June 14-15, 2016

Plasmonics Workshop

Duke University, Durham, North Carolina

Program

CENTER FOR METAMATERIALS AND INTEGRATED PLASMONICS

Message from the organizers

The last few years have been very exciting for the field of plasmonics. First, development of theoretical and computational approaches have improved our understanding of plasmons, particularly as the critical dimensions are shrunk to the scale of the nanometer and the effects of nonlocality become significant.

The parallel developments in the field of metamaterials have also offered a new way to interpret the collective properties of plasmonic elements, leading to the creation of metasurfaces and perfect absorbers, for example.

To the surprise of many, plasmonics has also proved to be an excellent platform for many nonlinear effects. Even though field enhancements are moderate, the field can be compressed into extremely small volumes, leading to very large Purcell factors. Some results even suggest that plasmonics may play an important role in the realization of optical computing.

None of these developments would have been possible without new fabrication approaches, such as film-coupled nanoparticles. These new platforms have enabled the confirmation of theoretical and computational predictions, such as nonlocality, as well as the demonstration of many of newly proposed devices.

We believe it is a great moment to reflect on the advancements that have taken place in recent years; it is our pleasure to welcome all of you at Duke University for this Plasmonics Workshop. We would like to thank the speakers who have accepted our invitation and we look forward to a great program.

Stéphane Larouche
Maiken Mikkelsen
David R. Smith

Program June 14 2015

9:00–9:10	**David Smith** *Welcome message*	Schiciano auditorium
9:10–9:30	**David R. Smith** *Film-coupled nanoparticles: A successful platform for investigating plasmonic enhancement*	
9:30–10:00	**John B. Pendry** *Transforming, cloaking and harvesting*	
10:00–10:30	**Antoine Moreau** *Physics of gap-plasmons*	
10:30–11:00	**Coffee break**	
11:00–11:30	**Maiken Mikkelsen** *Large Purcell enhancement: From dye molecules to single quantum dots*	Schiciano auditorium
11:30–12:00	**Christos Argyropoulos** *Strong light-matter interactions with plasmonic and dielectric optical metamaterials*	
12:00–13:30	**Lunch**	CIEMAS atrium first floor
13:30–14:00	**Alexandre Baron** *Nonlinear optics with surface plasmons*	Schiciano auditorium
14:00–14:20	**Xiaojun Liu, Stéphane Larouche and David R. Smith** *Retrieval method of nonlinear metasurfaces*	
14:20–14:40	**Zhiqin Huang, Alexandre Baron, Stéphane Larouche, Christos Argyopoulos, and David R. Smith** *New numerical method on optical bistability*	
14:40–15:15	**Coffee break**	
15:15–15:45	**Cristian Ciracì** *The impact of the electron density in mesoscopic plasmonic systems*	Schiciano auditorium
15:45–16:15	**Antonio I. Fernández-Domínguez** *Transformation optics approach to plasmon-exciton strong coupling in nanocavities*	
16:15–16:45	**Paloma Arroyo Huidobro** *Graphene plasmonic metasurfaces with transformation optics*	
18:30	**Banquet (upon invitation)**	Parizade 2200 W Main St

