

Work is supported by the Russian Foundation for Basic Research (grants No. 08-02-00569 and 09-07-00440) and the Russian Federal Agency of Education (grants 2.1.1/236 and 2.1.1/523).

A00945-01660

Emission Enhancement of Semiconductor Nanowires Based on Surface Exciton-plasmon Polaritons

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We studied the light-emission behavior from single semiconductor (ZnO) nanowires in the presence of surface exciton-plasmon polaritons (SEPPs). The SEPPs are introduced at the interfaces between single ZnO nanowires and aluminum contacts. The emission enhancement from single ZnO nanowires is studied via analysis of the micro-photoluminescence (μ-PL) measurements. PL enhancement ~ 20 times was observed in single ZnO nanowires integrated with aluminum nanogratings, where the SEPPs were generated at the interface between the metal structures and the nanowires. The enhanced light-emission from single semiconductor nanowires has the potential for highly efficient light sources, e.g. light-emitting diodes and polarized planar displayers.

Acknowledgments:
This work was financially supported by the National Natural Science Foundation of China (NSFC Nos. 90606023, 10574003, 10523001, 10804003), and the Singapore National Research Foundation (CRP Award No. NRF-G-CRP 2007-01).

A00966-03545

TeraHertz Plasmonic Waveguides and Antennas for Bridging the TeraHertz Gaps

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Recent progress on planar THz plasmonic waveguides will be presented. The electromagnetic field around the waveguide will be described with simulation and experimental results as well as basic structures like bendings and Y-splitters. The properties of these Planar Goubau-Sommerfeld Lines (PGSL) associated with Split Ring Resonators (SRR) with original design will be presented. Among the numerous applications of these structures, THz Near-Field Microscopy with semiconductor nanowires will be discussed. A second part will be dedicated to antennas at THz frequencies and their use in combination with several optoelectronic and nanoelectronic components and in particular for THz Quantum Cascade Lasers (THz-QCL). This is probably the most promising THz device for bridging the THz-gap.

A00994-01739

Optical Trapping and Transport of Particles in Air with Vortex Beams

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Optical guiding of particles is traditionally associated with forces of radiation pressure, and a vast majority of optical traps are based on the ponderomotive forces. However, the developed analysis suggests an additional possibility of trapping which stems from thermal interaction of the laser-irradiated particle and environment via photophoretic forces. Photophoretic forces are based on a transfer of energy from a particle absorbing light to molecules of an ambient gas.

The major difficulty in utilizing the photophoretic forces for the particle trapping is that a finite time of thermal relaxation within the particle is sufficient for its stochastic motion. Nevertheless, it has been shown experimentally that using a vortex beam with a ring-shaped profile leads to a strong transverse confinement of absorbing particles at the intensity minimum on the optical axis. This is in contrast to transparent aerosols trapped by radiation pressure (gradient) force at the intensity maximum. The key step forward that we demonstrate here for fully three-dimensional photophoretic trapping is the use of two counter-propagating vortices in the dual-beam scheme. The on-axis longitudinal confinement is achieved by a balance of the photophoretic forces induced by two vortex beams on the opposite sides of a particle.

The photophoretic force provides a major approach to the stable trapping of absorbing particles in gas media. For example, for a 1-micron size particle the photophoretic forces in air at normal conditions are several orders of magnitude stronger than the radiation pressure. Therefore, the translation distance, acceleration, as well as the translated mass of particles in such optical duct can reach unprecedented values.

Here we report on design and construction of a new scheme where air-born particles can be transported via an optical pipe between two optical traps over meter-long distances in air. The trapped particles could now be transferred backward and forward between the traps along the optical pipe by changing the intensity ratio between the beams forming the traps at the end of the pipeline.

Our proof-of-principal experiments demonstrate stable positioning and guiding of agglomerations of carbon nanoparticles with the total size ranging from 0.1 to 10 micrometers, and for laser powers as low as one mW. The alteration of physical properties of airborne particles is minimal in the trap because only a small fraction of the operating power is absorbed at the vortex core with vanishing intensity. We have transported particles of various sizes between the optical traps separated by a distance from 350 mm to 600 mm. The maximum speed transfer is ~60 mm/s.

These results demonstrate, for the first time to our knowledge, the ability of transporting particles in an optical pipeline over the distances limited only by a divergence of the laser beams. Our approach expands the applications of optical tweezers; it provides a necessary tool for experiments with absorbing aerosols, and allows simulating on the processes studied in atmospheric and planetary sciences in laboratory scales.

A01038-01811

Polarization-Independent Surface-Plasmon-Enhanced High-Speed Ultraviolet p^+-AlGaN/*i*-GaN/n^+-GaN Photodetectors

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Ultraviolet (UV) photodetectors based on SiC or GaN are desirable for free-space solar-blind optical sensing and communications. Due to the difficulty in p-type doping of AlGaN, we have demonstrated much higher speed in SiC detectors than in GaN detectors at 280 nm. However, external UV filters are required to mask the solar radiation for SiC detectors and sensitivity is decreased while size, weight and cost are increased. Therefore, we propose to use a surface-plasmonic metallic overcoat either to render SiC detectors solar blind or to increase the speed of GaN detectors through more efficient contact to p-AlGaN.

To date, most surface-plasmonic filters are fabricated by using Au or Ag and are effective against visible or near infrared lights. Little has been demonstrated in UV. Since the surface-plasmonic resonance of Al extends into UV, Al mesh is first designed and demonstrated on sapphire substrates. The mesh size is 240-320 nm; the gap-to-mesh ratio is 50% to 70%; the thickness is 50-150 nm. According to full-wave electromagnetic simulation, 70-80% transmission can be expected between 280 nm and 360 nm, depending on the mesh and gap sizes. Smaller mesh would lead to shorter wavelength but stronger resonance, while smaller gap would result in sharper resonance but more fabrication difficulty. There is little difference between TE and TM polarizations. These simulated performance characteristics have been confirmed by optical measurements in both near and far fields. Work is in progress to apply Al mesh on SiC or GaN detectors.

Acknowledgement:
Research was sponsored in part by the US Army Research Laboratory and was accomplished under Cooperative Agreement No. W911NF-06-2-0020. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Army Research Laboratory or the U.S. Government. The U. S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation heron.

A01044-01818

Plasmonic Nanoimaging

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The imaging resolution of conventional optical lens system is limited to the order of half wavelength due to the diffraction nature of the light. Emerging artificial metamaterials offer new possibilities to build a superlens that overcomes such a limit. We developed a so called optical hyperlens based on the plasmonic metamaterial concept which can significantly improve the resolution of a conventional optical microscope. Our initial experimental results have shown ~120nm resolution which is about 2.5X resolution enhancement compared with a conventional microscope. The ultimate resolution, however, is only limited by the intrinsic loss and the imperfect fabrication in practice. The curved geometry provides magnification that is crucial in the hyperlens, but also limits the imaging area as a return. We recently developed a novel plasmonic structured illumination microscopy (PSIM) concept by combining the surface plasmon interference on flat surfaces and the structured illumination microscopy. Without the geometry limitation as mentioned in the hyperlens, the new PSIM is able to image wide field with nanoscale resolution. Both the optical hyperlens and the PSIM have provided new and exciting possibilities for the fields such as real-time nanoscale optical imaging and sensing.

A01060-01841

Localization and Enhancement of SP Waves from Plasmonic Waveguide by a Dipole Nanoantenna

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The development of advanced optical structures has made light manipulation possible. However, this manipulation of light waves was thought to be limited by the fundamental laws of diffraction to relative large and wavelength scaled device components. Resent progress in plasmonics, in which the light propagation can be moulded at nanoscale at metal/dielectric interface, has opened a new way to tune light in nanometer scale. One of the examples of plasmonic applications is plasmonic waveguide, of which the dimension is much smaller than the diffraction limit of conventional dielectric optical waveguide.

Plasmonic optical antennas have recently received significant attention for their ability to couple electromagnetic radiation and focus light into the nanoscale with high local field intensity that traditionally achieved by dielectric optics. Metallic nanoantenna, analogy to a conventional RF antenna, can efficiently concentrate the light in the gap between the nanoparticles, leading to a strong interaction between light and materials in the gap. Well designed nanoantennas have been reported to enhance the electromagnetic field by several orders of magnitude.

The nature of plasmonic wave concentrators is different from that of the dielectric versions. By combining the advantage of light manipulation in nanoscale by surface plasmons and local enhancement effect of nanoantennas, one is able to design devices to concentrate the electromagnetic field from the plasmonic waveguides. Here, we report on the localization and enhancement of surface plasmonic waves from plasmonic waveguide by a dipole nanoantenna. The optical properties of plasmonic dipole nanoantenna placed next to the plasmonic waveguide are investigated in details. The influence of the geometry parameters, including antenna length, gap dimension, and antenna shapes (rectangular, bowtie, elliptical, and cylindrical shape), on the performance of nanoantenna is studied. It has been observed that with the help of nanoantenna this enhancement of averaged electric field intensity can reach up to 170 times in magnitude. For the given wavelength, structural optimization (antenna length and gap distance) are carried out to get highest volume based electric field intensity. Furthermore, the effect of the reflective index of substrate and environment are also investigated. Possible applications, such as optical to electronic transduction in photonic systems, on-chip interconnects, ultrafast low-noise photodetectors and biosensors are briefly addressed.

A01072-01857

Influences of Geometries and Material Compositions on the Performance of Dielectric-loaded Surface Plasmon Polariton Waveguides

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In recent years, Surface Plasmon-Polaritons (SPPs) have become an explosive research area, due to their ability to confine and guide optical signals on subwavelength scales and hence overcome the diffraction limit of conventional optical components.

Of all SPP based waveguide approaches, Dielectric loaded SPP waveguides (DLSPPWs), consisting of a thick dielectric stripe mounted above a metallic film, have received particular interest since they possess many significant advantages in comparing to others such as being easy to fabricate and to integrate optoelectronics and electronics, easily providing thermo-optical and all-optical functionalities. This kind of waveguide also allows achieving better lateral confinement, which is due to the fact that the refractive index of the SPP mode at the metal-dielectric interface is greater than that of the outer metal-air interface. Several optimal DLSPPW geometries that support single-mode propagation while achieve high mode confinement and low propagation loss simultaneously have already been proposed in literature. However in all these studies, the dielectric loaded stripes are only based on rectangle-like shapes and the metal film is chosen as gold material. Therefore, the dependence of their performance on different geometries as well as material compositions are still required further investigations.

