Frontier's Lectures on Metamaterials and Plasmonics

July 24 (Mon.), Seoul National University
Room 118, Building 301, Dept. of ECE

Lecturer	Session	Title
	08:50-09:00	**Opening**
Thomas Zentgraf	09:00-10:00	**Nonlinear Metasurfaces**
Jensen Li	10:00-11:00	**Spin-enabled optics with metamaterials and metasurfaces**
Yongmin Liu	11:00-12:00	**Reconfigurable Plasmonics and Metamaterials**
	12:00-13:30	**Lunch**
Mu Wang	13:30-13:55	**Meet Editors – Physical Review Letters**
Zachary Lapin	13:55-14:20	**Meet Editors – Nature Communications**
Ling Lu	14:20-15:20	**Topological Photonic Crystals**
	15:20-15:30	**Coffee Break**
Andrey Miroshnichenko	15:30-16:30	**Multipole decomposition and nonradiating sources in nanophotonics/metamaterials**
Renmin Ma	16:30-17:30	**Plasmonic nanolasers: fundamental, application and challenges**
Cristian Ciracì	17:30-18:30	**The optics of film-coupled nanoparticles: a bridge to the quantum realm**

Tutorial is free of charge, but registration is required. Please follow the link below to register:
https://docs.google.com/forms/d/1w4N8SrZSUlfRWgeuqDhmHoIDmMCgp9L7xEoPc5kowBI/edit

Chairs:

Namkyoo Park
Seoul National University

Hakjoo Lee
CAMM

Junsuk Rho
POSTECH

Session will be held in **Multimedia Room 118 of Building 301**
Lunch will be served at the faculty **cafeteria, first floor of Building 301**

Access to Meta Pre-conference
- Rm. 118, Building 301, Seoul National University

- **From ‘*Incheon*’ or ‘*Gimpo*’ International Airport**

- **By public transportation** [~2 hours: KRW ~10,200 (Incheon),~1.5 hour: KRW ~5,200 (Gimpo)]
o Board the limousine bus line number **6003** (The bus stop is **6A,12B in Incheon and 6 in Gimpo**).
o Get off at the front gate of Seoul National University.
o Board a bus line **5511 or 5513, or take a taxi.**
o Get off at either bus stop number 9 or 10 which are in front of buildings 301 and 302 (**last stop**).
- By taxi [~1 hour, KRW ~49,000 (Incheon), ~1 hour, KRW ~19,600 (Gimpo)]

- **From Seoul Station**

- **By public transportation** [~1 hour, KRW ~1300]
o Take the subway (**line No. 4**) **from Seoul station to Sadang station.**
o Transfer the subway line from No. 4 to No. 2.
o Take the subway (**line No. 2**) **from Sadang to Nakseongdae station.**
o Get out of **Exit 4**, turn left around the GS gas station, and board a bus line **02**.
o Get off in front of buildings 301 and 302 (**last stop**).
- By taxi [~45 minutes, KRW ~13,500]

- **From Songdo Convensia, Incheon**

- **By public transportation** [~1 hour, KRW ~2,000]
o Take the subway (**line Incheon No. 1**) **from Incheon Nat’l Univ station to Bupyeong station.**
o Transfer the subway line from ‘Incheon No. 1’ to ‘No. 1’ (not Incheon No. 1!).
o Take the subway (**line No. 1**) **from Bupyeong to Sindorim station.**
o Transfer the subway line from ‘No. 1’ to ‘No. 2’.
o Take the subway (**line No. 2**) **from Sindorim to Nakseongdae station.**
o Get out of **Exit 4**, turn left around the GS gas station, and board a bus line **2**.
o Get off in front of buildings 301 and 302 (**last stop**).
- By taxi [~45 minutes, KRW ~32,500]