Program June 15 2015

9:00–9:30	**Yu Luo** *Transformation optics and spoof plasmon hybridization*	Schiciano auditorium
9:30–10:00	**Rongkuo Zhao Yu Luo, and John B. Pendry** *Fluctuation Induced Electromagnetic Interactions between Nanostructures*	
10:00–10:20	**Roberto Zecca, Patrick T. Bowen, David R. Smith, and Stéphane Larouche** *Advances in modeling of stimulated Brillouin scattering*	
10:20–11:00	**Coffee break**	
11:00–11:30	**Aloyse Degiron** *Parity-time symmetry and artificial electroluminescence*	Schiciano auditorium
11:30–12:00	**Stéphane Larouche** *Anisotropic and resonant diffractive devices*	
11:50–13:30	**Lunch**	CIEMAS atrium first floor
13:30–13:50	**Jiani Huang, Gleb M. Akselrod, Tian Ming, Jing Kong, and Maiken H. Mikkelsen** *Selectively controlling the exciton emission of monolayer MoS2 using a tunable plasmonic nanocavity*	Schiciano auditorium
13:50–14:10	**Thang B. Hoang, Ankun Yang, Montacer Dridi, Claire Deeb, George C. Schatz, Teri W. Odom, and Maiken H. Mikkelsen** *Active tuning and long coherence characteristics of a lattice plasmon laser*	
14:10–14:30	**Patrick T. Bowen and David R. Smith** *Effective medium theory of a metasurface composed of a periodic array of nanoantennas coupled to a metallic film*	
14:30–15:00	**Coffee break**	
15:00–15:30	**Willie Padilla** *The impact of surface electromagnetic waves on metamaterial absorbers*	Schiciano auditorium
15:30–16:00	**Gleb Akselrod** *Colloidal plasmonic metasurfaces*	
16:00–16:20	**Jon W. Stewart, Gleb M. Akselrod, David R. Smith, and Maiken H. Mikkelsen** *Multiscale metasurface absorbers for hyperspectral optoelectronic*	

Abstracts
(in alphabetical order of first author)

Gleb M. Akselrod

Duke University, USA

Colloidal Plasmonic Metasurfaces

Absorption of light is a central to devices such as photovoltaics, photodetectors, imaging sensors, biosensors. Naturally occurring materials either have weak absorption or produce strong reflections, and have poorly defined spectral features beyond the visible spectrum. In this talk I will discuss our work at Duke on creating artificial materials that have controlled absorption resonances not possible with natural materials. Each meta-atom is composed of a deeply-subwavelength metallic nanocube coupled to a metal film. Metasurfaces composed of such elements have unique and highly customizable absorption features for various optoelectronic and coating applications. The fabrication method that we have developed for these metasurfaces is colloidal and assembly can be done in solution, making this approach highly scalable and commercializable.

Christos Argyropoulos

University of Nebraska-Lincoln, USA

Strong light-matter interactions with plasmonic and dielectric optical metamaterials

Plasmonic and dielectric optical metamaterials can tailor, control and manipulate the electromagnetic radiation in unprecedented ways and at nanoscale regions leading to strong light-matter interactions. Metals or high refractive index dielectrics can be used to construct these nanophotonic systems. The large field enhancement in the vicinity of these systems due to localized or collective resonances ensures a significant boosting of optical nonlinear effects, collective spontaneous emission (superradiance), and other quantum effects at the weak and strong coupling regime. In addition, two dimensional (2D) materials, such as graphene, can be integrated in these resonating systems and hybrid reconfigurable metadevices can be obtained with new functionalities. In my talk, I will present recent theoretical and experimental advances towards demonstrating new designs based on these technologies. Several future integrated nanophotonic components and optoelectronic systems are envisioned based on the proposed hybrid nanostructures, such as tunable optical sensors and filters, nonlinear optical wave mixers and low-THz sources, nanolasers, all-optical switches and efficient electro-optical modulators with compact footprints.

Paloma Arroyo Huidobro

Imperial College, UK

Graphene plasmonic metasurfaces with transformation optics

In this talk I will present a tunable plasmonic metasurface by considering a graphene sheet subject to a periodically patterned doping level. The unique optical properties of graphene result in electrically tunable plasmons that allow for extreme confinement of electromagnetic energy in the technologically significant regime of THz frequencies. Here we add an extra degree of freedom by using graphene as a metasurface, proposing to dope it with an electrical gate patterned in the micron or sub-micron scale. By extracting the effective conductivity of the sheet we characterize metasurfaces periodically modulated along one or two directions. In the first case, and making use of the analytical insight provided by transformation optics, we show an efficient control of THz radiation for one polarization. In the second case, we characterize numerically a metasurface with an isotropic response that is independent of wave polarization and orientation.