In this paper, we have done a comprehensive investigation of the influences of geometries and material composition on performance of DLSPPW at the excitation wavelength of 1.55 μm. First of all, using full vectorial finite different numerical simulation, we characterize the propagation mode profile of the conventional DLSPPW consisting of the polymer rectangular stripe 600 x 600 nm^2 above a gold metal of 100 nm and compare to the results obtained by other references.

As a next step, three shapes of dielectric stripe: triangle, rectangle and ellipse are proposed. The dimensions of the stripe in terms of thickness and width are also investigated in order to understand the propagation performance by means of the effective index, the propagation length and the field distribution. Moreover, different metal films: gold, silver and aluminum as well as different dielectric materials of the stripe are also taken into consideration. Results shown that, in general, the rectangular shape DLSPPW provides the best confinement i.e. largest effective index while the triangle shaped DLSPPW offers the longest propagation length. Best confinement is achieved when silver film is used while minimum loss can be obtained by using the aluminum film regardless of the shape and material properties for the dielectric stripe. Furthermore, the effective index increases with the increase of the refractive index of the dielectric stripe, however, the loss also increases at the same time.

A01081-01872

From Surface Enhanced Raman Spectroscopy (SERS) to Tip Enhanced Raman Scattering (TERS): A Raman Enhancement Study Using Individual Single-crystalline Silver Nanowires

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Silver nanoparticles have been widely studied for their plasmonic properties and Raman enhanced effect. In this article, we first timely reported the Raman enhancement from the end of individual single-crystalline silver nanowires. An extraordinary strong Raman signal was observed when incident laser is polarized parallel to the long axis of the nanowire. Such polarization depended enhancement is resulted from the well studied “lightning rod” effect. Based on this result, we propose a new approach of TERS by utilizing individual single-crystalline silver nanowires as probes. The silver nanowires can be attached to the electrochemical etched W tip or metal coated AFM tip by alternating current dielectrophoresis (AC-DEP) method, so this method is applicable to both AFM and STM based TERS system. By controlling the parameters used in AC-DEP, success rate of attaching nanowires is higher than 50%. We also demonstrated TERS experiment by using silver nanowires as probe to study the analyte of 4-Mercaptobenzoic acid (4-MBA) and carbon nanotubes. The repeatability of TERS using nanowire probe is very high (>90%) and such nanowire probes are not easily worn out like conventional TERS probes. Such single-crystalline silver nanowire is believed to have stronger enhancement comparing to the conventional poly-crystalline tips as the domain boundary and defects scattered the surface plasmon and decrease the intensity of the confined electromagnetic field. In our results, an enhancement over 10^5 times is found while tip and sample surface in contact. This is also the first report of the TERS using single-crystalline nanostructures.

For a coated tip, a smooth and substantial metal (normally is gold, silver or copper) film is criteria and the size of the tip is greatly limited by the thickness of coated film. Beside this, such a thin film is very easy to be “worn out” after several times6, and for silver coated, oxidation in several days is also a problem. Although the etched tips do not have obvious worn out problem, the etching technique normally involves using of some toxic chemical and to make it feedback available is complicated7. More important, most of the tips prepared for TERS experiment utilize poly crystalline metal, which may decreases the efficient of localized surface plasmon due to scattering from the domain boundaries, roughness or defects8. Although some groups made other approaches as using gold nanospheres as TERS probe, complicated process and low yield are still some problems to be solved. Here, we propose a simple and high yield method of using the single crystalline metal nanowire as TERS probe, which may help to solve these problems and produce stable and repeatable Raman enhancement. People have already effort a lot in synthesis the metal nanowires using different method and can make the fabrication more controllable in size and length. Recently Wang et. al reported the chemical method of making nanowires with diameter of around 2 nm. All these achievements will help the development of TERS become much easier and more accessible.

A01141-01997

Epsilon-near-zero Material Makes a Universal Cloak

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Attempts to decrease the radar cross-section of macroscopic objects, which were, first of all, air intakes of submarines, were launched during the Second World War. It was suggested employing radio-absorbing coatings that reduced the reflection of electromagnetic waves. Further progress in the problem was achieved by optimization of the shape of the object and by synthesis of frequency broadband coatings, so-called Stealth technologies.

Recently a new approach has been proposed, which is usually referred to as cloaking. More specifically, there are three methods of cloaking. The first one suggested by J. B. Pendry and U. Leonhardt is based on a well-known phenomenon of mirage, which consists in bending of the light rays passing a room with gradient of the refractive index. It has been shown that by a proper choice of space distribution of permittivity and permeability one can force the light rays go perfectly round the object. The second approach elaborated by the team of Prof S.A. Tretyakov, growth out from the first one and consists in design of a network of waveguides terminated with impedance-matching with free space antennas. This system enables field propagation from free space to the network and vice versa. Thus, the incident waves are transmitted through the waveguides bending the cloaked object. The third approach, so-called, plasmonic cloaking, is aimed at decrease of the dipole response of the object and is based on the solution to the Hashin-Strikman problem. The cloak in this case reduces to a uniform shell covering the object. Though the realization is rather simple the cloak is not perfect.

In this communication we show that the key moment of all these approaches is to apply a material, the permittivity of which is nearly equal to zero, so-called epsilon-near-zero metamaterial (ENZM). It is the interface with zero permittivity and permeability material that prevent propagation of the light into cloaked volume because normal components of both electric and magnetic inductions are equal to zero at this interface. Recently the team of Prof N. Engheta has been shown that a wave guide made of ENZM material can support waves' traveling even if the cross section of this wave guide is very small. Thus, the ENZM wave guides may work in accordance with the second cloak method. In this communication it is show in quasi-static approach that the perfect plasmonic cloak of aspherical object is asymptotically possible. Beyond the quasi-static condition such a cloak works as wave guide.

A01229-02107

Interactions between Magnetic and Non-magnetic Materials for Plasmonics Applications

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Plasmonics is an emerging technology which has the potential to solve miniaturization and high speed data challenges of exiting technologies. In plasmonics signal travels at the interface of metal and dielectric; by using this concept a wide number of applications have been simulated and fabricated in the fields of nanophotonics, chemical and biological sensing. In plasmonics, the size of devices is compact like in electronics and the operating speed is high similar to photonics devices. This property of plasmonics supports its usefulness for new systems and applications. In this paper, we study some interesting and novel phenomena caused by the interaction of magnetic and nonmagnetic materials for plasmonics applications. Four different options of materials interactions are investigated and each option can be used for different applications. In these options gold nanoparticles of different sizes are embedded into the magnetic material and different magnetic nanoparticles are embedded into the gold nanoparticles. Interesting behaviors of these nanoparticles and their surrounding materials are observed and visualized.

In the first option, a small magnetic nanoparticle is placed inside the gold nanoparticle and their interaction and effects are studied. It is observed that the magnetic nanoparticles support the field enhancement of the combined structure.

In this structure field not only confines around the magnetic particle (embedded inside gold nanoparticle) for longer time, but also maintain the field oscillations around the surrounding particle (gold) for longer time. In the second option, a gold nanoparticle is placed inside the magnetic material. It is observed that initially field is scattered in different directions and the field localization remains for very short time, almost negligible and disappears very quickly as compared to other cases. In the third option, we placed a magnetic ring around the gold nanoparticle. It is observed from results that in addition to the field enhancement and longer oscillation time, the strong field confines around the inner and outer edges of the magnetic ring. In this case field enhancement and oscillation time is longer than the first two cases. In the fourth case, a nanoparticle with magnetic properties is considered. For this case interesting results are observed. In addition to higher field enhancement, the field confinement around the particle remains for longer time compared to all other cases. For all these options the field enhancement and oscillation time of the conventional gold nanoparticle is used as a reference. In addition to interaction between gold and magnetic material particles, the interaction of magnetic materials with some other nonmagnetic materials is also studied.

It is noticed from the results that the understanding of surrounding geometries of nanoparticles is very important to figure out their correct applications and to observe new phenomena. Some interesting anisotropic behaviors of the magnetic materials are also observed. From results, it is also found that the interaction between magnetic and non-magnetic materials not only enhances and confines the field, but also increases their oscillation time. This study will be helpful in the development of efficient nano-biosensors, data storage applications etc.

A01231-02111

Enhancement in the Efficiency of Light Extraction from Semiconductor Laser Microcavity with Plasmonics Effect

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The extraction of light energy from a source is vital for "powering-up" optical based systems and circuits, characterization of optical devices and many other applications. However, with the rapid growth in multi-functional optical systems and device densities, there is a need to harvest more light energy so as to support this increment.

In this paper, we proposed a method to enhance the extraction of light energy from an elliptical shaped laser microcavity with thin metal film. The metal film is coated on the outer surface of the minor arc of the elliptical microcavity. A plasmonic effect is generated when the electrons in the thin film interact with light photon to form plasmon-polariton. The localization due to the plasmonic effect focuses the light energy toward the desired direction and enhances light extraction from the elliptical microcavity.

The microcavity structure consists of semiconductor material with index of 3.4. It has a semi-major and semi-minor length of 1.3 μm and 0.8 μm respectively. The elliptical microcavity is electrically pumped by external current source to ensure population inversion for generation of laser light energy. An excitation source is pumped into the microcavity to initiate lasing. At steady state, light is coupled out by evanescent coupling process at the minor arc of the elliptical microcavity. By trapping the light on the surface of the gold metal film by effect, surface plasmonic resonance (SPR) is formed and this can be used to enhance the extraction efficiency. It is also possible to focus the light in sub-wavelength width to increase extraction efficiency and make measurement more convenient. The gold thin film is fixed at a thickness of 80 nm. A characterization waveguide is placed at 4 μm to measure the extraction efficiency. The gold film spans over an angle of 10° with respect to the vertical axis.

The amount of light extracted with the thin gold film is enhanced as compared to the case without the gold thin film. The amount of light energy extracted from the minor arc of the elliptical microcavity is enhanced by 12.8% while the arc is coated with 80 nm of gold metal film. The optimal extraction efficiency is achieved at film thickness of 88 nm. The gold thin film can also be manipulated into different forms and patterns to further enhance the extraction efficiency. The amounts of light energy extracted from the major arc with and without gold film are also compared. Both cases produce lower extraction efficiency compared to the minor arc/thin film scenario.

In conclusions, this paper reports on the enhancement in the light energy extraction efficiency from the minor arc of the elliptical microcavity by using the plasmonics effect. Simulation results show that by coating the thin gold film on the outer surface of the minor arc improve the extraction efficiency by 12.8%. Further improvement on the extraction efficiency can be achieved by manipulating the gold film into different forms and patterns.

