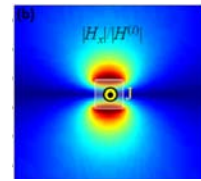
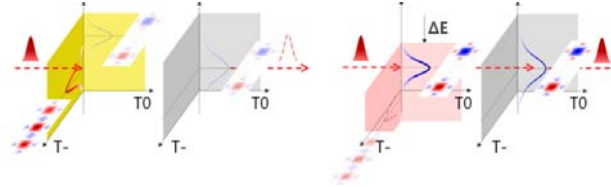
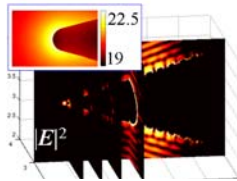


Distinguished Lectures on Plasmonics (*Post-conference of SPP5*)

**May 21-22, Seoul National University
Room 118, Building 301, School of EECS**



Lecturer	Session	Title	Saturday (May 21)
	08.45-09.00	Opening	
Mark Brongersma	09.00-11.00	Plasmonics : Fundamentals & Information Devices	
Luis Martin Moreno	11.00-12.30	Extra-Ordinary Transmission	
	12.30-14.00	Lunch : Cafeteria at 1 st Floor, Semi-buffet	
Lukas Novotny	14.00-15.30	From Near-field Optics to Optical Antennas	
Martin Wegener	15.30-17.00	Metamaterials and Transformation Optics	

Lecturer	Session	Title	Sunday (May 22)
	08.45-09.00	Opening	
Harry A. Atwater	09.00-10.30	Plasmonics in Photovoltaics	
Harald Giessen	10.30-12.00	Coupling 3D Metamaterials and Plasmonic Oligomers	
	12.00-13.30	Lunch : Cafeteria at 1 st Floor, Semi-buffet	
Ajay Nahata	13.30-15.00	THz Plasmonics	
Jacob Khurgin	15.00-16.30	Fundamental limits of Plasmonics : Battling Loss	

Session Chairs ; N. K. Park (SNU), J. H. Shin (KAIST), B. Min (KAIST), K. S. Yu (KAIST)

Chairs ;

Namkyoo Park (SNU), Jung H. Shin (KAIST), and Mark Brongersma (Stanford)



Organized by ;

Global Research Lab (SNU, EECS), and World Class University (GSNT, KAIST)

Financial Supports ;

SNU : Office of Research Affairs, Research Support Ctr (College of Engineering), BK21 (EECS)



서울대학교 연구처
Research Affairs of SNU

ENGINEERING
COLLEGE OF ENGINEERING
SEOUL NATIONAL UNIVERSITY
서울대학교 공과대학

BK21 정보기술사업단
BK21 INFORMATION TECHNOLOGY

Access to the Building 301, School Of EECS, Seoul National University.

- **Seoul National University Station on Seoul subway line number 2 (green line).**
 - Exit on the Seoul National University side.
 - Board bus line 5511, 5512, or 5513 (fee : KRW 900 in cache) or board the Shuttle bus operated by Seoul National University or take a taxi
 - Get off at either bus stop number 9 or 10 which are in front of buildings 301 and 302.
- **NakSeongDae Station on Seoul subway line number 2 (green line)**
 - Exit on the In Hun elementary school side (Exit 4).
 - Board local bus number 02
 - Get off at either bus stop number 9 or 10.
 - **For the conference, free-shuttle dedicated for the attendees will be provided, at 8.10am, & 8.45am (departing Nakseongdae Shuttle bus stop in below, connecting Hoam guest house and Bldg 301)**



- **Using buses**
 - NakSeongDae line : local bus number 02
 - Shillim-dong line : 5516
 - Bongcheon-dong line : 5511, 5512 or 5513
- **From Incheon International Airport**
 - Board the limousine bus line number 603 (The bus stop is 5B or 12A).
 - Get off at the front gate of Seoul National University
 - Board a campus shuttle bus or bus line 5511, 5512, 5513 or 5516
 - Get off at the bus stop number 9 or 10.