Alexandre Baron

Université de Bordeaux, France

Nonlinear optics with surface plasmons

Nonlinear optics plays a major role in modern photonics applications, because it has enabled the development of ultrafast lasers, optical frequency converters, nonlinear microscopy and optical switches. Surface plasmons, which are coupled oscillations of electromagnetic radiation and charge density at metal/dielectric interfaces, are of particular interest in this context because they carry highly concentrated fields well below the diffraction limit. Since enhancing power densities lowers the nonlinear threshold, surface plasmons may hold the potential for designing efficient or highly sensitive nonlinear devices. The metamaterials and nanophotonics communities have both taken an interest in nonlinear plasmonics recently, though often by designing situations where the dielectric is considered to be the nonlinear material. However metals are known to have high nonlinear optical susceptibilities. The nonlinear physics of metals is rich as it has different origins depending on the time-scale over which the nonlinearity is probed. I will present our work on ultrafast nonlinear plasmonics. We focus on situations where both the metal and the dielectric materials are nonlinear and derive a metric that enables us to determine which of the two materials is the dominant contributor to nonlinearity. We also investigate experimentally the nonlinear response of plasmonic waveguides composed of a single air/gold interface to intense 100 fs pulses. These measurements reveal that the surface plasmon undergoes strong self-action in the form of self-induced absorption.

Patrick T. Bowen and David R. Smith

Duke University, USA

Effective medium theory of a metasurface composed of a periodic array of nanoantennas coupled to a metallic film

An effective medium theory of film-coupled metasurfaces is presented, where a metasurface is placed close enough to a metal film such that the dipoles that comprise the metasurface couple to surface plasmon modes of the metal film. The susceptibility of the metasurface is found by explicitly evaluating the interaction constant, which is the infinite sum of fields from all the dipoles in the lattice. It is shown that the radiation reaction force due to the coupling to the surface plasmon modes is exactly canceled by the forces that the dipoles exert on each other, and the lattice thereby conserves energy in the limit of zero Ohmic loss. When Ohmic losses are present, the overall loss of the lattice to absorption in surface plasmons is given by the imaginary part of the interaction constant, which may be compared with the losses to radiation and Ohmic absorption in the metasurface.

Cristian Ciracì

Istituto Italiano di Tecnologia, Italy

The impact of the electron density in mesoscopic plasmonic systems

Form the theory stand point, it is really challenging to fully take into account the multi-scale nature of such systems. A density functional approach allows a full description of the quantum nature of the free electrons however, it becomes prohibitive for clusters that exceed only few thousands atoms. An alternative approach is to use the hydrodynamic model that takes into account the nonlocal behavior of the electron response by including the electron pressure. The Hydrodynamic model can be generalized in order to describe nonlocal and spill-out effects near metal surfaces by using orbital-free energy functionals. We show that the hydrodynamic model can be derived from first-principles, and examine the approximations that lead to the quantum hydrodynamic equation. We explore the impact of the equilibrium charge density in such model for the case of spherical nanoparticles and compare our results to time-dependent density functional theory based calculations up to 5000 electrons. Our implementation allows to compute extinction spectra for spheres or more in general axis symmetric structures of order of many tens of nanometer in size, describing the full range of effects going from the nonlocal/spill-out effects up to retardation effects.

Aloyse Degiron

Université Paris Sud, France

Parity-time symmetry and artificial electroluminescence

This presentation will focus on two developments in the field of active plasmonics. First, we will see that plasmonic absorption losses can be turned into an asset by realizing the optical equivalent of Parity-Time (PT) symmetry—a concept invented to extend the validity of quantum mechanics to non-Hermitian operators. The idea is to add gain in the system so as to create “exceptional” points around which new intriguing properties emerge. Second, we will see how plasmonics can be used to develop metamaterial-based optoelectronic components. In particular, I will introduce the concept of structural electroluminescence (arising from the hybridization between plasmonic nanostructures and colloidal quantum dots) and discuss the potential of this approach for LEDs, displays, light-harvesting devices and sensors.

Antonio I. Fernández-Domínguez

Universidad Autónoma de Madrid, Spain

Transformation optics approach to plasmon-exciton strong coupling in nanocavities

In this talk, I will present a transformation optics description of the electromagnetic interaction between a single quantum emitter and the localized plasmonic modes supported by a dimer of metal particles separated by a nanometric gap. I will employ this methodology, which incorporates naturally the full richness of the plasmonic spectrum supported by this system, to explore the conditions yielding plasmon-exciton strong coupling at the single emitter level in this archetypal nano-optical cavity.