A01257-02178

An Innovative Platform for Transmission Localized Surface Plasmon Transducers: Au/Al_2O_3 Nanocomposite Film

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It is well-studied that Au island films display a characteristic surface plasmon absorption band, whose position is sensitive to the effective dielectric constant of the surrounding medium, which triggers the construction of various chemical and biological sensors in transmission localized surface plasmon resonance (T-LSPR) mode. However, the first and main obstacle hampering the development of T-LSPR sensors is the instability of Au island films, manifested as change in the surface plasmon absorbance band following immersion in different solvents or by sonication treatment. Herein we present an innovative strategy to construct T-LSPR transducers by replacing Au island film with Au/Al_2O_3 nanocomposite film. This study has demonstrated that the radio frequency magnetron co-sputtering process is a feasible method of generating Au/Al_2O_3 nanocomposite film, which is exceedingly stable during immersion in solvents, drying, and binding of different molecules; and it successfully passes the adhesive tape test and sonication treatment. The superior adhesion and stability are attributed to the Au nanoparticles embedding and Al_2O_3 rim formation during the sputtering process. The mechanism of embedding and stabilization is tentatively proposed, suggesting that the crystallization and embedding of Au species with high energy in the plasma, as well as the rimming function of matrix Al_2O_3 in recrystallization, are essential. The simple one-step preparation, the greatly improved stability, and the remarkable adhesion to the substrate without the use of any intermediate adhesion layer or protective overlayer, as well as the unquestionable features of excellent sensitivity, low detection limits, and inexpensive and portable instrumentation of the T-LSPR transducers makes this system highly promising in sensing applications, as demonstrated here with the Pd (II) sensing process. Thus, we believe that the Au/Al_2O_3 nanocomposite film holds promise as an innovative sensing platform in T-LSPR detection technology and that the use of Au/Al_2O_3 nanocomposite film speeds the viability of employing the T-LSPR sensing technique and opens the possibilities of further developments in a wide range of chemical and biological applications.

Dr. S. Gao thanks the support by the Japan Society for the Promotion of Science (JSPS).

A01337-02337

Enhanced Saturation Absorption due to Gold Nanoparticles Embedded as Core in Core-shell Silver Nanoprisms

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Saturation absorption is observed in a enhanced manner when gold nanoparticles (NP's) were put as core in silver nanoprisms as compared to pure silver nanoprisms. Experiments were done in femtosecond regime where wavelength 780nm is used to shine the well dispersed silver NP's and gold embedded core-shell NP's in water to perform the Z-scan experiments. Theoretical calculations exhibits the basic linear and non-linear optical properties of these NP's which helps in grasping more fundamental picture of these complex system.

A01350-02355

Mimicking EIT, BEC, FERROMAGNETISM, the Mössbauer and the Bunn Effects in Photonic METAMATERIALS

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We introduce a new class of coherent metamaterials where regular ensembles of meta-molecules show collective, coherent narrow-band response leading to unusual electromagnetic properties that invits drawing the parallels with some well-know physical phenomena.

A01357-02390

Plasmon Behavior of Au-based and Ga-based Bimetallic Nanoparticles Supported on Si, GaN and ZnO Surfaces and Nanowires

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Application of plasmon resonant metallic nanoparticles for technological enhancement of various devices (solid-state, polymer-based, *etc*) is popular across a host of disciplines including medical, biological, electronic, and photonic research. These plasmon resonant metals have typically been confined to Ag and Au.

Indeed, recent advances in Ga plasmonics has piqued the interest because of the unique plasmonic properties of Ga nanoparticles supported on substrates. Those nanoparticles extend the plasmon range of metal particles from the UV

to the NIR spectral range by tuning and tailoring the NP shape and size.

In this work we demonstrate the tailoring of metal bimetallic systems both Ga-based and Au-based NPs deposited on semiconductors including ZnO, GaN, Si and dielectrics such as sapphire and glass.

The interest in those hybrid plasmonic metal/semiocnductor systems is twofold: (i) they show the *surface plasmon resonance* (SPR) of metal nanoparticles, which can be exploited for plasmonics devices for biosensors, chemical sensors, new optical detectors, etc., and (ii) they can be used for the further metal catalysed growth of nanostructure. Those hybrid systems are synthetized by dry methodologies including sputtering and UHV metal evaporation.

The peculiarity of our study is the use of spectroscopic ellipsometry (phase modulated ellipsometer UVISEL, Jobin Yvon) for monitoring, also *in real time,* the metal nanoparticles formation and detecting the corresponding SPR behavior.

By considering deposition temperature, flux ratios, and ordering effects we show the formation of both mixed-metal NPs and segregated (coated) bimetallic NPs.

Plasmonic ellipsometry is also used for investigating the dependence of the surface plasmon resonance of those systems as a function of the bimetallic system composition and of the interface with the semiconductor substrate. Plasma surface treatments (e.g. H2 and N2 plasma exposure) are used for changing the substrate surface energy and affect the metal nanoparticles wetting and shape, which also determine the SPR wavelength.

Plasmonic ellipsometry is also used for probing stability of the corresponding surface plasmon resonance peak to temperature variations of the NPs, probing phase transitions of the metal ensembles and stability to oxidation environment.

Finally, application of those plasmonic structures in the plasmon-based detection of NO by functionalizing the metal nanoparticles with porphyrins through a mediated by a charge-transfer mechanism is demonstrated. Additionally, changes and response of the plasmon resonance behavior and properties to interaction with hydrogen are investigated.

A01385-02414

Near-field Coupling Effect between Individual Au Nanospheres and Si Substrate

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We studied the far-field optical reflection contrast spectroscopy (FORCS) properties of the following system: individual Au nanospheres (radius R) immobilized above Si substrate with different thicknesses (d) spacer between them. It is found that peaks in the FORCS red-shift exponentially with d decreasing. The near-field coupling between the Au nanosphere and its supporting substrate is revealed to contribute to this while the coupling strength is demonstrated to decrease exponentially with a decay length of 0.30 in units of d/R. Theoretical calculations using quasi-static approximation was given as well. Our results demonstrate that the FORCS can provide insight into the near-field coupling.

A01399-02431

Fabrication and LSPR Properties of Hierarchical Noble Metal Micro-Nano Structures Utilizing Combined Soft Lithography and Block Copolymer Self-Assembly

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Soft lithography is a set of lithographic technique that has been developed as an alternative to photolithography. This technique uses a patterned elastomer (usually PDMS) as the mold and stamp to generate or transfer the pattern. Popular methods include microcontact printing (μCP) and micromolding in capillary (MIMIC). μCP uses the relief pattern on the surface of a PDMS stamp to form patterns of desired materials on the surface of substrates by conformal contact. In MIMIC, the PDMS is placed on a substrate surface, where the two makes conformal contact each other. As a result, a network of channels is formed between the mold and the substrate. These techniques provide a simple and rapid yet exceedingly powerful method of patterning arbitrary materials on surfaces.

Block copolymer (BCP) self-assembly is a useful platform to generate well defined, ordered periodic nanostructures. Herein, we suggest an unprecedented protocol for the fabrication of hierarchical structures combining soft lithography, e.g., μCP and MIMIC, and self-assembly of BCPs by one step process. Typically, noble metal hierarchical structures are created using BCP micelles loaded with metal precursors as target sources in μCP and MIMIC processes. Diblock copolymers composed of two different polymers form nanometer-sized micelles consisting of a soluble corona and an insoluble core in a selective solvent for one of the blocks. Metal precursors are bound selectively to one of the constituent BCPs by specific chemical interactions. For example, polystyrene-block-poly(4-vinyl pyridine) (PS-b-P4VP) forming micelles in toluene is used as templates. $HAuCl_4$, a precursor of Au nanoparticle, is loaded to the P4VP nanodomains selectively. We utilize thus prepared BCP micelles containing Au precursors as inks or target materials in μCP and MIMIC, respectively. After the release of PDMS mold, the PS-b-P4VP template is subsequently removed by oxygen plasma treatment, leaving behind highly dense arrays of Au nanoparticles on the substrate surface. Morphologies and optical properties of the resulting Au hierarchical structures are investigated by atomic force microscopy, field emission scanning electron microscope and ultraviolet-visible spectroscopy.

Utilizing the resulting hierarchical Au structures derived from the initial hybrid materials, we first investigate their coupled localized surface plasmon resonance (LSPR) phenomena, and then selected functions are evaluated in terms of biosensing based on the LSPR properties. We also compare the sensing properties using a few selected Au hierarchical nanostructures with different dimensions, i.e., size, width and spacing, of Au arrays.

A01401-02437

Preparation of Advanced Powdered TiO_2 Photocatalyst Recycling by Low Temperature Plasma

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Recently, powdered Titanium Oxide(TiO_2) photocatalyst for sewage treatment was developed. Powdered TiO_2 phothcatalyst is used for recycling less efficient one because organic adsorption of contained in sewage. To a more efficient photocatalyst, in this study, adsorbed organics was reduced by Low Temperature Plasma process and its photo catalytic activity was investigated.

Used powered TiO_2 photocatalyst was treated by Low Temperature Plasma using O_2 and Ar gas. In addition, a variety of flow and processing time has been changed. We measured photocatalytic activity of the plasma treated used TiO_2 by monitoring the decomposition of methylene blue in an aqueous solution during the Ultra Violet irradiation and Visible Light. To analyze the photocatalytic activities of the plasma treated used TiO_2, we used field-emission scanning electron microscopy and Ultra Violet spectrophotometer.

A01402-02436

Effect of Acrylic Acid Polymerization of Titanium Surfaces on the Cell Behavior

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Plasma surface modification can be used to improve the surface properties of commercial pure Ti, in order to create different surface topographies, and changes in the surface wettability. In this study, plasma surface modification of titanium surface could be provided by modifying the titanium surface with acrylic acid (AA) plasma polymerization. The structure and component of the AA polymer films are characterized by fourier transform infrared (FTIR) and atomic force microscopy (AFM). The contact angle of films with simulated body fluid was measured. The *in vitro* investigation of cultured normal human oral keratinocyte (NHOK) cells on AA films indicated that the cell behavior of NHOK, such as adherence, growth, and proliferation were better biologically for AA coated titanium surface than for untreated titanium surface. As a result, the AA coated titanium shows good biocompatibility.

A01405-04165

Study of Dielectric Properties of (006) $LiNbO_3$ Thin Film Using Surface Plasmon Resonance

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Lithium Niobate ($LiNbO_3$) is one of the most suitable candidate for electro-optic, optical waveguide and SAW devices because of its good electro-optic, piezoelectric, pyroelectric, photo-elastic and non-linear optical properties. $LiNbO_3$ in thin film offers great advantages over the bulk because of producing high electric field with low applied voltage, the possibility to produce step-index profiles and ease introduction of dopant. It is desirable to grow $LiNbO_3$ films with (006) orientation to couple the large eleectrooptical and non- linear optical coefficients along this direction. However a suitable buffer layer is essentially required for the growth of the c-axis oriented $LiNbO_3$ film on the amorphous substrates.