Campus Map of Seoul National University

Accommodation

No.	Name	Distance	Rates	
1	**Hoam Faculty House**	4km (Bus #02, to the last stop: 15 minutes)	Standard Double (KRW 104,500) Standard Twin (KRW 104,500) Deluxe Double (KRW 148,500) Deluxe Twin (KRW 148,500)	http://www.hoam.ac.kr/
2	**Novotel Ambassador Seoul Doksan**	10km (~1 hour)	Superior Double (KRW 125,000) Superior Twin (KRW 125,000)	https://www.ambatel.com/main.amb?null
3	**Shilla Stay Guro**	10km (~1 hour)	Standard Double (KRW 126,000) Standard Twin (KRW 126,000) Deluxe Double (KRW 137,000)	http://www.shillastay.com/guro/index.do
4	**Sheraton Seoul Palace Gangnam Hotel**	14km (~1 hour)	Deluxe Double (KRW 147,250) Deluxe Twin (KRW 147,250)	http://www.sheratonseoulpalace.com/overview
5	**Mercure Ambassador Gangnam**	13.5km (~1 hour)	Standard Double (KRW 132,300) Standard Twin (KRW 132,300) Superior Double (KRW 146,300)	https://mercure.ambatel.com/gangnam/meeting/hallInfo.amb?brand_code=M0456&gnbCode=040000&lnbCode=040200&menu_se=M1244

*Hotel information is just for your reference. You have your own responsibility to reserve your accommodation.

Nonlinear Metasurfaces

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For efficient nonlinear processes the engineering of the nonlinear optical properties of media becomes important. In particular, the phase relation between the fundamental and the nonlinear waves plays here an important role. The most well-known technique for spatially engineering nonlinear properties is the quasi-phase matching scheme for second-order processes like second harmonic generation (SHG). The quasi-phase matching leads to efficient frequency conversion compared to a homogeneous nonlinear medium by providing the extra momentum to compensate the phase mismatch between the fundamental and harmonic waves. The so-called 'poling' is the most widely employed technique for achieving quasi-phase matching. By periodically reversing the crystalline orientation of ferroelectric materials, the sign of the $\chi^{(2)}$ nonlinear susceptibility can be spatially modulated along the propagation direction. However, such a poling only leads to a binary state for the nonlinear material polarization, which is equivalent to a discrete phase change of π of the nonlinear polarization.

Here I will discuss a novel nonlinear metamaterial with homogeneous linear optical properties but continuously controllable phase of the local effective nonlinear polarizability. For the demonstration we use plasmonic metasurfaces with various designs for the meta-atom geometry together with circular polarized light states. The controllable nonlinearity phase results from the phase accumulation due to the polarization change along the polarization path on the Poincare Sphere (the so-called Pancharatnam-Berry phase) and depends therefore only on the spatial geometry of the metasurface. By using a fixed orientation of the meta-atom the nonlinear phase can be spatially arbitrarily tailored over the entire range from 0 to 2π. In contrast to the quasi-phase matching scheme the continuous phase engineering of the effective nonlinear polarizability enables complete control of the propagation of harmonic generation signals, and therefore, it seamlessly combines the generation and manipulation of the harmonic waves for highly compact nonlinear nanophotonic devices. We will demonstrate the concept of phase engineering for the manipulation of the SHG and THG from metasurfaces and the restriction on the symmetry properties of the geometry.

Furthermore, I will discuss a nonlinear Berry phase in the time domain which arises from the rotational Doppler shift that can be observed on spinning metasurfaces. The rotational Doppler shift in nonlinear optics was predicted nearly 50 years ago and recently demonstrated at nonlinear crystals. The Doppler frequency shift was determined for the SHG of a circularly polarized beam passing through a spinning nonlinear optical BBO crystal with three-fold rotational symmetry. In our experiments we found that the SHG signal with a circular polarization opposite to that of the fundamental beam experiences a Doppler shift of three times the rotation frequency of the optical crystal. This finding is of fundamental significance in nonlinear optics and also for tailored nonlinearities, as it provides a further degree of freedom with the design of nonlinear materials, in particular for moving media. We will briefly discuss how this rotational Doppler Effect can be also utilized for spinning metasurfaces in the nonlinear regime.

Biography: Professor Thomas Zentgraf received his bachelor's degree of Engineering from University of Applied Sciences Jena, Germany, in 2001 and a master's degree of Physics of the Technical University Clausthal, Germany, in 2002. After that, he joined the University of Stuttgart, Germany, where he under the supervision of Professor Harald Giessen received his PhD in the 2006. Prof Zentgraf was honored with a Feodor-Lynen-Fellowship by the Alexander von Humboldt Foundation in 2007 and joined as a research fellow the group of Professor Xiang Zhang at the Mechanical Engineering Department at University of California at Berkeley, USA. In 2011 he returned to Germany and became full professor for Applied Physics at the Department of Physics, University of Paderborn, where he is head of the Ultrafast Nanophotonics Group. His research interests focus on using ultrafast spectroscopy to study linear and nonlinear effects in plasmonic and dielectric metamaterials and plasmonic-hybrid materials.