Thang B. Hoang[1], Ankun Yang[2], Montacer Dridi[2], Claire Deeb[2], George C. Schatz[2], Teri W. Odom[2], and Maiken H. Mikkelsen[1]

1 Duke University, USA
2 Northwestern University, USA

Active tuning and long coherence characteristics of a lattice plasmon laser

We experimentally report dynamic tuning of an optically-pumped plasmon laser based on lattice plasmon resonance of arrays of gold nanoparticles and liquid gain materials [A. Yang, T. B. Hoang *et al*, *Nature Communications*, 6, 6939 (2015)]. The plasmon laser consists of an array of gold disks with 120 nm in diameter, 50 nm height and 600 nm spacing. Liquid gain medium composed of IR-140 dye molecules dissolved in a variety of organic solvents. By changing the dielectric environment surrounding the gold nanodisks, the lasing wavelength can be dynamically tuned over a 55 nm range. We will also discuss recent experiments where we probe both the temporal and spatial coherence characteristics of the plasmon laser by using a combination of a modified Michelson interferometer and ultrafast pulse measurement techniques. The tunable plasmon laser offers opportunities to enhance and detect weak physical and chemical processes at the nanoscale in real time as well as insight into the coherence characteristics from arrays of nanoscale plasmon resonators.

Jiani Huang[1], Gleb M. Akselrod[1], Tian Ming[2], Jing Kong[2], and Maiken H. Mikkelsen[1]

1 Duke University, Durham, USA
2 Massachusetts Institute of Technology, USA

Selectively controlling the exciton emission of monolayer MoS_2 using a tunable plasmonic nanocavity

Tailoring the interaction between light and matter is critical for the performance of optoelectronic and nanophotonic devices. Two-dimensional molybdenum disulfide (MoS_2) with extraordinary optical responses is an ideal candidate for a wide range of applications such as photodetectors, field effect transistors and photovoltaics. However, atomically thin MoS_2 monolayer suffers from weak light absorption (~3 %) and low photoluminescence (PL) quantum yield (~0.4 %). Furthermore, among its complex excitonic states, the B exciton emission is inherently weak compared to the dominant A exciton emission. Here, we demonstrate the selective enhancements of the A or B exciton peaks by integrating monolayer MoS_2 into plasmonic nanocavities with tunable plasmon resonances. By tuning the nanocavity resonance across the emission spectrum, we observe a 1,200-fold enhancement for the A exciton peak and a 6,100-fold enhancement for the B exciton peak. Moreover, we show a strong modification of the PL emission peaks and reveal a correlation between the emission wavelengths and the plasmon resonances. In contrast to the free space PL spectrum with a dominant A exciton peak, we observe a dominant B exciton peak when the nanocavity is resonant with the B exciton emission. Manipulating the optical properties of these two-dimensional materials using tunable plasmon resonances is promising for the design of novel optical devices with precisely tailored responses.

Zhiqin Huang[1], Alexandre Baron[2], Stéphane Larouche[1], Christos Argyopoulos[3], and David R. Smith[1]

1 Duke University, USA
2 Université de Bordeaux, France
3 University of Nebraska-Lincoln, USA

New numerical method on optical bistability

Optical bistability is an intensity-dependent nonlinear absorption or refraction effect, where an optical device can have two stable states for the same input. The traditional approach to investigate the properties of such devices, the geometric approach, assumes that the related field is uniform. This assumption is obviously not accurate in the case of a plasmonic device such as the film-coupled nanocube system. In this presentation, we will present a new numerical approach based on finite element simulations that properly accounts for the inhomogenous distribution of the field. We will present some bistable plasmonic devices designed with this approach, including devices incorporating anisotropic materials.

Stéphane Larouche

Duke University, USA

Anisotropic and resonant diffractive devices

Metamaterials and metasurfaces offer new possibilities for the fabrication of diffractive devices. In this talk, I will demonstrate two examples of diffractive devices recently realized at Duke. First, I will present an anisotropic hologram which produces different images when illuminated with different polarizations. Second, I will present an hologram realized with a metasurface made of resonant elements which offers great phase control as well as high efficiency with a single layer of elements.