In the present work (006) oriented Lithium Niobate thin film has been deposited by Pulsed laser deposition on the gold (Au) coated face of the prism (BK7 glass) using c-axis oriented ZnO intermediate layer. Dielectric properties and refractive index of the $LiNbO_3$ thin films have been studied using Kretschmann-Reather configuration based Surface Plasmon Resonance (SPR) technique. The influence of substrate temperature (300 – 500 ^oC) on the dielectric properties has been investigated. SPR data has been taken for the $LiNbO_3$ thin film deposited on different substrate temperatures. The complex dielectric constant and refractive indices values are obtained at 632 nm wavelength by fitting the experimentally obtained data with the theory. Refractive index was found to increase with decrease in substrate temperature. The refractive index and dielectric constant for oriented $LiNbO_3$ thin film deposited at 400^oC were found to be very close to the reported bulk value, and attributed to the reduction in the packing density.

A01420-02460

Plasmon Coupling of Gold Nanorods at Short Distances in Different Geometries

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A direct consequence of the localized surface plasmon resonance (LSPR) of metal nanoparticles is an enhancement of the electric field close to the nanoparticle surface, known as the near field. When two particles are located close to one another, the near-fields of the two particles interact. The near-field coupling of particles spaced less than one diameter apart allows the transmission of light energy through a 2D array or down a linear array of particles. The interaction between nanoparticles is highly distance-dependent, however, until now, the degree of near field coupling at extremely small interparticle separation (less than 2 nm) has not been experimentally investigated, this is the distance of strongest plasmon coupling.

Previous investigations into these interactions have predominantly utilised electron beam lithography (EBL). However, the resolution limit of modern EBL is about 2 nm. Whilst there have been many theoretical investigations of the nanoparticle interactions when the nanoparticles are less then 2 nm apart, experimental fabrication and investigation of such particle pairs has remained a challenge.

In this presentation we report our investigation into the coupling between two discrete nanoparticles, specifically gold nanorods, with interparticle distances smaller than 2 nm and with the pairs in different orientations. The particles were chemically synthesized and are single crystals. The investigation was carried out utilizing the recently reported Focussed Ion Beam Registration Method, allowing correlation of the SEM image of the particle pairs with their scattering spectrum.

The shape anisotropy of nanorods leads to different possible orientations of the nanorods within the dimer and different orientational modes of coupling. We measure the interaction of rod dimers in side-to-side and end-to-end orientations at extremely close approach and compare their spectra to those determined by electrodynamic simulations. The nanorod anisotropy also gives rise to many other possible dimer geometries, including “L”-shaped and “T”-shaped dimers as well as dimers laterally and longitudinally displaced with respect to one another and these are also measured at the single-dimer level and characterised in terms of the active coupled modes.

These experiments highlight important differences between coupling for practical waveguiding applications. Whilst both “L” and “T” geometries are models for T junctions in optical circuits, for these geometries to act as T-junctions strong coupling between the two rods must occur. Our results show that the degree of coupling between the two geometries significantly different and is maximized for the L geometry with transmission of the plasmon resonance throughout the full structure, unlike that for the T geometry.

We conclude the interparticle coupling may be controlled through the interaction geometry as well as nanoparticle separation. We have elucidated new plasmon interaction modes, introduced due to the different possible interaction geometries of the rods. The distance dependence of the plasmon coupling between nanoparticles has been extended to include small interparticle distances (< 2 nm) and this will be discussed with reference to the limits of the recently reported “Universal Plasmon Ruler”.

A01436-02491

Layer Structure Effects of Silver Lens System on Its Imaging Quality using Spatial Convolution Formulation

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Silver lens multilayer systems for subwavelength imaging have been studied both experimentally and theoretically using wave-number (k) formulations. With this formulation, image fidelity can not be directly evaluated with respect to the object leading to difficulties in ascertaining the appropriate system structural parameters for its desired performance. In this work, a spatial convolution method is introduced along with the associated convolution function $T(x,x')$ relating the object point x and the image point x' for the system which proves effective in overcoming the above mention shortcoming. Using this approach, we have studied the performances of various layer structures of the silver lens system for imaging a variety of objects on the basis of direct comparison between the object and the image. It is found that the best images are obtained by a good matching between geometrical profile of the object and the spatial profile of the convolution function. In the case of a single silver layer, a near Dirac delta characteristics of $T(x,x')$ can be attained for a thin silver layer. For a multilayer system and multi slits object, a good imaging quality can only be achieved by detailed, case-by-case adaptation of the system parameters.

This work is supported by the Hibah Kompetensi grant of the Ministry of National Education, Indonesia.

A01448-02517

FDTD Studies of EM Field Enhancement in Silver Nano - Cylinders Arranged in Triangular Geometry

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Enhancement and confinement of electromagnetic fields is an important problem in nano photonics. Metallic nano structures exhibit interesting optical properties due to the coupling of surface plasmon resonances with the electromagnetic fields. Hence metal nano structures have potential applications in photonic and plasmonic devices. Metal nano particles exhibit dramatic field enhancement in the vicinity of the nano particle which have been investigated by many researchers. This enhancement can be further increased by near field coupling between closely spaced particles. Various arrangements of the particles give rise different complex surface plasmon resonances. In this paper, we study a system made of three nano cylinders placed at the vertices of an equilateral triangle. Near field optical responses of the system of silver nano cylinders interacting with the incident plane wave was simulated by finite difference time domain (FDTD) method in the visible light region. We study the effects of the radius of the nano cylinders, interparticle distances and the orientation of the system on the local field enhancement and also the effect of the wavelength on the shift of resonances.

A01507-02620

Ion Beam-based Fabrication of Metal Nanoparticle Composites for Nonlinear Optical Applications

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Nanofabrication methods on a few nanometer scale have been increasingly demanded to meet requirements for the next-generation nanodevices. Metal nanoparticles are promising for plasmonics associated with surface plasmon resonance, e.g., ultrafast nonlinear optics or near-field effects. To meet various applications of metal nanoparticles, spatial control of metal nanoparticles in dielectrics, i.e., of size and distribution, is vital. Since particle size suitable for plasmonics is typically of the order of 10 nm, neither a top-down approach of lithography nor atom manipulation, such as in SPM, is practical. Accordingly, self-assembly methods, such as thermal precipitation or chemical reactions, have been applied to produce nanoparticles, but they are mostly poor in spatial controllability. Ion-beam-based nanofabrication offers various possibilities for 3D control of nanostructures. The ion implantation is a robust and efficient method to meet industrial production, having advantages in arbitrary atomic injection of immiscible elements and good spatial controllability in depth. In this paper, we firstly demonstrate surface-plasmon energy tuning by changing either metal ion species or substrates, by using ion implantation. Next, we present the lateral control methods of nanoparticle distribution which the conventional ion implantation is not good at. We introduce two groups of control methods for nanoparticles embedded in insulators: One is the masked ion implantation using stencil masks, and the other is a perturbation method by applying an external field interactive with precipitation. The stencil masks are required to have both a relatively small aspect ratio of pores (< 5) and radiation resistance. Two types of stencil masks are fabricated for patterned implantation: a thinned Si wafer and an anodic porous-alumina membrane. The Si masks were fabricated from a Si-on-insulator (SOI) wafer, by properly controlling the thinning process. The patterns with the various pore sizes

from 5 μm to 100 nm were formed. The anodic porous-alumina masks with highly-ordered nanopores were also fabricated by a two-step anodization process. Negative Cu ions of 60 keV were irradiated to crystalline or amorphous SiO_2 substrates with the stencil masks, at an ion flux of 3 $\mu A/cm^2$ to a fluence of 5×10^{16} $ions/cm^2$. By using micron or nano-sized masks, we have succeeded in fabricating periodic arrays of nanostructures. The masked ion implantation to crystalline SiO_2 demonstrated spot-lattice-patterned swelling down to 100 nm. For comparison, we also present the perturbation methods to control nanoparticle precipitation, that is, laser-ion combined irradiation and strain-controlled ion irradiation. The both methods were effective to control the precipitation states by controlling the perturbation fields. These unique control methods contribute to development of various plasmonic applications.

A01514-02635

Study of Phase Modulation Behavior of Surface Plasmon Polaritons in Surface Relief Dielectric Structures

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The current trend towards miniaturization of optical devices has recently raised the interest for surface plasmon polaritons (SPP) propagating along metallic thin films with the modulation of surface structures. SPP waves along the propagating direction are equivalent to the free-space plane waves with a spatial decay component and a temporal decay component. Therefore, SPP can be used to realize a wide range of practical applications. In this paper, we propose the optimization of the dimensional polymethylmethacrylate (PMMA) structures on top of a metal surface to modulate phase behavior of SPP with the finite-difference time-domain method. The phase shift observed on SPP propagation through the PMMA structure can be explained by taking an effective refractive index into account. The length of the PMMA structure exerts a higher influence than the thickness in SPP phase modulation due to the exponential decay property of SPP wave. Specifically, we study the application of a phase-modulated in-plane Fresnel zone plate for focusing SPP waves on the metal surface. With the optimized PMMA structure, higher electric field intensity can be obtained at the focal point than that of an amplitude-modulated zone plate with the focused spot size beyond the diffraction limit. Consequently this phase modulation behavior can be used for manipulation of SPP waves and adapted for applications in integrated photonics circuits, improved the performance of SPP in-plane microscopy and enhanced Raman scattering for sensing.

A01535-02684

Study of Metal Deposition Techniques: Influence on Grain Size and Surface Roughness

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With increasing interest in surface plasmon based devices, metal grain sizes are of paramount importance as device dimensions shrink to a few tens of nanometers or smaller. Small plasmonic devices pose a stringent requirement on the grain size of deposited metal. Large grain sizes (g) compared to the device dimensions (d), $g \sim d$, will cause excessive scattering losses as well as the interface effects in surface plasmon generation and propagation. Thus, ideally for plasmonic nano-devices, the condition $g << d$ has to be satisfied for good device performance. In this present work, metal thin films relevant in plasmonic devices are deposited by various deposition techniques including, magnetron sputtering, electron- beam evaporation, ion-assisted deposition, and filtered cathodic vacuum arc. The main goal of this experiment is to minimize the grain size of the deposited metal. The growth mechanisms in regards to various deposition techniques are studied to understand their influence on grain size and surface roughness. The grain size of deposited thin films is characterized by X-ray Diffractometer (XRD) while their surface roughness is measured by atomic force microscopy (AFM). The results are compared for as-deposited and annealed thin films.