<http://www.useoul.edu/> About SNU / Maps and Directions / Campus Map



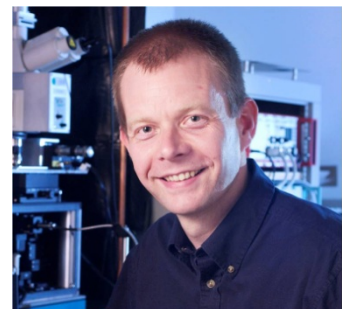
Plasmonics - Fundamentals and Information Devices

Plasmonics is an exciting new field of science and technology that aims to exploit the unique optical properties of metallic nanostructures to enable routing and manipulation of light at the nanoscale. Nanometallic objects derive these properties from their ability to support collective electron excitations, known as surface plasmons (SPs). Presently we are witnessing an explosive growth in both the number and range of plasmonics applications; it is becoming eminently clear that both new fundamental science and device technologies are being enabled by the current plasmonics revolution. The intention of this tutorial is to give the participants a fundamental background and working knowledge of the main physical ideas used in chip-scale plasmonic structures and devices, as well as an overview of modern uses in information technology devices.

The tutorial will begin with a general overview of the field of plasmonics. This will be followed by an introduction to the basic concepts that enable one to understand and design a range of plasmonic functionalities. This part will be followed by an in-depth discussion of a range of active and passive plasmonic devices that have recently emerged. Particular attention will be given to nanometallic structures in which surface plasmons can be generated, routed, switched, amplified, and detected. It will be shown that the intrinsically small size of plasmonic devices directly results in higher operating speeds and facilitates an improved synergy between optical and electronic components. At the end of the tutorial, a critical assessment of the entire field is given and some of the truly exciting new opportunities for chip-scale plasmonics are identified.

Biography

Mark Brongersma is an Associate Professor and Keck Faculty Scholar in the Department of Materials Science and Engineering at Stanford University. He leads a research team of eight students and four postdocs. Their research is directed towards the development and physical analysis of new materials and structures that find use in nanoscale electronic and photonic devices. His most recent work has focused on Si-based light-emitting materials, light sources, modulators, detectors, and metallic nanostructures that can manipulate and actively control the flow of light at the nanoscale. Brongersma has given over 50 invited presentations in the last 5 years on the topic of nanophotonics and plasmonics. He has also presented 3 tutorials at International conferences on these topics. He has authored/co-authored over 85 publications, including papers in Science, Nature Photonics, Nature Materials, and Nature Nanotechnology. He also holds a number of patents in the area of Si microphotonic and plasmonics. He received a National Science Foundation Career Award, the Walter J. Gores Award for Excellence in Teaching, the International Raymond and Beverly Sackler Prize in the Physical Sciences (Physics) for his work on plasmonics, and is a Fellow of the Optical Society of America. Dr. Brongersma received his PhD in Materials Science from the FOM Institute in Amsterdam, The Netherlands, in 1998. From 1998-2001 he was a postdoctoral research fellow at the California Institute of Technology.



Extraordinary transmission

Extraordinary optical transmission (EOT) is a phenomenon in which a structure containing subwavelength apertures in an opaque screen transmits more light than might naively be expected from the knowledge of the transmission through individual apertures. Its discovery in 1998 by Ebbesen and coworkers [1] triggered a wealth of experimental and theoretical studies that, in turn, have revealed new effects [2] such as: EOT and beaming of light in single apertures flanked by surface corrugations, the strong influence of the hole shape on transmission properties in both hole arrays and isolated holes, and interesting nonlinear transmission effects.

This tutorial will present the main physical mechanisms at work in the different aspects of EOT, such as the influence of surface electromagnetic modes and of localized resonances within the holes. We will show that these mechanisms have a broad applicability to other types of waves, so some of EOT phenomena found for electromagnetic fields can be transferred (*mutatis mutandis*) to acoustics or matter waves.

[1] T. W. Ebbesen, H. J. Lezec, H. F. Ghaemi, T. Thio, and P. A. Wolff, 1998, *Nature* _London_ 391, 667.