Xiaojun Liu, Stéphane Larouche and David R. Smith

Duke University, USA

Retrieval method of nonlinear metasurfaces

A patterned, plasmonic metasurface can strongly scatter incident light, functioning as an extremely low-profile lens, filter, reflector or other optical device. When the metasurface is patterned uniformly, its linear optical properties can be expressed using effective surface electric and magnetic polarizabilities obtained through a homogenization procedure. The homogenized description of a nonlinear metamaterial or metasurface, however, presents challenges both because of the inherent anisotropy of the medium as well as the much larger set of potential wave interactions available, making it challenging to assign effective nonlinear parameters to the otherwise inhomogeneous layer of metamaterial elements. We present a homogenization procedure to describe nonlinear metasurfaces, from which a set of effective nonlinear surface susceptibilities are uniquely determined. We start from the generalized sheet transition conditions (GSTCs) that describe the interactions between electromagnetic waves and a nonlinear metasurface by assigning effective surface nonlinear polarizations. These effective nonlinear surface polarizations densities are linked to the effect effective nonlinear surface susceptibilities and the averaged electromagnetic fields at both the pumping and nonlinear frequencies across the metasurface. The effective nonlinear surface susceptibilities can be uniquely determined by inverting the GSTCs. The validation of the retrieval method is demonstrated by retrieving the nonlinear surface susceptibilities of a homogenous nonlinear slab and a nonlinear metasurface. The method is applicable to any periodically metasurface whose thickness is much smaller than wavelength, with inclusions of arbitrary geometry and material composition from microwave regime and optical regime.

Yu Luo

Nanyang Technological University, Singapore

Transformation optics and spoof plasmon hybridization

Plasmon hybridization between closely spaced nanoparticles leads to new hybrid modes not found in individual constituents. This phenomenon suggests a feasible way to tune the resonance properties as well as field enhancement capabilities of metallic nanostructures. Until now, experimental verifications of plasmon hybridization have been limited to optical frequencies. At the lower frequency range (far infrared, terahertz, or microwave), metals feature poor confinement of electromagnetic fields, and hence do not support surface plasmons. In this talk, we introduce the concept of spoof plasmon hybridization, i.e. strong plasmonic coupling between adjacent metal structures corrugated with subwavelength textures. We demonstrated experimentally that the collective modes supported by such spoof plasmonic system can be categorized to bonding and antibonding resonances in analogy to existing hybridization of both molecular orbitals and plasmons. Moreover, such collective modes can be easily manipulated to produce enormous field enhancements at microwave frequencies. Our observation not only extends the range of applicability of the hybridization model, but also provides insightful guidance to export the exciting applications (e.g. sensing, nonlinearity enhancing, etc.) associated with plasmon hybridization at optical frequencies to the lower spectral range.

Maiken H. Mikkelsen

Duke University, USA

Large Purcell enhancement: From dye molecules to single quantum dots

In this talk, I will describe our recent experiments utilizing a tunable plasmonic platform where emitters are sandwiched in a sub-10-nm gap between colloidally synthesized silver nanocubes and a metal film. Utilizing dye molecules with an intrinsic long lifetime reveals spontaneous emission rate enhancements exceeding a factor of 1,000 while maintaining directional emission and high quantum efficiency [Nature Photon. 8, 835 (2014)]. Incorporating colloidal CdSe/ZnS semiconductor quantum dots into the nanocavities enables ultrafast spontaneous emission corresponding to emission rates exceeding 90 GHz [Nat. Commun. 6, 7788 (2015)] as well as an ultrafast and efficient single photon source [Nano Lett., 16, 270 (2016)]. Leveraging higher-order modes of the cavity allows optical processes at multiple energies to be optimized simultaneously. We demonstrate this by enhancing both the absorption and the quantum yield in monolayer MoS_2 resulting in a 2,000-fold enhancement in the overall fluorescence [Nano Lett. 15, 3578 (2015)]. Finally, pointing towards future reconfigurable devices, the plasmon resonance can be tuned electrically over 100 nm in the visible by applying a bias across the nanoscale gap which causes changes in the gap thickness and dielectric environment [Appl. Phys. Lett. 108, 183107 (2016)].