A01587-02817

Guiding of Surface Plasmon Polaritons in Laser Fabricated Structures

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Surface plasmon polaritons (SPPs) provide interesting possibilities for the realization of two-dimensional highly integrated optical components. They can find applications in biomedical sensing and telecommunication. This development is based on the rapid advance of nanostructuring technologies, opening new ways for a flexible and low cost fabrication of suitable micro- and nanostructures. Direct laser-writing into photosensitive polymers is one of the most promising technologies for the fabrication and prototyping of components and devices for excitation, guiding, and manipulation of SPPs.

In this contribution, we study applications of laser-based nonlinear lithography, e.g. two-photon polymerization and two-photon induced bond cleavage, as well as nanoimprinting of suitable polymer materials for the fabrication of dielectric and metallic plasmonic surface structures. These SPP-structures, such as couplers, waveguides, splitters, and interferometers, are very efficient for localization, guiding, and manipulating of SPPs on a subwavelength scale. The characterization of laser-written or imprinted SPP-structures is performed in the far-field by plasmon leakage radiation microscopy at 632.8 nm and 800 nm.

The nonlinear laser lithographic approach allows the fabrication of SPP components directly on metal surfaces. In these investigations thermally evaporated gold films with a thickness of 50 nm on 150 µm thick glass substrates are used. The fabrication and guiding properties of straight and bend waveguides, made from commercially available epoxy-, acrylate, and cresol-based polymers, as well as newly developed organic-inorganic hybrid sol-gel materials are investigated. The direct laser-writing is also applied for the fabrication of polymeric structures, serving as masters for subsequent nanoimprint lithography. This fast replication process opens possibilities for incorporation of nonlinear molecules, quantum dots, and nanoparticles into the guiding structures. For example, imprinting of polymer waveguides containing nonlinear dye molecules, such as N-ethyl-N-hydroxyethyl-4-(4'nitrophenylazo) phenylamine (Disperse Red 1) is demonstrated.

A01647-03997

Surface Plasmon Resonance Characterization of Vacuum Deposited Polyaniline Ultra-thin Film

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Ultra-thin films of emeraldine base (EB) and emeraldine salt (ES) form of polyaniline (PANi) were prepared using electron-gun vacuum deposition. Thickness range studied was between 100Å and 450Å. Dielectric permittivity of the films determined from Kretchmann Configuration Surface Plasmon Resonance (SPR) angles-scanning set-up showed value of $\varepsilon_r \geq 3.0$, and thickness dependant only for films less than 300Å. Absorbance spectra of S-polarized and P-polarized light show the orientation of the film. Correlation between optical properties and microstructure of the films is proposed. Comparison was made between the properties of EB and ES films, as well as between deposition on gold substrate and deposition on BK-7 glass.

A01652-02944

Near-field Raman Imaging by Optically Trapped Dielectric Microsphere

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Raman microscopy is a versatile characterization technique in research and industry. The main stumbling block of employing Raman microscopy in the nanoscience and nanotechnology is the spatial resolution, which is limited by the diffraction of light. Several approaches have been employed to improve the spatial resolution to nanometer scale, among which laser delivered through metal-coated tapered optical fiber (aperture) and tip-enhanced (apertureless) near-field Raman techniques are the most frequently used. Raman intensity using the aperture technique is extremely weak, making imaging impractical. The latter has very low success rate and the signal is not purely near-field. We report a new near-field Raman imaging technique by trapping and scanning a dielectric microsphere over the sample surface. Using this method, we have achieved spatial resolution of 50 nm. This spatial resolution is extremely useful for a range of applications such as the characterization of nano particles and nano devices. We will show the capability of our technique using a series of nanometer sized samples, e.g. Fischer's nano-patterns, device sample with 45 nm poly-Si gates with SiGe stressors. Raman imaging by this technique shows the capability to resolve the gold nanopatterns and the device samples with excellent reproducibility, which no other optical near-field techniques have been able to achieve. This technique is versatile, easy to use and reliable, making it extremely powerful for ultra-high resolution nano-characterization.

A01663-02878

Tuning Surface Plasmon Resonance Effects by Laser Nanoengineering

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Surface plasmon resonance (SPR) effects can be flexibly tuned by manipulating metallic nano-particles or nano-structures' sizes, thin film materials, and inter-coupling. In this talk, laser synthesis of TiO_2/Ag nano-composites in liquid is carried out. By adding Ag nano-particles, TiO_2's optical properties can be modified with additional resonance peak at visible light range to enhance the light absorption for photo-catalyst and solar cell applications. Meanwhile, SPR can be tuned as well by modifying the metallic thin film nano-patterns from nano-dots, to nano-rods and to nano-diamond shapes by laser interference lithography (LIL). Ag/Au, Au/Ni and Ag/Ni bi-metallic thin films and their nano-structures fabricated by laser means can be applied to achieve multi-peak SPR for wide-band plasmonic devices/structures. Due to the skin depth effect, thicknesses of the metallic thin films/nano-structures need to be properly selected. Micro-lens array (MLA) lithography is also used to make arbitrary plasmonic micro-/nano-structures at NIR and THz spectra. Compared to other nanofabrication means (electron beam and focused ion beam nanopatterning), laser interference lithography and micro-lens array lithography possess the unique advantages of being non-contact, multi-beam and maskless processes to make large-area plasmonic structures at a short time in air.

A01674-02894

Controlling Light in Hybrid Plasmonic Nanostructures

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Optical properties of metallic nanostructures are in many cases determined by one or another type of plasmonic excitations such as surface plasmon polaritons, localized surface plasmons, particle plasmons, etc. The coupling of light to such excitations, that are collective electronic modes in metallic nanostructures, allows one to confine the electromagnetic field on the sub-wavelength scales and manipulate it with high precision both spectrally and spatially. Hybritization of plasmonic nanostructures with functional materials, such as ferroelectric, magneto-optical, nonlinear optical materials and molecular species, results in metamaterials or stand-alone nanostructures whose photonic response can be actively controlled by application of external stimuli. Plasmonic dispersion and, thus, optical properties of such nanostructures and their response to applied control signals can be designed in a straightforward and controllable way by the appropriate structuring of the metallic host. In this talk we will overview magneto-optical, all-optical and electro-optical functionalities achievable with hybrid plasmonic nanostructures, focusing on magneto-optics of plasmonic crystals and electro-optics of anisotropic plasmonic nanostructures. Photonic functionalities in nanoscale plasmonic devices are important for nanophotonic applications, controlling light on the nanoscale as well as for development of tuneable and functional optical metamaterials.

Acknowledgments:
This work has been supported by EPSRC (UK) and the EC FP6 projects PLEAS and PLASMOCOM.

A01694-03201

Multiple-particle Nanoantennas for Enormous Enhancement and Polarization Control of Light Emission

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Manipulating light on the nanometer scale is a challenging topic not only from a fundamental point of view, but also for applications aiming at the design of miniature optical devices. Nanoplasmonics is a rapidly emerging branch of photonics, which offers variable means to manipulate light using surface plasmon excitations on metal nanostructures. As a spectroscopic phenomenon discovered over 30 years ago, surface-enhanced Raman scattering (SERS) has been an active topic of fundamental and applied research. The dominating electromagnetic enhancement in SERS even for single molecule detection is caused by surface plasmon resonance, which is the typical example to manipulate light intensity with plasmons. Here, we study light propagation controlled by surface plasmons for SERS and a theoretical model study.

We use single molecules to characterize the interaction of surface plasmons with light, and show that such interaction can strongly modulate the polarization of the emitted light. The simplest nanostructures that enable such polarization modulation are asymmetric silver nanocrystal trimers, where individual Raman scattering molecules are located in the gap between two of the nanoparticles. The third particle breaks the dipolar symmetry of the two-particle junction, generating a wavelength-dependent polarization pattern. Indeed, the scattered light becomes elliptically polarized and its intensity pattern is rotated in the presence of the third particle. We use a combination of spectroscopic observations on single molecules, scanning electron microscope imaging, and generalized Mie theory calculations to provide a full picture of the effect of particles on the polarization of the emitted light.

Furthermore, our theoretical analysis allows us to show that the observed phenomenon is very sensitive to the size of the trimer particles and their relative position, suggesting future means for precise control of light polarization on the nanoscale.

As a theoretical model study, we investigate the light emission from dipolar emitters located within nanoparticle antennas. It is found that the enormous emission enhancement can reach nearly a million fold. For multi-nanoparticle antennas, the polarization of the emissions strongly depends on the geometry of the antennas, the emitted wavelengths and the dielectric functions of surrounding media. It is shown that a polarization nano-rotator, which modulates the emission polarization on the nanometer scale, can be readily realized by varying either the geometry or surrounding media of nanoparticle antennas.

A01734-03016

SERS Study of a Single Silver Nanowire with Hotspots

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Hotspots are easily fabricated on an individual Ag nanowire via chemical etching method. Scanning electron microscopy (SEM) and atomic force microscopy (AFM) are used to characterize the surface of both the as-synthesized and the etched nanowire, revealing that the smooth surface could be effectively roughened by simple chemical etching process. With the help of this rough surface, we observed stronger surface enhanced Raman scattering (SERS) of 4-Mercaptobenzoic acid (4-MBA) from Ag nanowire after. The SERS images of 4-MBA show several hotspots along the nanowire. Considering the simplicity of the etching process and the high efficient of the enhancement, the chemically etched Ag nanowires could be a promising candidate for SERS.

A01741-04612

Homogeneous Waveguide Confined By Side Metal

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Small dimension waveguide has attracted wide attention recently due to the interests in nano-photonics and the on-chip photonic integrated circuits. A waveguide usually has the light confinement in the lateral direction by patterning and etching while in the vertical direction by using different materials through growth or deposition method. It would be of great interests to the photonics and semiconductor industry if there is a way to make waveguides and waveguide based devices in a homogenous material, like Si or GaAs.

In this paper, a novel waveguide formed in a homogeneous material is proposed. The optical field confinement in the vertical direction is realized through plasmonic mode stimulated by the metal strip on part of the sidewall. 3D full-vector beam propagation method (BPM) simulation showed that the confinement factor and transmission loss of the waveguide are greatly influenced by the side metal dimensions. For TE mode, the confinement factor is small since most of the optical power will couple into surface plasmon mode. For TM mode, optical field can be perfectly confined in the core material and the loss comes mainly from the absorption of the metal. The metal strip parameters are optimized to reduce the transmission loss and the waveguide device is being fabricated in the Si and GaAs materials.

