Session 3P2 Plasmonic Nanophotonics II - Theory, Design and Simulation

Electromagnetic Forces in Metallic Cavity	
Shubo Wang, Jack Ng, Hui Liu, H. H. Zheng, Zhihong Hang, Che Ting Chan,	616
Plasmonic Metamaterials: From Total Absorption to High Tunneling	
Jiaming Hao, Laurent Santandréa, Said Zouhdi,	617
Engineering of Radiation of Optically Active Molecules with Chiral Nano-meta-particles	
Vasily V. Klimov,	618
Plasmonic Toroidal Metamaterials at Optical Frequencies	
Yao-Wei Huang, Wei Ting Chen, Pin Chieh Wu, You Zhe Ho, Yuan-Fong Chau, Nikolay I. Zheludev,	
Din Ping Tsai,	619
Generalization of Superscatterer Design and Photorealistic Raytracing Thereof	
Alireza Akbarzadeh, Tiancheng Han, Aaron J. Danner, Cheng-Wei Qiu,	620
Subwavelength Modulational Instability And Plasmon Oscillons in Arrays of Metal Nanoparticles	
Roman E. Noskov, Pavel A. Belov, Yuri S. Kivshar,	621
Study of Transformation Optics with Uniform and Non-uniform Grid in Electro-optical Simulation	
Jian-Shiung Hong, Wei-Ming Cheng, Ruei-Cheng Shiu, Yung-Chiang Lan, Kuan-Ren Chen,	622
Coherence-converting Plasmonic Hole Arrays	
Greg Gbur, Choon How Gan, Yalong Gu, T. D. Visser,	623
Design of Optical Hybrid-Hyperlens for Go beyond the Diffraction Limit	
B. H. Cheng, You Zhe Ho, Yung-Chiang Lan, Din Ping Tsai,	624
$ Design \ of \ a \ Castle-like \ Shape \ Plasmonic \ Nanoantenna \ with \ Wavelengths \ Ranging \ from \ UV, \ Visible \ Light $	
and IR Light	
Yuan-Fong Chau,	625
Electromagnetic Field Confinement in Self-similar Chains of Magnetoplasmonic Core-shell Nanostructures	
M. Essone Mezeme, S. Lasquellec, Christian Brosseau,	626
Plasmonic Roche Limit in Metal-Dielectric-Metal Structure	
Ruei-Cheng Shiu, Yung-Chiang Lan,	627

Electromagnetic Forces in Metallic Cavity

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Abstract—Particles can be trapped or manipulated using light [1] through light-induced forces. After the invention of the laser, optical forces have been extensively studied and find useful applications in various sub-fields in physics and beyond. Optical tweezers, as an example, have been widely used in atoms cooling and biologic cell/molecule (e.g., DNA) manipulations. Using a boundary element method, we studied the forces induced by electromagnetic waves in a metalair-metal sandwich structure, which forms a metallic cavity under certain polarization of the incident wave [2,3]. Different frequency regimes are considered, from the plasmonic regime with nano-scale structures down to the microwave regime, which involves millimeter-scale structures. We found that at both length scales, electromagnetic-wave-induced forces can be significantly stronger than the usual photon pressure exerted by a laser beam if the cavity is excited at resonance, although the mechanisms that underlie the strong force are very different at different length scales. In the plasmonic regime, the strong force is induced by field penetration into the metal and the dominance of the internal inductance, whereas in the microwave regime, the electromagnetic force is induced by the leakage of electric field at the edges. We showed that a transmission line model can give simple expressions that can capture the essence of the physics. The effects of surface corrugation and surface roughness are also investigated, and we find that corrugation/roughness generally induces attraction between the plates as a consequence of spoof surface plasmon effect.

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Plasmonic Metamaterials: From Total Absorption to High Tunneling

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Abstract— Plasmonic metamaterials are artificial materials composed by subwavelength local resonance structures. Much attention has been attracted recently due to which display fascinating physical properties and promise many potential applications involving waves and energy (e.g., negative refraction, the superlensing effect, polarization control and invisibility cloaking). However, the existences of intrinsic material losses would greatly detrimental to their performance. In this paper, we firstly apply the concept of plasmonic metamaterials to design perfect optical absorption devices, in which the loss properties of the materials have been sufficiently exploited rather than avoiding them. On the other hand, in comparison with total absorption, systems with greatly transparent properties based on plasmonic metamaterials are also studied. Theoretical analyses and Numerical efforts are preformed for both cases around optical communication frequencies. The potential impact of our proposed systems in the field of photonics and nanoscience are discussed also.

