CREOL • UCF COLLEGE OF OPTICS AND PHOTONICS VOL. 12, NO. 1 • SUMMER 2011

Highlights

ACADEMICS • RESEARCH • PARTNERSHIPS • CREATING THE FUTURE OF OPTICS AND PHOTONICS

DEAN'S CORNER

BAHAA SALEH, Ph.D.

There are events during the year that we work very hard to prepare for and are so pleased when at the end of the day we meet with success. There are also days when we are so proud to hear great news resulting from years of hard work by the students or the faculty and ending up with milestones met or honors and recognitions received. Let me tell you about some of these events and news.

One of our most important events of the year is the Industrial Affiliates Day. Held on April 29th, this year's IAD was attended by more than 200 registrants, including more than 90 guests from industry and 26 exhibitors. A symposium on *Far IR and THz Photonics* featured key speakers from industry and government. The poster session, which provides students with an excellent forum to present their research to an industrial audience, attracted 27 posters covering a broad scope of topics in optics and photonics. The student-of-the year award went to Dimitrios Mandridis

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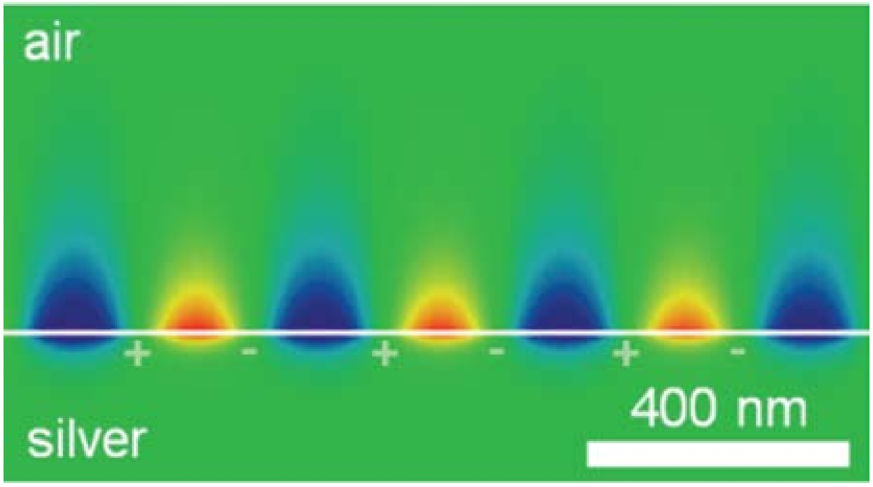
Surface Plasmon Nanophotonics

PIETER G. KIK, kik@creol.ucf.edu



Snapshot of the lateral electric field distribution (color) associated with a blue surface plasmon (λ_0=400 nm) at a silver-air interface. The location of the corresponding surface charges is shown schematically.

Nanophotonics is booming. The past two decades have seen an incredible growth in the research and technology of nanostructured optical materials, leading to the development of nanoscale waveguides, ultrasensitive chemical and biological detection methods, sub-diffraction limit imaging technologies, and dispersion engineered fibers. Many of these technologies were unthinkable until very recently, and have been realized thanks to new fabrication tools, new simulation software on ever faster computers, greatly improved physical analysis tools, as well as new optical measurement methods that allow us to see light at the nanoscale.

A particularly active field of nanophotonics is the area of surface plasmon nanophotonics, or *plasmonics*. Plasmonics involves the use of nanostructured metals to achieve new optical functionality. The increased use of metals in photonics appears surprising: metals are known to strongly reflect and absorb light due to interaction of the light with free electrons in the metal. Metals therefore hardly seem like a logical choice for the construction of photonic elements. As it turns out, these same free electrons can do surprising things at optical frequencies due to two key optical