A02048-04505

Effect of Using Thin Transparent Conductive Layer on Plasmonic Oscillations in Metal Nanoparticles Fabricated by Electron Beam Lithography

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The optical behavior of metal nanoparticles with different geometries is widely examined in last two decades for the plasmonic resonances in the visible and infrared region. The use of metal nanoparticles as optical antennas to enhance absorption is a promising way to increase performances of optoelectronic devices. Electron Beam Lithography, being a controllable manufacturing method, helps understanding the nature of the behavior. However, restriction of using conducting samples to be able to produce patterns brings additional parameters affecting the plasmonic resonance conditions. In this study, effects of using ITO layers over glass samples have been examined experimentally by use of several different arrays of Ag nanoparticles with varying size. Similar experiments have been conducted on Si substrate with a p-n junction diode. Both transmission data for glass samples and photocurrent for optical detectors with and without ITO conductive layer have been compared.

A02123-04485

Active Plasmonic Components and Metamaterials

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Dispersion control and active materials integration have yielded plasmonic components including i) three-dimensional single layer plasmonic metamaterials ii) all-optical, electro-optic and field effect modulation of plasmon propagation iii) plasmon-enhanced absorption in solar cells.

We expand upon recently reported work on direct observation of two-dimensional negative refraction in the visible frequency range to develop a general approach to realization of three-dimensional single-layer, all-angle, polarization-independent plasmonic metamaterials exhibiting negative refraction. Full wave simulations and dispersion calculations are used to demonstrate that metal-dielectric-metal plasmonic structures are characterized by negative wave vectors and negative refractive indices.

Metal-dielectric plasmon waveguides can serve as active switching elements when the dielectric refractive index can be actively modulated. We demonstrate electro-optic refractive index modulation in metal-dielectric-metal plasmon waveguides using low-voltage electro-optic modulation of both silicon and perovskites oxide dielectric layers.

The efficiency and cost effectiveness of photovoltaic cells can both be increased by reduction of the active semiconductor absorber layer thickness and ability to fabricate ultrathin absorber layers opens up new possibilities for solar cell device design. The strong mode localization of surface plasmon polaritons at metal-dielectric interfaces leads to strong absorption in semiconductors thin films, enabling a dramatic (10-100X) reduction in the semiconductor absorber physical thickness needed to achieve an optically thick film. Modal analysis in full wave simulation allows us to determine the fraction of power absorbed by the solar cell to be determined for both dielectric and plasmonic modes.

A02169-03733

Colloidal Synthesis of Plasmonic Metallic Nanoparticles

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Ag and Au nanoparticles display interesting optical properties on grounds of surface plasmon resonance (SPR), rendering the metallic nanoparticles and the nanostructures constructed therefrom useful for many applications. Since the properties of the nanoparticles are highly dependent on the attributes of the nanoparticles, it is important to be able to produce nanoparticles in well-controlled composition, size, shape and surface chemistry before these nanoparticles may be used directly or for device fabrication. Among the various fabrication techniques, colloidal synthesis has notable advantages such as low production cost and versatility in manipulating and controlling the functional attributes of the nanoparticles. In this presentation we will discuss some of our recent efforts in developing new chemical and biological procedures in colloidal synthesis to prepare nanoparticles with tunable SPR properties. The systems of interest include zero-dimensional Ag-Au bimetallic nanoparticles and one-, two-, and three-dimensional anisotropic Ag or Au monometallic nanoparticles.

The SPR location of zero-dimensional Ag-Au bimetallic nanoparticles was tuned by controlling the composition and/or composition distribution of bimetallic spherical nanoparticles. Three types of bimetallic nanoparticles, including alloy, core-shell and hollow nanoparticles, were synthesized using solution chemistry method. The structure and functional attributes of the bimetallic nanoparticles depend strongly on the preparation conditions. By varying the structure and functional attributes of the bimetallic nanoparticles, the SPR location of the particles could be tuned throughout the entire visible to near-infrared region.

The as-synthesized bimetallic nanoparticles could self-assemble to form 2-D and 3-D superlattices on substrates due to the un iform morphology and narrow size distribution. The nanoparticles in the superlattices exhibit various packing patterns and the packing pattern of the nanoparticles is strongly dependent on the native morphology of the nanoparticles. These 2-D and 3-D superlattices may be used to study the effects of the close coupling of proximal alloy nanoparticles on their application properties.

Besides zero-dimensional spherical bimetallic nanoparticles, a number of anisotropic monometallic nanoparticles were also synthesized to tune the SPR properties. These anisotropic nanoparticles were formed under kinetic control in the solution chemistry synthesis. One-dimension (nanowires), two-dimensions (nanoprisms) and three-dimensions (nanoflowers) Ag or Au nanoparticles were prepared by using microorganisms, biomolecules and relatively “green” chemicals. These anisotropic particles have multiple SPR bands and the position of these SPR bands could be tuned by changing the shape and the aspect ratio of the nanoparticles. These biologically-synthesized nanoparticles are particularly useful for biomedical applications.

A02183-03850

Self-Assembly of Gold Nanoparticles and Its Application to SERS and Nonlinear Optics

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Self assembly of gold nanoparticles into one-dimensional (1D) or two-dimensional (2D) nanostructures and their associated collective vectorial properties are of particular interest in nanoelectronics, optoelectronics, nanomagnetism, and biosensor devices. The coupling of gold nanoparticles has been demonstrated by using surfactants, bifunctional organic molecules, DNA duplex formation and bio-recognition systems. Recently we have demonstrated very simple strategies to assemble the gold nanoparticles into 1D nanostructure by using amino acid or water soluble conjugated polymer. In the first method, We have synthesized the self assembled gold nanoparticles in a single step by reducing aqueous chloroaurate ions with sodiumborohydride in the presence of an amino acid (glutamic acid and histidine) as a stabilizer. The open aperture *z*-scan measurements on self assembled gold nanoparticles showed an optical switching behavior from saturable absorption to reverse saturable absorption as the pump intensity increase. In another method, gold nanochains were prepared by the assembly of citrate-stabilized gold nanospheres induced by cationic conjugated polymers. This assembly method was rapid, and the assembled product was very stable. A longitudinal plasmon resonance band was formed as a result of the coupling of gold nanoparticles and can be tuned from visible to near infrared by adjusting the polymer/Au molar ratio. The gold nanochains were used as a SERS substrate and gave a large enhancement, which is ~400 times larger than that on the isolated gold nanosphere substrate.

A02235-03817

Optical Shielding Nano-Systems Achieved by Multiple Metallic Nano-Cylinders under Plasmon Resonances

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An optical shielding system is proposed in this paper using nanoparticles and/or nanotubes. The system consists of metallic nanocylinders under plasmon resonances surrounding the area purposely shielded. The incident wave under the design system is assumed to be TE polarized so that the plasmon resonance of two-dimensional cylindrical structures can be excited. The incident wavelength is assumed to be 366 nm and the nanocylinders are electrically small (whose radii are much smaller than the wavelength). It is found that the total magnetic and electric fields in the central region of the shielding system can be significantly reduced. To show the practical applications, several cases with different distributions of plasmonic nanocylinders have been discussed for better shielding effects. The field intensity inside the shielding system has been shown versus different incident wavelengths ranging from 300 to 500 nm. To further demonstrate the shielding effects, mutual interactions between a cylinder placed at the central point of the shielding system and the shielding system elements (other nano cylinders) are illustrated and the shielding effect is evaluated using the peak value of the field intensity around the nanocylinder. Loss effects of the nano cylinders or dissipation effects of the shielding system are also discussed. From various intensive calculations, an electrically effective thickness t of the nanoparticle shell consisting of nanocylinders (whose permittivity is -1 + 0.1 *i*) is found for an efficient optical shielding of an object, that is, $k_0 t > 2$ or $t >$ wavelength/Pi where k_0 denotes the free-space wavenumber.

A02265-03862

Sensitive Nanostrips-array Surface Plasmon Biosensor on Polymer Substrate Fabricated Using Novel Technique Based on Nanoimprint

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Prism- and grating-based surface plasmon resonance (SPR) sensors have been used widely for highly sensitive, label-free biological analysis. However, the bulky prism, precise

optical alignment, and reflection-mode detection lead to challenges of scalability, miniaturization, and multiplexing. Employing the same principle of using evanescent field to probe near-surface biomolecular interactions by exciting surface plasmons (SPs), nanostrips-based sensors can be used for highly sensitive biosensing applications. Compared to conventional SPR sensors, nanostrips-based sensors offer the advantages of prism-less sensing, small probe surface, small sample volume requirement and easy integration with high numerical aperture optics. In addition, difficulties with optical alignment are avoided as detection is based on zero-order transmission mode.

Common fabrication methods of nanostrip arrays involve e-beam lithography and focused ion-beam. The expensive and time-consuming[1] beam-based fabrication techniques are unsuitable for fast mass production of low cost sensors for high throughput detection of biomolecules. Hence, we introduce a facile, inexpensive, non-serial and time-efficient alternative method based on nanoimprint and oblique metal evaporation to fabricate high sensitive nanostrips sensors. Typically, a disposable polymeric SPR sensor chip is fabricated by first using a silicon wafer mold to nanoimprint 250 nm step gratings onto poly(methyl methacrylate) (PMMA) polymer substrate. This is followed by a second step of oblique evaporation of gold at a steep angle to form gold nanostrips of gold with 50 nm thickness, 250 nm width, 250 nm slit gap and having 500 nm periodicity coated onto transparent PMMA step gratings. SEM images show that the nanostrips profile is uniform and well-defined. This two-step technique can be amendable for fabricating nanostrips sensors incorporated into microfluidic devices by using an imprint mold pre-designed with multiple microchannels.

We have tested the UV-visible transmission response of the nanostrips array sensor to changes in bulk refractive index of liquid medium by exposing the substrate to different concentration of glycerol. A refractive index unit (RIU) sensitivity of 500 nm per RIU was recorded. This is close to the theoretical prediction based on momentum-matching conditions for nanostrips of periodicity 500 nm. Our *measured* RIU sensitivity based on nanostrips was higher than that of nanoholes, gold nanoislands, nanoshells, colloidal- and substrate-based nanoparticles by nanosphere lithography, and comparable to reflection–mode based SPR gratings[2]. Lastly, we have applied the nanostrip sensors for detecting protein and DNA. The results of nanostrips biosensing is compared with those obtained using a prism-based commercial SPR machine.