[2] For a review, see F.J. Garcia-Vidal, L. Martin-Moreno, T. W. Ebbesen, and L. Kuipers, *Rev. Mod. Phys.* 82, 729 (2010)

Biography

Luis Martin-Moreno is a Professor at the Instituto de Ciencia de Materiales de Aragon (Consejo Superior de Investigaciones Cientificas and Universidad de Zaragoza), placed in Zaragoza (Spain). He leads a research group of two students and three post-docs. Their research is on different theoretical aspects of Nanophotonics, concentrating on the optical transmission through apertures in metal films, guided plasmon modes and nanofocusing, and the design of effective electromagnetic susceptibilities through surface patterning. Martin-Moreno has given over 20 invited presentations in the last 5 years on the topic of nanophotonics and plasmonics. He has authored/co-authored over 150 publications, including papers in *Science*, *Nature Physics*, *Nature Photonics*, and *Physical Review Letters*. Prof. Martin-Moreno received his PhD in Physics from the Universidad Autonoma de Madrid, Spain, in 1989. From 1989-1992 he was a postdoctoral research fellow at the Cavendish Laboratory in Cambridge (UK) and from 1993-1995 he had a postdoctoral position at the Instituto de Ciencia de Materiales de Madrid, spending several periods at the Imperial College of London. From then till 2008 he was a lecturer at the Universidad the Zaragoza.



From Near-field Optics to Optical Antennas

In optics, lenses and mirrors are used to redirect the wavefronts of propagating optical radiation. Strong focusing of light can be achieved by directing light from a large angular range towards a common point (the focus). The paraxial approximation is no longer valid for strongly focused light and, consequently, it is not possible to describe a strongly focused laser beam by a Gaussian beam. The angular spectrum representation provides a theoretical framework to understand strongly focused light and to discuss applications ranging from science to technology.

Because of diffraction there is a limit for the degree of light localization that can be achieved with propagating fields. Roughly speaking, propagating radiation cannot be localized to dimensions much smaller than the optical wavelength. To overcome the diffraction limit it is necessary to include non-propagating, evanescent waves in the light-matter interaction; a feat originally pursued in the field of Near-field Optics. Several schemes of near-field microscopy have been developed ranging from apertures to scattering centers. Today, near-field optical probes are commonly viewed as optical antennas, devices designed to efficiently convert optical radiation into localized energy, and vice versa.



Optical antennas enhance the interaction between light and matter, and have the potential to boost the efficiency of optoelectronic devices ranging from light-emitting diodes to solar cells. For short separations between antenna and sample (e.g. receiver / transmitter) we are no longer able to ignore the mutual interaction and have to consider short-range forces and energy transfer.

In this lecture I will review the history of near-field optics and optical antennas and demonstrate their use for localizing optical radiation to length-scales much smaller than the wavelength of light. I will discuss experiments that use a single molecule as an elementary receiver and transmitter and demonstrate that the emission efficiency can be controllably increased by two orders of magnitude.

Biography

Lukas Novotny is a Professor at the University of Rochester's Institute of Optics where he heads the Nano-Optics research group. Novotny earned his MS and PhD degrees from the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland. From 1996-99 he was a postdoctoral fellow at the Pacific Northwest National Laboratory, working on new schemes of single molecule detection. In 1999 he joined the faculty of the Institute of Optics. Novotny's general interest is in localized light-matter interactions with applications ranging from solid-state physics to biology. Ongoing projects are described under www.nano-optics.org.



Metamaterials and Transformation Optics

Ideally, in optics, we would like to bend light at our own will. Such bending would be possible if we were able to distort the space-time continuum at will. Such distortions may indeed occur on a cosmic scale due to heavy masses in the framework of General Relativity, but they are not feasible in the laboratory. However, transformation optics allows for mapping the required distortions of actual space onto equivalent distortions of optical space. This means that the local electric permittivity and the local magnetic permeability have to be varied in a mathematically well-defined pre-described manner. Metamaterials allow for realizing these spatially inhomogeneous structures.

In this talk, I will give an introduction into this field and review our recent experiments regarding three-dimensional structures operating at infrared or visible frequencies. Our fabrication approach based on direct laser writing, including work using stimulated emission depletion to beat the diffraction limit, will also be reviewed. Examples include gold-helix metamaterials, three-dimensional telecom-wavelength carpet cloaks and three-dimensional invisibility cloaks operating at visible wavelengths.