Spin-enabled optics with metamaterials and metasurfaces

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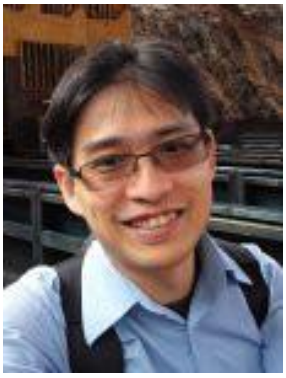

Light, similar to other vector waves such as elastic waves, has a spin-degree of freedom in its propagation. The interaction between spin and motion provides an interesting way to manipulate the orbital motion of light, in addition to the driving force from a refractive index gradient in conventional optics. In this tutorial, I will give an introduction of geometric phase and the associated optical-spin Hall effect in a systematic approach and will show its applications and new opportunities in metamaterials and metasurfaces. For example, the optical spin-Hall effect can be utilized to control dynamically the generation of surface plasmon on a plasmonic metasurface by putting a tailor-made array of anisotropic metamaterial atoms on a surface. When these anisotropic metamaterial atoms are assembled into a three dimensional material, I will also show how these can be used to generate a pseudo-magnetic field or gauge field for photon, which can guide light into cyclotron motion, as if it is a real magnetic field acting on electron motion. These discussions provide a feasible route to spin-enabled optics.

Biography: Dr. Jensen Li received his BEng degree with first class honours in electrical and electronic engineering from the University of Hong Kong in 1998 and his MPhil, PhD degree in physics from the Hong Kong University of Science and Technology in 2000 and 2004. In this period of time, he worked on the zero-th order photonic band gap and the theoretical proposal of acoustic negative index metamaterials.

From 2005 to 2007, Jensen worked in Imperial College London, with support from a Croucher Foundation postdoctoral fellowship, where he developed a theoretical scheme of carpet cloaking.

From 2007 to 2009, he was a postdoctoral researcher at the University of California at Berkeley, participated in the realization of carpet cloaking at infrared frequencies. He also started to work on acoustic metamaterials with super-resolution there.

From 2009 to 2013, he was an assistant professor at the City University of Hong Kong. He continued his research in metamaterials and also worked on alternative schemes in achieving acoustic negative indices without local resonance from theory to realization.In 2013, he joined University of Birmingham as a senior lecturer.

Reconfigurable Plasmonics and Metamaterials

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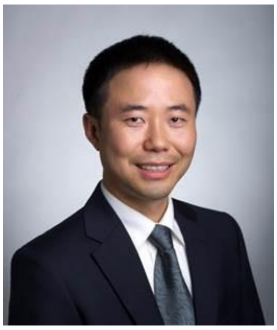

Plasmonics has become a very important branch in nano optics. It allows us to concentrate, guide, and manipulate light at the deep subwavelength scale, promising enhanced light-matter interaction, next-generation optical circuits, sub-diffraction-limited imaging, and ultrasensitive biomedical detection [1-3]. Furthermore, the assembly of judiciously designed metallic structures can be used to construct metamaterials and metasurfaces with exotic properties and functionalities, including anomalous refraction/reflection, strong chirality and invisibility cloak [4,5]. There is a pressing need of tunability and reconfigurability for plasmonics and metamaterials, in order to perform distinctive functionalities and miniaturize the device footprint. In this talk, I will present our recent work in reconfigurable plasmonics and metamateirals. First, I will discuss the first demonstration of reconfigurable plasmonic lenses operating in microfluidic environment, which can dynamically diverge, collimate and focus surface plasmons [6]. Second, I will present a novel graphene metasurface to fully control the phase and amplitude of infrared light with very high efficiency. It manifests broad applications in beam steering, biochemical sensing and adaptive optics in the crucial infrared wavelength range [7]. Finally, I will discuss origami-based, dual-band chiral metasurfaces at microwave frequencies. The flexibility in folding the metasurface provides another degree of freedom for geometry control in the third dimension, which induces strong chirality from the initial, 2D achiral structure [8]. These results open up a new avenue towards lightweight reconfigurable metadevices.