A02272-03948

Simulation of Plasmonic Devices with Gain using Multi-Level Multi-Electron FDTD Method

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Plasmonic Devices are of great interest because of their small sizes. However, plasmonic devices are made up of metallic structures. A major problem in plasmonic devices is the high optical loss of metallic materials. The loss problem is particularly serious when operating at close to the plasmon resonance frequency of metal, which is the region of particular interest for many plasmonic devices. The optical loss can be so high that it limits the device size to be less than a few micrometers. One way to overcome the optical loss is to combine plasmonic device structures with optical gain. It is thus of great interest to simulate the spatial temporal interactions of electromagnetic fields with plasmonic device structures that involve optical gain media.

A powerful spatial-temporal simulation method for computational electromagnetics is based on finite-difference time-domain (FDTD) method. FDTD method has been quite successful in simulating passive device structures but has not been very sophisticated in incorporating complex material madia with optical gain. Realistic gain media typically involve sophisticated electron energy level structures and electron pumping dynamics, which can play important roles under transient or high-speed medium-field interactions. To address this problem, recently, we have developed a powerful quantum mechanical model of material media called the multi-level multi-electron (MLME) model, which can be applied to modeling a wide variety of active atomic, molecular, or semiconductor media. For the case of semiconductor, the MLME model is sophisticated enough to incorporate all the essential interband and intraband electron dynamics and yet it is simple enough to be computationally efficient. The model takes into account the Pauli Exclusion Principle as well as Fermic-Dirac thermalization for the interacting electrons, which is important for modeling the carrier band-filling effect and carrier dynamics appropriately at finite temperature.

We will describe our efforts in applying this powerful MLME-FDTD active-medium model to simulate novel plasmonic devices with active gain media, including the simulation of nanolasers based on plasmonic microcavities.

A02294-03915

Magnetic Light Emitters: Plasmon-enhanced Magnetic Dipole Transitions

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Over the past decade, advances in both negative index metamaterials and resonant optical antennas have challenged traditional assumptions about light-matter interactions. While metamaterials research has shown that metallic structures can be engineered to support strong optical frequency magnetic resonances, resonant optical antennas have been designed to amplify and re-direct the emission from electric dipole emitters. In this talk, we explore the intersection of these distinct fields and investigate how resonant optical effects may be used to challenge the electric dipole approximation. Specifically, we will show how Purcell effects may be used to enhance the natural optical frequency magnetic dipole transitions in Lanthanide ions. We will present experimental and numerical results that demonstrate enhanced magnetic dipole emission from trivalent Europium ions near metallic films and nanoparticle composites. We will explore how the varying symmetries of electric and magnetic dipoles can be used to characterize and optimize magnetic light emission. Finally, we will discuss the implications of enhancing and controlling higher-order optical transitions for optical spectroscopy and photonic devices.

A02377-04135

Surface Plasmon Interference Nanoscale Lithography Using Periodic Nanoparticle Layer

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The growing importance of the nanotechnology research leads to the need for fabrication technique with the capability to fabricate nanometer scale features and one such technique is the optical lithography. Also, it is unable to pattern high resolution nanostructures with conventional photolithographic techniques due to optical diffraction limit. Surface plasmon enabled lithography, which is not restricted by free space diffraction limit, is one of the potential research thrust areas as it offers the possibility for high resolution nanopatterning.

A new concept for high resolution nanoscale surface plasmon interference lithography is proposed using periodic metal nanoparticle layer. The concept is then illustrated through FDTD simulation to pattern one-dimensional periodic nano-structures beyond the diffraction limit. A modified Kretschmann configuration in which bimetallic layer for interference lithography is also presented using FDTD method. It is found that the proposed configuration gives very high electric field distribution, and good exposure depth and contrast by using Ag and Al nanoparticle layer. The dependence of dielectric layer thickness on the intensity distribution on the photoresist layer is investigated. The post-development resist topology using cellular automata is also discussed. In short, this proposed concept and methodology promises good potential for nano lithography at high resolution to fabricate sub–30nm periodic nanostructures. This proposed concept and methodology and its variants are expected to play a big role in nanoscale feature fabrication that can find potential applications in different areas such as semiconductor industry, photonic crystals, and biochips for biomedical applications.

The authors acknowledge the financial support received through ARC 3/08 and A STAR SERC*

A02387-04094

Characteristics Polymer Layer in Polymer Light Emitting Diode Investigated by SPR Spectroscopy

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Surface plasmon resonance (SPR) spectroscopy of metallic layer has been considered as a powerful technique in chemical and biological sensing experiments. Under resonance condition, the penetration depth of electromagnetic-field could reach a hundreds nm. In this presentation, we will report our work on using SPR spectroscopy to investigate the characteristics of conjugated polymer layer at the interface polymer/electrode inside a polymer light emitting diode (p-LED) structure. We fabricated simple pLED structure of ITO/PEDOT/MEH-PPV/Ag on a prism. Typically, the thickness of polymer layer is about 100 nm. We then measured SPR spectra at various angle under the OTTO configuration. Under the excitation of He-Ne laser, from the ITO side, the resonance was observed at the incident angle at 20° - 85°. By changing the incident angle, we tried to sense polymer molecules at different layer depth. We measured also the SPR spectra for various voltage bias of the p-LED. The measured SPR spectra were correlated with the degradation process of the p-LED.

A02396-04173

Far-Field and Near-Field Optical Studies of Localized Surface Plasmon Resonance of Single Au Nanowires

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We have utilized atomic force microscopy nanolithography to fabricate single Au nanowires on silicon substrates, and far-field and near-field optical techniques to investigate their localized surface plasmon resonance (LSPR). Under far-field mode, the scattering spectrum of a single nanowire consists of two resonance peaks in the red and the blue wavelength regions. The two peaks are found independent of the nanowire length and therefore attributed to resonances along the width and the thickness directions. The red resonance peak experiences an apparent and linear red-shift from 625 to 635 nm when the nanowire width increases from 50 to 103 nm. The blue resonance peak centers at 490 nm and remains unchanged when the thickness is below 22 nm. Under near-field measurement, a 532 nm laser source is incident underneath a glass substrate with Au nanowires in attenuated total reflection, and an optical fiber tip is used to probe the near-field optical intensity. With the polarization of incident electric field perpendicular to the long axis of the nanowires, an interference pattern due to the propagation of surface plasmon polaritons is observed. The observed wavelength is 479 nm and in good agreement with the calculated result of 471 nm at the air-Au interface. On the other hand, with the polarized electric field parallel to the long axis of the nanowires, enhancement of optical intensity on both long-axis sides of an Au nanowire is observed. The polarization dependent near-field study confirms that the red peak in the scattering spectrum is due to resonance along the width direction. In addition, the shift of LSPR peaks due to medium change is also investigated.

A02416-04118

Enhancement of Surface Plasmon by Gain Assisted Medium

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Surface Plasmon polariton (SPP) is an electromagnetic wave propagating along the interface between two media possessing permittivities with opposite signs. To date, a variety of passive and active plasmonic devices have been demonstrated. The main attraction lies in the fact that SPs are characterized by strong enhancement and spatial confinement of the electromagnetic field, allowing light to propagate below the diffraction limit. However, they suffer from strong damping due to the scattering from the rough metallic surfaces, the propagation loss due to the surrounding dielectrics and the inherent loss resulting from the complex dielectric constant of the metal. This energy dissipation limits the effective propagation in the nanometer to micrometer range, thereby creating an obvious obstacle in utilizing them in practical optical devices and circuits. Amplification of plasmons analogous to photon amplification in a laser could be a solution to this problem.

A metal film bounded by dielectrics at both sides can be used as a SPP planar waveguide structure. When the thickness of this film is small enough, it can support a mode with propagation loss considerably lower than that of the single interface mode. Such a mode, termed a long-range SPP (LRSSP) mode, owes its low loss to a weak field penetration in the metal. The active medium consists of organic-dye molecules with emission wavelengths lies in the visible region is doped in polymer matrix. The active medium is index matched to the substrate and serves as upper cladding, forming a symmetric waveguide structure. The large gain coefficients that can be obtained with organic dyes together with the low attenuation coefficients offered by symmetric long-range surface plasmon-polariton waveguides make these structures good candidates to achieve net amplification in the visible region.

Acknowledgments:
The authors acknowledge the financial support received through ARC 3/08.

A02425-04559

Investigation of the Plasmonic Properties of Two-dimensional Metallic Nanostructured Arrays

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Two-dimensional (2D) metallic hole arrays with different aperture sizes have been fabricated by using interference lithography and their optical properties have been studied by using angle-dependent reflectivity measurements. Verified by finite-difference time-domain simulation, features arising from Bragg scattered surface plasmon polaritons (SPPs) and Wood's anomalies are clearly observed from the dispersion relations. More importantly, the lifetimes of different SPP modes have been determined from the line widths of reflectivity spectra for different resonance wavelengths (λ) and hole sizes. Lifetime is an important parameter in plasmonic systems because it provides information on the local field enhancement. Longer lifetime thus induces stronger field enhancement. From our results, it is found that the lifetimes display an λ^n dependence, where *n* is strongly dependent on hole radius. In particular, n increases from 4, which is consistent with Rayleigh scattering, to 11 as a function of hole size. Therefore, our results provide a complete guideline in manipulating the lifetime of SPPs by managing the geometry of the hole size. It is expected that our results will find applications in areas such as surface-enhanced Raman scattering and thermovoltaic devices.

Acknowledgment:
The work is partially supported by the Shun Hing Institute of Advanced Engineering, CUHK, particularly, under Grant No. BME-p2-08.

A02440-04162

Compact Plasmonic Devices with Low Polarization-Dependent Loss

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In recent years, a substantial research effort has focused on plasmonic waveguiding and basic components operating at telecommunications wavelengths. This work has been partly motivated by the prospect of realizing highly integrated optical circuits, utilizing the strong light confinement at metal surfaces. However, two main factors still prevent plasmonic components from competing with current and emerging platforms for integrated optics: high loss and strong polarization dependence.

In the present work, we investigate the possibility of using simple plasmonic components within current telecommunications networks. We demonstrate that polarization-independent operation is possible using metal nanowire waveguides and show an example of a compact thermo-optic variable optical attenuator, based on a plasmonic nanowire waveguide, suitable for integration with, e.g., polymer integrated optical components.

We will discuss key parameters of the plasmonic VOA device such as insertion loss, polarization dependent loss, extinction ratio, power consumption, response time, scalability, mean time to failure, fabrication tolerances, and compare with commercially available VOA devices based on other technologies.