Biography

After completing his PhD in physics in 1987 at Johann Wolfgang Goethe-Universität Frankfurt (Germany), Martin Wegener spent two years as a postdoc at AT&T Bell Laboratories in Holmdel (U.S.A.). From 1990-1995 he was C3-Professor at Universität Dortmund (Germany), since 1995 he is C4-Professor at Universität Karlsruhe (TH). Since 2001 he has a joint appointment at Institut für Nanotechnologie of Forschungszentrum Karlsruhe GmbH. Since 2001 he is also the coordinator of the DFG-Center for Functional Nanostructures (CFN) in Karlsruhe. His research interests comprise ultrafast optics, (extreme) nonlinear optics, near-field optics, photonic crystals, photonic metamaterials, and transformation optics. This research has led to various awards and honors, among which are the Alfried Krupp von Bohlen und Halbach Research Award 1993, the Baden-Württemberg Teaching Award 1998, the DFG Gottfried Wilhelm Leibniz Award 2000, the European Union René Descartes Prize 2005, the Baden-Württemberg Research Award 2005, and the Carl Zeiss Research Award 2006. He is a member of Leopoldina, the German Academy of Sciences (since 2006), Fellow of the Optical Society of America (since 2008), Fellow of the Hector Foundation (since 2008), and Adjunct Professor at the Optical Sciences Center, Tucson, U.S.A. (since 2009).



Plasmonic and Metamaterials in Photovoltaics

Solar energy is currently enjoying substantial growth and investment, owing to worldwide sensitivity to energy security and sustainability, and this has spurred basic research on light-matter interactions relevant to solar energy and photovoltaics. I will discuss design of light-trapping plasmonic structures and metamaterials to enhance photovoltaic conversion efficiency. Conventionally, photovoltaic cells have had physical thicknesses comparable to their 'optical thickness' for full light absorption and photocarrier current collection. Solar cell design and material synthesis considerations are strongly dictated by this simple optical thickness requirement. Dramatically reducing the absorber layer thickness or volume confers several fundamental and practical benefits, including increased open circuit voltage and conversion efficiency, and also expansion of the scope and quality of absorber materials that are suitable for photovoltaics. Design approaches using metallic nanostructures can also enhance the radiative emission rate and hence also the photovoltaic material quantum efficiency relative to conventional light-trapping structures. Finally, future design metamaterials for broadband resonant absorption and spectrum-splitting will be discussed.

Web Resources: LMI-EFRC: <http://lmi.caltech.edu/> Atwater Group: <http://daedalus.caltech.edu/>

Biography

Harry Atwater is currently Howard Hughes Professor and Professor of Applied Physics and Materials Science at the California Institute of Technology. His research interests center around two interwoven research themes: photovoltaics and solar energy; and plasmonics and optical metamaterials. Atwater and his group have been active in photovoltaics research for more than 20 years. Recently they have created new photovoltaic devices, including the silicon wire array solar cell, and layer-transferred fabrication approaches to III-V semiconductor III-V and multijunction cells, as well as making advances in plasmonic light absorber structures for III-V compound and silicon thin films. He is an early pioneer in surface plasmon photonics. He has authored or co-authored over 200 publications, and his group's developments in the solar and plasmonics field have been featured in Scientific American and in research papers in Science, Nature Materials, Nature Photonics and Advanced Materials.

Atwater received his S.B. (1981), S.M. (1983), and Ph.D. (1987) in Electrical Engineering from the Massachusetts Institute of Technology. He currently serves as as Director of the DOE Energy Frontier Research Center on Light-Matter Interactions in Solar Energy Conversion (<http://lmi.caltech.edu>) and was recently named Director of the Resnick Institute for Science, Energy and Sustainability, <http://resnick.caltech.edu/>, Caltech's largest endowed research program focused on energy. Atwater is founder and chief technical advisor for Alta Devices, a venture-backed company in Santa Clara, CA developing a transformational high efficiency/low cost photovoltaics technology, and SiWire, which is developing a flexible high-efficiency silicon photovoltaics technology. He has also served an editorial board member for Surface Review and Letters. Professor Atwater has consulted extensively for industry and government, and has actively served the materials community in various capacities, including Material Research Society Meeting Chair (1997), Materials Research Society President (2000). In 2008, he served as Chair for the Gordon Research Conference on Plasmonics. Atwater has been honored by awards including the MRS Kavli Lecturer in Nanoscience in 2010; Popular Mechanics Breakthrough Award, 2010; Joop Los Fellowship from the Dutch Society for Fundamental Research on Matter in 2005, A.T. & T. Foundation Award, 1990; NSF Presidential Young Investigator Award, 1989.