References: [1] S. A. Maier, "Plasmonics: fundamentals and applications", Springer Science+ Business Media (2007); [2] T. Zentgraf et al., "Plasmonic Luneburg and Eaton lenses", **Nature Nanotechnology** 6, 151 (2011); [3] Y. M. Liu, et al., "Compact magnetic antennas for directional excitation of surface plasmons", **Nano Letters** 12, 4853 (2012); [4] Y. M. Liu and X. Zhang, "Metamaterials: a new frontier of science and technology", **Chemical Society Reviews** 40, 2494 (2011); [5] K. Yao and Y. M. Liu, "Plasmonic metamaterials", **Nanotechnology Review** 3, 177 (2014); [6] C. L. Zhao et al., "A reconfigurable plasmofluidic lens", **Nature Communications** 4:2350 (2013); [7] Z. B. Li et al., "Graphene plasmonic metasurfaces to steer infrared light", **Scientific Reports** 5, 12423 (2015); [8] Z. Wang et al., manuscript in preparation.

Biography: Dr. Yongmin Liu obtained his Ph.D. from the University of California, Berkeley in 2009. He joined the faculty of Northeastern University at Boston in fall 2012 with a joint appointment in the Department of Mechanical & Industrial Engineering and the Department of Electrical & Computer Engineering. Dr. Liu's research interests include nano optics, nanoscale materials and engineering, plasmonics, metamaterials, biophotonics, and nano optomechanics. He has authored and co-authored over 50 journal papers, including *Science*, *Nature*, *Nature Nanotechnology*, *Nature Communications*, *Physical Review Letters* and *Nano Letters*. Dr. Liu received Office of Naval Research Young Investigator Award (2016), 3M Non-Tenured Faculty Award (2016), Air Force Summer Faculty Fellowship (2015), and Chinese Government Award for Outstanding Students Abroad (2009). Currently he serves as an editorial board member for *Scientific Reports*, *EPJ Applied Metamaterials* and *Nano Convergence*.

Topological Photonic Crystals

Ling Lu
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Due to the recent discovery of topological insulators, it has been recognized that topology is indispensable in distinguishing phases of matter. Similarly, new optical material systems are being discovered with non-trivial topologies of their global wave-functions in the momentum space, whose interfaces support novel states of light with ideal transport properties such as the robustness to large disorder or fabrication imperfections.

In this talk, I will show experimental realizations and theoretical predictions of 2D and 3D photonic crystals with topologically protected edge and surface states. Specifically, I will discuss single and multimode one-way waveguides, the observation of Weyl points, a single Dirac cone surface state immune to random disorder and topological one-way fibers. This research can be extended to phonons, plasmons and other bosons. These new degrees of freedom in bosonic band topologies promise wide exciting opportunities in both fundamental physics and technological outcomes.

Biography: Ling Lu is a professor in the Institute of Physics of Chinese Academy of Sciences in Beijing China. He obtained his bachelor in Physics in 2003 from Fudan University in Shanghai, China. He got his Ph.D. in Electrical Engineering in 2010 at University of Southern California in Los Angeles. His thesis work, advised by Prof. John O'Brien, was on photonic crystal nanocavity lasers. He was a postdoc and later a research scientist in the Physics Department of Massachusetts Institute of Technology, where he worked with Prof. Marin Soljačić and John Joannopoulos and collaborated with Prof. Liang Fu. His current research focuses on topological photonics.

Multipole decomposition and nonradiating sources in nanophotonics and metamaterials

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Multipole decomposition is indispensable tool in analyzing the optical response of nanoscale structures consisting of finite size elements. In general, there are two complementary approaches based on Cartesian (current) multipoles and Spherical (scattered field) multipoles. For subewavelength elements they produce similar description. But for larger elements certain deviations might occur. In this tutorial, I will provide the basic description of both methods and specify kind of complementary information they provide. I will also introduce the concept of nonradiation sources, provide specific examples of so-called *anapole* modes and demonstrate the importance of toroidal dipole moments.

References:

1. Kaelberer, M. et al., *Science* **330**, 1510, (2010).
2. Chen, J. et al., *Nature Photonics* **5**, 531 (2011).
3. Grahn, P. et al., *New J. Phys.* **14** 093033 (2012).
4. Miroshnichenko, A. E. et al., *Nature Comm.* **6**, 8069 (2015).