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Engineering of Radiation of Optically Active Molecules with Chiral Nano-meta-particles

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Abstract— It is well known that nanoparticles influence substantially both fluorescence of molecules and Raman scattering of light by molecules. These effects are especially strong in the case of metallic nanoparticles where plasmon resonances can be excited. When investigating such processes it is usually assumed that only electric dipole transitions are important. However, both electric and magnetic dipole momenta of transitions are important in chiral biomolecules. The goal of present work is to investigate influence of nanoparticles made of metamaterial on spontaneous emission of chiral molecules. We have built general theory, where decay rate was expressed through Green's function of Maxwell equations in presence of nanoparticle. Then we apply our general theory to spontaneous emission of chiral molecule placed near nanosphere made of different materials, including chiral "left-handed" metamaterial. We have found general conditions when radiation of right or left molecules can be fully suppressed. It paves the way to control radiation of chiral molecules. In Fig. 1, the example of our calculations is shown.

From this figure one can see the substantial (by a factor of fifty at $\varepsilon = -0.75$, see right panel of Fig. 1) influence of nanoparticles on spontaneous emission of chiral molecules with different chiralities ("right" and "left" molecules) due to appearance of interference between radiation of electric and magnetic dipoles. Let us stress that "left-handedness" of chiral sphere is of crucial importance for such discrimination.

An application of results obtained to separate racemic mixtures of drug enantiomers is suggested.



Figure 1: Relative decay rates of chiral molecules placed near chiral nanosphere. Blue curve corresponds to parallel orientation of electric and magnetic dipole moments of chiral molecule, while red curve corresponds to antiparallel orientations. (a) Dashed lines correspond to quasistatic approximation. (b) Ratio of decay rates of right and left molecules as function of sphere dielectric constant ε . Sphere parameters: Magnetic permeability $\mu = -1.9$, dimensionless chirality parameter $\kappa = 0.1$, size parameter $kR_0 = 0.1$. Electric and magnetic dipole momenta of chiral molecules are oriented along radius and their ratio is equal to $m_{or}/d_{or} = \pm 0.1$.

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Plasmonic Toroidal Metamaterials at Optical Frequencies

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Abstract— Toroidal dipole is created by currents flowing on a surface of a doughnut-shaped structure along its meridians first considered by Zel'dovich in 1957 [1]. Toroidal metamaterials were first theoretically proposed in 2007 [2]. In 2010, the toroidal metamaterials consisted by four three-dimensional resonant split rings show toroidal response in microwave region [3].

In this paper, we study the optical responses by integrating four U-shaped split-ring resonators (SRRs) together. The resonances of the four U-shaped SRRs array with magnetic field of incident light passing through the resonant rings was numerically investigated by using commercial software COMSOL 3.5a based on finite-element method (FEM). The permittivity of gold was described by the Lorentz-Drude model [4]. The size of a single U-shaped SRR is 250 nm (arms) $\times 300$ nm (bottom) and 50 nm line width wire loop. Simulation results shows toroidal and magnetic dipole resonance at free space wavelength 2520 nm and 2620 nm respectively. Incident light induced magnetic dipoles point in the same direction produced magnetic resonance. In contrast, four magnetic dipoles form a head-to-tail configuration which concentrates toroidal resonance.

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Generalization of Superscatterer Design and Photorealistic Raytracing Thereof

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Abstract— Enhancement of light scattering and absorption by optically small particles is of fundamental interest in both theoretical and experimental physics. It is known that the energy of light incident into a small particle is mostly stored in the near field and the radiation efficiency of such a particle is extremely low. In order to overcome this undesirable near field storage, different techniques have been proposed. Recently the concept of complementary media has been invoked to enrich the scattered or absorbed energy by a small particle, though the suggested approaches rely on initial knowledge of the spatial transformation [1, 2].

In this presentation, an inverse method based on the spatial transformation will be proposed to design a general superscatterer. In fact it will be shown that any well defined function can act as a generating function to produce the required parameters for the superscatterer profile. Accordingly the complementary media can be uniquely determined without having prior knowledge of the corresponding spatial transformation. However, the superscatterer profile is not unique and this inverse recipe is inclusive of all possible parametric profiles and hence leads to preferred field patterns in the complementary media. This concept provides a straightforward way to investigate the parameters of the superscatterer, which will be employed to obtain an isotropic retro-reflecting superscatterer with inhomogeneous negative refractive index. The mathematical formulation will be presented in a regressive manner in both 2D and 3D. Along with these calculations, several full wave simulations of the designed superscatterers will be provided, in which different generating functions will be examined. The required parameters for the design of an isotropic superscatterer will be driven and imaging characteristics of that will be studied. In addition to the full wave simulations, ray tracing analyses will be conducted to provide a better estimation on how the designed superscatterers actually work (Figures 1(a), (b)). On the basis of the given ray trajectories, time-flying animations will be illustrated to give an idea of how the superscatterers may look like in real life (Figures 1(c), (d)).