3-D optical metamaterials and nanoantennas: Chirality, Coupling, & Sensing

Metallic metamaterials have shown a number of fascinating properties over the last few years. A negative refractive index, negative refraction, superlenses, and optical cloaking are some of the ambitious applications where metamaterials hold great promise. We are going to present fabrication methods for the manufacturing of 3D metamaterials [1]. We are investigating their coupling properties and the resulting optical spectra. Hybridization of the electric [2] as well as the magnetic [3] resonances allows us to easily understand the complex optical properties. Lateral as well as vertical coupling can result in Fano-resonances [4] and EIT-like phenomena [5, 6]. These phenomena allow to construct novel LSPR sensors with a figure of merit as high as five [7]. The connection between structural symmetry and their electric as well as magnetic dipole and higher-order multipole coupling will be elucidated. It turns out that stereometamaterials [8], where the spatial arrangement of the constituents is varied (see figure), reveal a highly complex rotational dispersion. The chiral properties are quite intriguing and can be explained by a coupled oscillator model. Our three-dimensional stacking approach allows also for the fabrication of 3D nanoantennas, which are favorable for emitting and receiving radiation from quantum systems [9].



- [1] Na Liu, Hongcang Guo, Liwei Fu, Stefan Kaiser, Heinz Schweizer, and Harald Giessen: Three-dimensional photonic metamaterials at optical frequencies, *Nature Materials* 7, 31 (2008).
- [2] N. Liu, H. Guo, L. Fu, S. Kaiser, H. Schweizer, and H. Giessen: Plasmon Hybridization in Stacked Cut-Wire Metamaterials, *Advanced Materials* 19, 3628 (2007)
- [3] Na Liu, Liwei Fu, Stefan Kaiser, Heinz Schweizer, and Harald Giessen: Plasmonic Building Blocks for Magnetic Molecules in Three-Dimensional Optical Metamaterials, *Advanced Materials* 20, 3859 (2008).
- [4] B. Lukyanchuk, N. I. Zheludev, S. A. Maier, N. J. Halas, P. Nordlander, H. Giessen, and C. T. Chong: The Fano resonance in plasmonic nanostructures and metamaterials, *Nature Materials* 9, 707 (2010).
- [5] Na Liu, Stefan Kaiser, and Harald Giessen: Magnetoinductive and Electroinductive Coupling in Plasmonic Metamaterial Molecules, *Advanced Materials* 20, 4521 (2008).
- [6] Na Liu, N. Liu, L. Langguth, T. Weiss, J. Kästel, M. Fleischhauer, T. Pfau, and H. Giessen: Plasmonic EIT analog at the Drude damping limit, *Nature Materials* 8, 758 (2009).
- [7] Na Liu, T. Weiss, M. Mesch, L. Langguth, U. Eigenthaler, M. Hirschner, C. Sönnichsen, and H. Giessen: Planar metamaterial analog of electromagnetically induced transparency for plasmonic sensing, *Nano Lett.* 10, 1103 (2010).
- [8] Na Liu, Hui Liu, Shining Zhu, and Harald Giessen: Stereometamaterials, *Nature Photonics* 3, 157 (2009).
- [9] H. Giessen and M. Lippitz: Directing light emission from quantum dots, *Science* 329, 910 (2010).

Biography

Harald Giessen graduated from Kaiserslautern University with a diploma in Physics and obtained his M.S. and Ph.D. in Optical Sciences from the University of Arizona in 1995. After a postdoc at the Max-Planck-Institute for Solid State Research in Stuttgart he moved to Marburg as Assistant Professor. From 2001-2004, he was associate professor at the University of Bonn. Since 2005, he holds the Chair for Ultrafast Nanooptics in the Department of Physics at the University of Stuttgart. He was guest researcher at the University of Cambridge, and guest professor at the University of Innsbruck and the University of Sydney. He is a fellow of the Optical Society of America.