Antoine Moreau

Université Blaise Pascal, France

Physics of gap-plasmons

Gap-plasmons, the mode propagating in a gap typically smaller than the skin depth in metals, allow to build deeply subwavelength resonators in the visible regime and thus self-assembled metasurfaces with the potential to efficiently absorb, or scatter light. The fact that huge Purcell effect and fluorescence enhancements have been demonstrated recently contributed to the attention they attracted. It appears relevant to discuss some fundamental aspects of the physics of gap-plasmon, that we have recently studied.

Using the energy point of view, we first tried to give a physical insight into the reasons why the wavevector of gap-plasmons is theoretically diverging when the gap tends to zero. We have then studied how gap-plasmons are reflected when they meet the edges of a patch and shown that there is a critical angle above which the gap-plasmons were totally reflected—and that this angle can be related to the surface plasmon effective index. Optical patch antennas can be considered as cavities excited from all sides, which allows an interferometric control of the absorption to occur in these resonators. Building on this idea, we have an almost purely analytical expression for the fields under 2D patch antennas and for the absorption, clearly showing the effect. Furthermore, gap-plasmons are sensitive to the spatial dispersion in metals because of their high wavevectors. Following this idea, we found several situations for which nonlocality could manifest itself clearly, paving the way for eventual future experiments. Finally, there is a limit to the maximum wavevector that gap-plasmons can reach. We have a model taking into the way electrons spill out of metals that shows it is the first phenomenon likely to limit the wavevector.

Willie Padilla

Duke University, USA

The impact of surface electromagnetic waves on metamaterial absorbers

Metamaterial absorbers have been demonstrated across much of the electromagnetic spectrum and exhibit both broad and narrow-band absorption for normally incident radiation. Absorption diminishes for increasing angles of incidence and transverse electric polarization falls off much more rapidly than transverse magnetic. We unambiguously demonstrate that broad-angle TM behavior cannot be associated with periodicity, but rather is due to coupling with a surface electromagnetic mode that is both supported by, and well described via the effective optical constants of the metamaterial where we achieve a resonant wavelength that is 19.1 times larger than the unit cell. Experimental results are supported by simulations and we highlight the potential to modify the angular response of absorbers by tailoring the surface wave.

John B. Pendry,

Imperial College, UK

Transforming, cloaking and harvesting

The paradigm of function through structure permeates much of recent electromagnetic research. Metamaterials enabled the first realisation of negative refraction and provided the wherewithal to construct the first cloak of invisibility. Transformation optics provided the design = specifications for the cloak, built here at Duke, and gave a new understanding of negative refraction as "negative space". More recently transformation optics has been applied to of plasmonic systems where the surface structure dramatically changes the response to light. Seemingly diverse singularities in surface structure, such as touching surfaces, or knife edges, all of which act as concentrators of electromagnetic energy, can be related to a common "ancestor" through singular transformations.

David R. Smith

Duke University, USA

Film-coupled nanoparticles: A successful platform for investigating plasmonic enhancement

The film-coupled nanoparticle provides a robust and reproducible platform for the study of many plasmonic phenomena. Early investigations of many plasmonic effects—such as surface-enhanced Raman scattering, fluorescence enhancement, or nonlinear enhancement—were hampered by the lack of control over the features and gaps of plasmonic structures. The film-coupled nanoparticle system, however, leverages planar deposition and fabrication techniques, such that the gap between a nanoparticle and its electromagnetic image can be precisely controlled over large areas with sub-nanometer precision. This platform has enabled far more controlled experiments to go forward, allowing us to probe even effects such as the non-locality of electron response. In this talk, I will describe the path our group has taken, in collaboration with Sir John Pendry's group, to develop and apply the film-coupled nanoparticle platform for a variety of plasmonic studies.