Figure 1: (a) Ray trajectories of a superscatterer. (b) Ray trajectories of a bare mirror which shows equivalence with the outgoing rays in (a). (c) A snapshot of the coated mirror (the superscatterer). (d) A snapshot of the bare mirror.

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Subwavelength Modulational Instability And Plasmon Oscillons in Arrays of Metal Nanoparticles

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Abstract— Nonlinearity-induced instabilities are observed in many branches of physics, and they provide probably the most dramatic manifestation of strongly nonlinear effects that can occur in Nature. Modulational instability in optics manifests itself in a decay of broad optical beams or quasi-continuous wave pulses into optical filaments or pulse trains [1], and such effects are well documented in both theory and experiment. It is expected that the study of subwave-length nonlinear systems such as metallic nanowires or arrays of nanoparticles will bring many new features to the physics of modulational instability and the scenarios of its development, however such effects were never studied before.

Over the past decade, surface plasmon polaritons were suggested as the mean to overcome the diffraction limit in optical systems. In particular, by using plasmons excited in a chain of resonantly coupled metallic nanoparticles [2], one can spatially confine and manipulate optical energy over distances much smaller than the wavelength. In addition, strong geometric confinement can boost efficiency of nonlinear optical effects, including the existence of subwavelength solitons [3, 4].

In our work, we study modulational instability in nonlinear arrays of subwavelength metal nanoparticles, and analyze numerically nonlinear scenarios of the instability development. We demonstrate that modulational instability can lead to the formation of regular periodic or quasiperiodic modulations of the polarization. We reveal that such nonlinear nanoparticle arrays can support long-lived standing and moving oscillating nonlinear localized modes which can be termed *plasmon oscillons*, in analogy with the similar localized modes excited in driven granular materials [5] and Newtonian fluids [6].

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Study of Transformation Optics with Uniform and Non-uniform Grid in Electro-optical Simulation

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Abstract— We employ the parallel 3D finite-difference time-domain (FDTD) method to simulate the enhanced transmission of electromagnetic wave through a rectangle subwavelength slit in an infinite film of perfectly electric conductor (PEC). Since the slit is much smaller than the wavelength, high resolution is required for the simulation so that the computation can be extremely large. The technique of transformation optics is applied to simulate a system with non-uniform cell size and thus to reduce significantly the computation requirement. It offers the possibility of realizing the coordinate mapping of light between physical and numerical system by changing the material properties, ε and μ , with a designed transform function. In the point view of simulation, the advantage of this technique can be taken so that the resolutions of both systems can be tuned. We design a physical system that has a higher resolution around the slit area as required while the resolution is lower at other areas so that the overall cell number is greatly reduced. With the use of transformation optics, the non-uniform physical cell system is transformed into a uniform numerical cell system while the uniform material properties become non-uniform. The Courant condition for numerical stability is also derived. The numerical cell system is then simulated by a FDTD code, MEEP. The numerical result yielded is then transformed back to physical system and is found to be consistent with a large computation with uniform physical cells and with the analytical result.

Coherence-converting Plasmonic Hole Arrays

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Abstract— It has been known for some time that the presence of surface plasmons on a metal plate can influence the amount of light transmitted through an array of subwavelength-size holes, in a phenomenon now referred to as "extraordinary optical transmission". This transmission is typically larger than that predicted by classical theoretical optics, though under certain circumstances it can also be smaller. Both enhanced and suppressed transmission has been shown to be the result of plasmon-mediated coupling of light emitted from different holes; this was demonstrated in a simple manner both theoretically and experimentally using a plasmonic version of Young's double slit experiment. In this experiment, a pair of slits were etched in a metal screen that supports plasmons at optical frequencies. The transmission showed strong oscillations as a function of wavelength, readily interpreted as interference between light directly transmitted through a hole with light coupled from the other hole via surface plasmons.