A02524-04322

Channel and Wedge Plasmons in the Optical and THz Regimes

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The guiding of light within a subwavelength cross section has recently been attracting a great deal of attention because of ever increasing demands for miniaturization of photonic circuits.

In this talk we present theoretical results for the modal shape, dispersion relation and losses of bounded electromagnetic modes in a V-shaped channel in a metal film (the so called Channel Plasmons). It will be shown that modes spatially located closed to the opening of the channel hibrydize with modes appearing at the edges of the channel. These modes, termed Wedge Plasmons will be studied separately in a wedge (the inverse geometry to the V-channel). Strategies for coupling into this modes and for further focusing the electromagnetic field will be discussed.

A02526-04324

Plasmonic Nanostructures for Photo-catalytic Reactors

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3D-FDTD is used to compute the electromagnetic response of various plasmonic nanostructures. Results of computation and simulation are used to design the contact area of the photo-catalytic reactors. Novel nano-fabrication techniques are developed to implement large surface area of plasmonic nanostructures for photo-catalytic reactors. Measurement and analysis of the photo-catalytic process happened in the newly designed photo-chemical reactors clearly demonstrate better efficiency of some photo-catalytic chemical process such as the decomposition of the Methyl Orange to carbon dioxide and water.

Acknowledgments:
Authors thank the supports from the Ministry of Economic Affairs and National Science Council of Taiwan (ROC) under project

number 97-EC-17-A-09-S1-019, NSC-97-2120-M-002-013-, NSC-97-2112-M-002-023-MY2, NSC-96-2923-M-002-002-MY3, NSC-97-2119-M-002001, and NSC-97-2915-I-002-001. D. P. Tsai also thanks the supports from Center for Nano Science and Technology, National Taiwan University.

A02548-04358

Quantum Description of Plasmons in Strongly Coupled Metallic Nanostructures

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The plasmonic couplings between closely positioned metallic nanoparticles can induce extraordinary large electric field enhancements in the junctions between the particles of relevance for surface enhanced spectroscopies such as SERS. Such plasmonic couplings can also lead to plasmonic interference and coherence effects that manifest themselves as narrow Fano resonances in the optical spectra with extraordinary sensitivities to their dielectric environment. Until very recently, the modeling of the plasmonic response of closely coupled metallic nanoparticles has been made using classical approaches neglecting quantum mechanical effects such as electron tunneling between the particles and screening due to the finite electron density in the junction. In this talk we will present a fully quantum mechanical investigation of the plasmonic response of two coupled metallic nanoparticles as a function of interparticle separation. We identify three distinct regimes of interaction. In the classical regime for separations larger than 1 nm, the nanoparticles remain neutral and the plasmonic response is well described using classical theory. In the cross-over regime for separations between 0.5 and 1nm, electrons begin to tunnel between the nanoparticles and a reduction of the plasmonic couplings and field enhancements result. In the conductive regime for separations smaller than 0.5nm, a large conductive overlap is established between the two particles and a blue-shifted Charge Transfer Plasmon (CTP) emerges. The CTP is a collective plasmon mode which both includes a polarization of the electron distribution of each individual nanoparticle and a significant electron current between the two particles.

A02569-04582

Transformation Optics Applied to the Design of Plasmonic Devices

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Plasmonics offers a whole range of novel applications ranging from waveguides to sub wavelength resolution lenses. At the same time the technique of transformation optics shows how to map a device familiar in one geometry into an entirely new geometry. In this way, starting from the planar Veselago lens we can generate a whole family of lenses some of which act as sub wavelength magnifiers. Several other examples of mappings that take familiar systems and generate novel devices will be given.

A02768-04732

Poynting Vector Optics of Multilayer Superlenses

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A necessary condition for the near-field superlens is the excitation of coupled surface plasmon-polariton (SPP) modes at both interfaces of a metamaterial slab. For certain polarisations it is sufficient to rely on materials with only ε or μ negative. The most prominent example is a slab of silver that supports SPP modes with high k values due to its negative permittivity. Such a slab can be used to replicate field distribution from the objects with subwavelength features for TM polarisation. The excitation of coupled SPPs ceases, however, if the slab is not thin enough. A silver slab of 60 nm would, e.g., be too thick to act as a superlens at the wavelength of 360 nm. Yet, it is desirable for the image to be transferred over a larger distance.

The solution is offered in the form of a multilayer metamaterial made from a series of slabs with negative permittivity separated by layers with positive permittivity. The idea of such a multilayered metamaterials lens, first proposed in 2001 by Shamonina et al., was later discussed by many authors, verified experimentally and formed a basis of the design of the magnifying superlens, or hyperlens, with multiple cylindrical annuli.

Multilayered lens (both the flat and the cylindrical variety) can be regarded an anisotropic medium that features opposite signs of the permittivity tensor components parallel and normal to the boundaries of the layers. This type of anisotropy leads to an unusual hyperbolic dispersion equation. The result is that all high frequency components, evanescent in free space, turn into propagating components inside the metamaterial.

A simple way to visualise and understand the microscopic mechanism behind this unusual macroscopic picture is to rely on Poynting Vector Optics which, when dealing with subwavelength phenomena involving evanescent waves, is a useful alternative to the ray picture of Geometrical Optics. In a multilayer superlens, Poynting vector streamlines expand in the positive permittivity and contract in the negative permittivity layers thus refracting negatively. This physical picture is related to the excitation of short-wavelength SPP modes with the group velocity approaching zero. The net power flow along the boundary is indeed close to zero as the power flow outside the slab diverging away from the small object is compensated by the power flow inside the slab.

In this talk we provide an overview of Poynting Vector Optics of multilayer superlenses relating analytical and numerical results to experimental data on imaging. We address the key issues of excitation of surface plasmon-polaritons, of the optimisation of geometrical parameters, of the effect of losses and surface roughness on the image fidelity and on achievable resolution/magnification.

Acknowledgments:
Financial support of the DFG (Graduate School in Advanced Optical Technologies SAOT and Emmy Noether-Programme) is gratefully acknowledged.

A02770-04734

Plasmonics at the Nanoscale: Taking Light in New Directions

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Plasmonic structures provide extraordinary opportunities to manipulate light at the nanoscale, and to modify the optical far field in new ways. This is increasingly the case where symmetry breaking can modify the plasmonic properties of nanostructures: under reduced symmetry, dark modes become bright, and new interactions between plasmon modes ensue. Experiments as simple as placing a plasmonic nanoparticle on a dielectric surface lift mode degeneracies and provide new understandings of plasmon linewidths in real systems. Nanosystems of reduced symmetry can support both magnetoinductive and electroinductive plasmon modes, each with their own unique light-scattering signatures. Plasmonic properties can also be tailored to dramatically reduce the radiative lifetime and increase the quantum yield of molecules positioned near a metallic nanostructure, resulting in bright plasmon-emitter complexes that enable new frontiers in bioimaging in tissue and within single cells.

A02893-04956

Study Electromagnetic Near Field Around Metallic Nano Particles for Fluorescence Enhancement

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Fluorescence technology is attributed to the foundation of modern life science. Under special experimental approach, the high sensitivity of certain fluorophore leads to single molecule detection. However, there are still many fluorophores with unsatisfactory fluorescence emission. As a result of rapid development in life science, drug discovery and nano-scale detection, there has been endless quest for higher detection sensitivity. Among all the viable fluorescence enhancement approaches, the most promising is by using metallic nano particles for surface plasmon induced fluorescence enhancement, which is also termed as metal-enhanced fluorescence.

Metallic nanoparticles have optical extinction cross-sections that remarkably surpass their geometric cross-sections at certain wavelengths of light. While the peak position of the absorption and scattering spectra is relatively insensitive to changes in particle diameter, the surface plasmon resonance and the peak absorption efficiency of nano rods can be readily tuned from the visible into the infrared by changing the aspect ratio of the nano rods. Thus nano rods can be considered as easy-engineered “plasmonic absorbers” and “scatterers” with comparatively simpler shape than nano spheres. They have intrinsic advantages when serving as contrast agents, bio-markers and heat mediators.

A fluorophore in the excited state has the properties of an oscillating dipole. The excited fluorophore can induce oscillations of electrons in metal, and the electric field created by metal can interact with the excited fluorophore and alter its emission. This interaction is bidirectional so that light-induced oscillations in metal can affect the fluorophore. The distance between the fluorophore molecule and a nearby NP is a critical factor to determine whether quenching / enhancement of fluorescence occurs under light illumination. The interaction of fluorophores with metallic surface gives rise to a number of useful effects, including increased quantum yield, increased photo stability, increased distance for resonance energy transfer, and decreased lifetime. These changes can result in increased sensitivity, increased photo stability, decreased interference from unwanted background emission.

In this study we will investigate both the electromagnetic scattering phenomena due to metallic nanoparticle with silica shell and the effect of such nano-structure on fluorescence emission. We will present both the far field quantities such as scattering, absorption and extinction cross-sections, as well as description of the near field. The effect on fluorescence will be investigated in terms of quantitative relation between local field and fluorescence parameters such as quantum yield, lifetime, excitation rate and fluorescence rate. Both analytical and numerical analysis of local field enhancement will be given. The NPs are prepared with Ag or Au core and SiO_2 shell with shapes ranging from spherical to ellipsoidal and cylindrical. For bio-stability and feasibility in synthesis, SiO_2 is selected as the dielectric layer, whose function is to maintain an optimum distance between the NP and fluorophore molecules. The dependence of fluorescence on NP-fluorophore separation is used to guide the synthesis of the metallic core-shell structure. Preliminary fluorescence tests using tailor-made Au/Ag nano colloids and colloid coated thin films both give promising fluorescence enhancement.

A02950-05046

New Horizons of Nanoplasmonics: from SPASER to Attoseconds

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Nanoplasmonics deals with collective electron dynamics on the surface of metal nanostructures, which arises as a result of excitations called surface plasmons. The surface plasmons localize and concentrate optical energy in nanoscopic regions creating highly enhanced local optical fields. They undergo ultrafast dynamics with timescales as short as a few hundred attoseconds. There are numerous existing applications of nanoplasmonics: nanoantennas and waveguides for efficient coupling of light with semiconductor devices including photovoltaic cells and light-emitting diodes, labels for biomedical research, ultrasensitive detectors and sensors of molecules and biological objects for biomedicine and defense, etc. We will focus on the latest developments in nanoplasmonics. Among them is SPASER as a quantum nanoscale generator of optical fields [1, 2], generation of high harmonics in the EUV range [3], ultrafast optical modulator with THz bandwidth [4], generators and modulators of THz radiation [5], coherent control of ultrafast processes on the nanoscale [6-8], attosecond nanoplasmonic field microscope [9],etc.

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