THz Plasmonics

Much of the scientific community is currently focused on Plasmonics at optical frequencies, because of potential nanophotonic device applications. Although there has been excellent progress in this area, any resulting plasmonic device technologies would need to compete with existing optical capabilities. This is not the case in the THz spectral range. Although significant advances has been made in creating THz sources and detectors, there is a nearly complete lack of other device capabilities in the THz spectral range, which severely limits the development of useful technologies in areas such as communications, computing and imaging. Over the last two decades, there has been significant work in adapting ideas that were originally developed for microwave and optical applications. However, these approaches have not yet proven successful. In large part, this is because conventional dielectric materials typically exhibit high loss at THz frequencies. Metals, on the other hand, exhibit extremely low loss, making plasmonics extremely well suited for THz device fabrication. The goal of this tutorial is to give the participants a fundamental background and working knowledge of the main ideas and techniques used in understand and use the properties of surface waves in this spectral region.

The tutorial will begin with a general overview of the field of THz radiation and THz time-domain spectroscopy. This will be followed by an introduction to the basic differences between plasmonics at optical frequencies and in the far-infrared. Following this, there will be an in-depth discussion of the unique capabilities that THz techniques allow, including time-domain properties, frequency domain properties and imaging capabilities. The latter part of the tutorial will focus on several emerging plasmonic device capabilities with the intent of demonstrating the exciting opportunities that lie ahead.

Biography

Ajay Nahata is currently a Professor the Department of Electrical and Computer Engineering at the University of Utah. The focus of the research effort is on THz optoelectronics, with particular emphasis on plasmonics and metamaterials. He received his B.S. from MIT and his M.S. from Columbia University, both in electrical engineering. He then spent approximately 5 years investigating the nonlinear optical properties of organic materials at AlliedSignal Inc. He returned to Columbia University to pursue his Ph.D. in electrical engineering, working in the areas of ultrafast optics and terahertz optoelectronics with David Auston and Tony Heinz. After completing his Ph.D., he returned to industry, spending another three years at AlliedSignal Inc., then three years at NEC Research Institute before returning to academia.



Fundamental limits of Plasmonics : Battling Loss

Surface Plasmons are the collective modes concentrated in sub-wavelength volumes and capable of enhancing various linear and nonlinear optical processes, such as absorption, fluorescence, Raman process, frequency conversion, Forster transfer and others. In this tutorial it will be shown that for different processes the enhancement provided by plasmons varies and that optimization of such processes should follow very distinct specific routines. The arrangements involving multiple surface plasmon modes will be explicated using the coupled modes formalism. In the end, the enhancement is always limited by the loss in the metal and in the tutorial it will be explained that optimizing the geometry alone cannot lead to breakthrough in the efficiency enhancement and one should look for the means of reducing the metal loss intrinsically.

The tutorial will briefly outline the physical nature of loss in metals at optical frequencies and show how drastically different it is from the nature of low frequency loss, thus traditional methods of reducing loss in the microwave domain, such as cooling become futile at optical frequencies. Thus good conductors do not necessary make good reflectors and vice versa. The last part of the tutorial will deal with some speculative ideas of synthesizing novel materials with very low loss in the window in visible or near IR

Biography

Jacob B. Khurgin graduated with his M.S. degree in optics from the Institute of Fine Mechanics and Optics in St Petersburg, Russia, in 1979. In 1980 he immigrated into the US, and joined Philips Research Laboratories, of Philips Electronics N.V., in Briarcliff Manor, NY. There for eight years he worked on miniature solid-state lasers, II-VI semiconductor lasers, various display and lighting fixtures, x-ray imaging, and small appliances. Simultaneously, he was pursuing his graduate studies at Polytechnic Institute of New York, where he received his Ph.D. in EE in January 1987. In January 1988, he joined the Electrical Engineering department of Johns Hopkins University, where he is currently a Professor. His research topics over the years have included an eclectic mixture of semiconductor nanostructure optics, nonlinear optical devices, optical communications, microwave photonics, THz technology, and condensed matter physics. Currently, he is working in the areas of mid-infrared lasers and detectors, plasmonics, laser cooling, RF photonics, phonon engineering for high-frequency transistors, coherent optical communications, and slow light propagation. His publications include six book chapters, one edited book, more than 220 papers in refereed journals and 14 patents. Professor Khurgin is a Fellow of the Optical Society of America.