Biography: A/Prof. Andrey Miroshnichenko obtained his PhD in 2003 from the Max-Planck Institute for Physics of Complex Systems in Dresden, Germany. In 2004 he moved to Australia to join the Nonlinear Physics Centre at ANU. During this time A/Prof. Miroshnichenko made fundamentally important contributions to the field of photonic crystals and bringing the concept of the Fano resonances to photonics. In 2007 A/Prof. Miroshnichenko was awarded by APD Fellowship from the Australian Research Council. It allowed him to initiate the research on a new class of tunable photonic structures infiltrated with liquid crystals. Later, in 2011 he was awarded by Future Fellowship from the Australian Research Council. During this period, he pioneered the research of high-index dielectric nanoparticles in the visible range, including one of the first demonstrations of the optically induced magnetic response in silicon nanoparticles. The current topics of his research are nonlinear nanophotonics, topologiccal photonics, and resonant interaction of light with nanoclusters, including optical nanoantennas and metamaterials.

Plasmonic nanolasers: fundamental, application and challenges

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Plasmonic nanolasers are a new class of quantum amplifiers that deliver coherent surface plasmons well below the diffraction barrier which brings fundamentally new capabilities to biochemical sensing, super-resolution imaging and on-chip optical communication. In this talk, I will review fundamental, application and challenges of this emergent device.

Biography: Ren-Min Ma is an assistant professor in the School of Physics, Peking University. He received his PhD from Peking University. His dissertation was focused on semiconductor physics and devices in low dimensional structures and received the National Top 100 Ph.D. dissertations of China Award. He was a postdoc researcher at UC Berkeley during 2009-2014. He developed the first room temperature semiconductor plasmon laser, directionally emitted waveguide embedded plasmon laser and applied plasmon lasers to sensing field. His current research interests include nanophotonics and nanomaterials.

The optics of film-coupled nanoparticles: a bridge to the quantum realm

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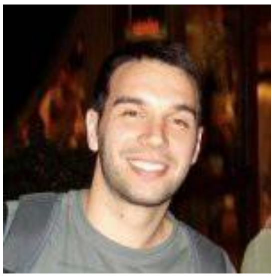

Metals support surface plasmons at optical wavelengths and have the ability to localize light to sub-wavelength regions. The film-coupled nanoparticle system—in which plasmonic nanoparticles are separated nanometer distances from a metal film by an insulating spacer—has unique properties that make it useful for a variety of processes depending on the nanoparticle shape. Nanospheres that are coupled to a film, for example, have been predicted to produce enormous field enhancements—as much as thousands of times that of the incident radiation—in the separating region between nanoparticle and film. For the narrowest (<1 nm) gaps, light can be so tightly confined that the nonlocality associated with the dielectric response of the metal and quantum effects can have a strong impact on the scattering properties of the system, placing strict bounds on the ultimate field enhancement.

Another interesting system is that of nanocubes or planar structures, which support transmission line-like modes between the two planar metal contact regions. Collective scattering of film-coupled nanocubes can strongly modify reflectance properties of the underlying surfaces, creating a nearly ideal absorber at desired wavelengths. The controlled reflectance of the surface might provide a means for enhancing nonlinearity, for example by allowing potentially all of a fundamental beam to be converted into higher harmonics. Moreover, we numerically find a sub-nm gap regime in which nonlocal effects can dramatically enhance the nonlinear optical response of the metal by several order of magnitude.

All mentioned structures can be easily and cheaply fabricated using colloidal nanoparticles, surface chemistries, or atomic layer deposition lithography, allowing for near angstrom-scale control over the spacer thickness and large-area uniformity. At the same time, a reliable way to theoretically describe and numerically model optical properties of plasmonic nanostructures with different length scales requires methods beyond classical electromagnetism. In this tutorial I will present an implementation of the hydrodynamic model that takes into account the nonlocal behavior of the electron response by including the electron pressure and it is generalized so that it can describe electron spill-out and tunneling effects, including nonlocal broadening near metal surfaces.

Biography: Cristian Ciracì obtained his BSc in Computer Science Engineering in February 2005 and his MSc in Science for Engineering in July 2007 at Sapienza, University of Rome (Italy). He received his Ph.D. in Condensed Matter Physics from University of Montpellier, France, with honor degree in September 2010. In November 2010 he joined the Center for Integrated Metamaterials and Plasmonics at **Duke University (U.S.)** as a Postdoc. In March 2014 he joined the Center for Biomolecular Nanotechnologies at the **Istituto Italiano di Tecnologia (IIT)**, Italy, where he currently holds a position as Researcher. His main research activities concern numerical modeling and investigation of electromagnetic propagation in complex media, with particular emphasis on nonlinear optical phenomena. During the years of his research activity he has co-authored several publications on top-tier scientific journals and has been invited to several international conferences. In 2012 his work was featured on the **cover of Science Magazine**.