More recently, it has been shown that this coupling can also affect the spatial coherence of light in a Young-type interferometer with two or three slits [1]. The spatial coherence of light can be enhanced or suppressed on transmission through the interferometer, depending on the wavelength of light, the slit separation, and the light-plasmon coupling. This modification of spatial coherence is created by the plasmon-mediated mixing of light between apertures, and the modification can often range from complete spatial coherence to complete incoherence of the emerging wavefield.

Spatial coherence is an important characteristic of a light field, and can influence its propagation characteristics, spectral properties, polarization, and interference-causing capability. The existence of plasmon-induced coherence changes suggests that it may be possible to use an array of holes in a metal plate to change the global state of coherence of an optical beam, and could be extremely useful in applications where variable coherence is necessary.

In this paper, we extend the plasmon coherence results for the Young interferometer and consider the effect of surface plasmons on the spatial coherence of light on transmission through an array of holes in a metal plate. Simulations suggest that the overall global state of spatial coherence of a light beam can be modified on transmission, making a plasmonic hole array a "coherenceconverting" optical device.

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Design of Optical Hybrid-Hyperlens for Go beyond the Diffraction Limit

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Abstract— We proposed a new design device called "*Hybrid Hyperlens*" which is capable of overcoming the diffraction limit. This device is composed of two anisotopic metamaterials that possess opposite signs of the two permittivity tensor component in each constituent. The upper part is a planar layered metal-dielectric system proposed by Pendry et al. [1]. The lower part, "hyperlens" [2–4] takes a form of cylindrical metamaterial comprising periodic metal and dielectric layers. Both upper part and lower part which are the anisotropy medium have interesting properties. The subwavelength details of the object which are the high-spatial-frequency component are enhanced and transmitted through the upper hyperlens at certain frequencies [1]. Then the lower hyperlens form a magnified optical image of subwavelength object in the far field [3].

In this paper, we reported $150 \,\mathrm{nm}$ resolution at $410 \,\mathrm{nm}$ working wavelength with the flat object plane which is convenient for placing object.

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Design of a Castle-like Shape Plasmonic Nanoantenna with Wavelengths Ranging from UV, Visible Light and IR Light

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Abstract— A plasmonic nanoantenna is proposed and investigated numerically by using the three-dimensional finite element method. The influence of the dielectric hole in nanoshell on the antenna field enhancement and spectral response is discussed. Results show that the resonant wavelength of the proposed nanoantenna may be tuned over a broad spectral by considering the contour of a castle-like shape core antenna and introducing the design parameters, the gap distance and contour thickness. These new antennas allow for a threefold reduction in the antenna footprint and increase in the gap enhancement.



Figure 1: Corresponding power flow on side view and top view: (a) for solid case and (b) for DHs cases.

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Electromagnetic Field Confinement in Self-similar Chains of Magnetoplasmonic Core-shell Nanostructures

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Abstract— We apply first-principles methodology to study the spatial localization of electric field enhancement at plasmonic resonance and magnetic field enhancement at gyroresonance in a self-similar chain of magnetoplasmonic core-shell nanostructures (MCSN). Localized regions of high electric and magnetic fields in the vicinity of metal nanostructures can be created in a controlled manner by adjusting the physical parameters characterizing this system and the polarization of the external harmonic excitations. We demonstrate the high degree of control achieved on electric field confinement, of the order of 10^3 , down to a feature size of $\lambda/1000$ in self-similar chains of MCSN, where λ denotes the free space wavelength of the resonant excitation. We also compare our findings with recent investigations in related plasmonic nanostructures.

Plasmonic Roche Limit in Metal-Dielectric-Metal Structure

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Abstract— Roche limit, an astronomy phenomenon observed in a two-star system, defines the trajectories within which a celestial body will be disintegrated by the gravitational fields of the two stars. Roche limit can be mimicked by the coupled surface plasmon that propagates in a designed Metal-Dielectric-Metal (MDM) structure. When the MDM structure contains two neighboring circle regions in which the refraction index of dielectric layer has the same function form as the gravity potential (i.e., $n(r) \propto 1/r$), a Gaussian beam that moves in the plasmonic Roche limit will also be disintegrated by the optical force. This phenomenon has never been proposed and observed in the literature. In this work, plasmonic Roche limit is investigated by using both FDTD simulations and theoretical analyses. The simulation results exhibit that the relative magnitude of the refraction index gradients between the first and second circles strongly modulated the motion of the incident beam. That the beam will rotate around the first circle or disperse and approach the second circle depends on its incident position being within or outside the plasmonic Roche limit. The beam's trajectories forecasted by ray optics method and Newton's law of motion closely correspond to the simulation results.