Jon W. Stewart, Gleb M. Akselrod, David R. Smith, and Maiken H. Mikkelsen

Duke University, USA

Multiscale metasurface absorbers for hyperspectral optoelectronic

Multispectral imaging is an extremely powerful technique in a wide variety of fields including, chemical analysis, surveillance, remote sensing, and geospatial analysis. Current approaches for multispectral imaging require complex, bulky, and expensive optical systems. One approach to overcome these limitations is by constructing multispectral photodetectors with spectrally selective pixels to simultaneously achieve spatial and spectral resolution. However to date, plasmonic pixels have been unable to simultaneously achieve spectral selectivity, strong absorption, and scalable fabrication. Here we demonstrate high-performance plasmonic multispectral pixel arrays based on gap-plasmon resonators that exhibit absorptions upwards of 85 percent with spectral widths near 100 nm. The key to our approach is a multiscale fabrication method, which combines bottom-up colloidal fabrication to form the plasmonic elements and top-down fabrication to define the pixels. By tuning the size of the plasmonic resonators, the sub-pixels can span resonances from 580 to 1125 nm. We demonstrate the power of our approach by reconstructing an RGB image using the plasmonic pixels, which show over 9,000 possible plasmonic color combinations. Integrating the passive plasmonic metasurfaces with an electrically active material is promising for future on-chip multispectral photodetectors in the infrared.

Roberto Zecca, Patrick T. Bowen, David R. Smith, and Stéphane Larouche

Duke University, USA

Advances in modeling of stimulated Brillouin scattering

Stimulated Brillouin scattering (SBS) is the stimulated nonlinear interaction between two photons and an acoustic phonon. Recently, there have been efforts to investigate waveguide systems able to greatly enhance SBS effects, e.g. amplification and slow light. To describe such devices, theories and computational approaches have been established, but they all suffer from fundamental flaws that prevent them from capturing the SBS phenomenon in its entirety. In this work, we show how the current methods fail and present a revised coupled-mode theory and a novel finite-element, frequency-domain simulation strategy based on transformation optics. We demonstrate how these descriptions are self-consistent, and we demonstrate their application to a simple two-dimensional backward-SBS dielectric waveguide.

Rongkuo Zhao[1,2] Yu Luo[2,3], and John B. Pendry[2]

1 University of California-Berkeley, USA
2 Imperial College, UK
3 Nanyang Technological University, Singapore

Fluctuation Induced Electromagnetic Interactions between Nanostructures

On an electrically neutral surface, fluctuations of charge density can randomly produce temporary charges. When two surfaces approach each other, the instant charges on one surface induce opposite charges on the other. The electromagnetic interactions between these fluctuation-induced charges give rise to attractive force between closely spaced nanostructures – the so called van der Waals force or Casimir force. It plays an important role in surface adhesion and friction, and nanoparticle self-assembly. Remarkably, this is the mechanism for gecko to walk on ceilings. On the other hand, if two separated surfaces undergo relative lateral motion, charges on one surface cannot follow up the ones on the other due to material resistance. The lateral interactions give frictional forces via the shearing vacuum.

In my talk, I will overview my past work on repulsive Casimir force, van der Waals force between plasmonic nanoparticles with transformation optics, and quantum friction. (1) In most cases the resulting Casimir force between the two media is always attractive, which is a challenge for flexibly operating the micro/nano- electromechanical system devices. I [2] proposed a possibility to use cross-polarizable materials (e.g., chiral metamaterial, topological insulator, etc) if the ability of the cross-polarization is strong enough. (2) Exact calculation of van der Waals interactions between closely spaced metallic nanoparticles is challenging both numerically and analytically due to strong concentration of electromagnetic fields at the nearly touching gap between them. Transformation optics is capable of mapping a small volume into any desired length scale [3]. Applied it to the study of the van der Waals interactions, I could obtain not only fast convergence of exact calculations but also very accurate analytical approximations [4]. The nonlocal effect can also be appropriately considered [5]. (3) The quantum frictional force acting on a small sphere rotating near a surface was theoretically investigated [6]. The prominent enhancement and the realistic geometry open up the possibility of experimental verification.