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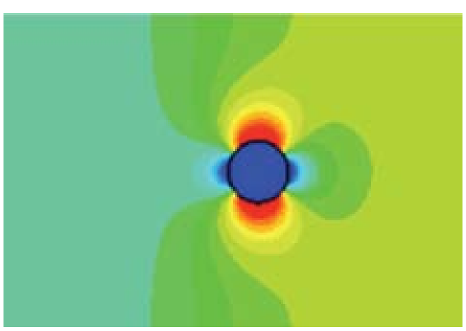
Surface Plasmon Nanophotonics *(continued from page 1)*

phenomena. The first of these is the **surface plasmon** (or 'surface plasmon polariton'), a propagating charge density wave that can be created along the surface of a metal. These waves appear as ripples in the electron density near the metal surface, along with their associated electromagnetic fields. Surface plasmons typically exist at frequencies from the ultraviolet to the terahertz regime. Surprisingly, thanks to these unusual electromagnetic waves a metal surface can act as a 'single-sided waveguide', without requiring the typical upper and lower cladding that dielectric waveguides require. In addition, the corresponding optical modes are highly confined. For example, a blue plasmon on a silver surface extends only ~10 nm into the silver, and about 100 nm into air, corresponding to a mode size below a third of the optical wavelength.

The second important phenomenon is the **localized surface plasmon**, which occurs on metal nanoparticles. In the case of metal nanoparticles the otherwise free electrons in the metal are now constrained to the particle volume. This leads to charge oscillations that are localized on the particle, turning the nanoparticle into a nanoscale resonator that can be optically excited. When the particle is illuminated at specific resonance frequencies, the electrons on the particle undergo charge motion with large amplitude, leading to large electric fields near the surface. These surface fields easily exceed the illuminating field strength by a factor of ten for silver nanospheres, and even more in the case of closely spaced particles or specially shaped particles such as nanoneedles. Due to these localized plasmon resonances, metal nanoparticles have surprisingly large optical absorption and scattering cross-sections that can in some cases even exceed their physical cross-section. Consequently, applications that require nanoscale light localization, high local irradiance, localized heat deposition, or high optical contrast can all benefit from plasmonics.



Snapshot of the vertical electric field distribution (color) associated with a localized surface plasmon on a 20 nm diameter silver particle in air, excited by plane-wave illumination with blue light. Note the enhanced field near the particle, and the high field confinement in a volume comparable to that of the nanoparticle.

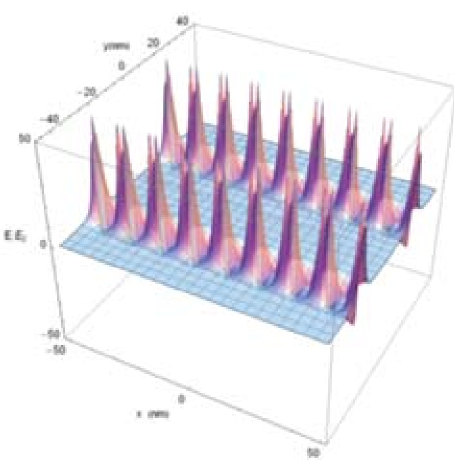
The unique properties of plasmon waves and plasmon resonances have enabled several new technologies. For example, the strong field confinement of surface plasmons makes them especially sensitive to the presence of polarizable material. Any molecules present on a metal surface can significantly affect the propagation of plasmon waves, which has enabled the development of now commercialized ultrasensitive protein detection schemes by measuring the plasmon wavelength. A second example is the use of plasmons in long-wavelength quantum cascade lasers. In these devices, plasmons have successfully been used to vastly reduce the amount of materials growth required in order to achieve a confined laser mode at long wavelengths. This is accomplished by using a metal top contact that simultaneously acts as a plasmonic guiding layer, providing small laser modes without the need for growing a lower cladding layer. Finally, in medical research, the use of plasmon resonant nanoparticles as local optically driven heat sources in targeted cancer treatment is nearing commercialization.

CREOL Students Seyfollah Toroghi, Amitabh Ghoshal and Alex Savchyn preparing the E-beam Lithography System in the Class 100 Cleanroom.

In addition to these existing commercial and near-commercial applications, several more advanced applications of plasmons are being intensely investigated. In recent work, students in the Nanophotonics and Near-field Optics Group (NPNO) at CREOL demonstrated that it is possible to control the localized plasmon resonance frequency of metal nanoparticles simply by placing the particles close to a conductive surface (J. Phys. Chem. C 114, 7509 (2010), see http://goo.gl/TfCN). While silver nanoparticles normally exhibit plasmon resonances in the near-UV, it was shown that by placing 60 nm diameter silver particles close to a gold film, the resonance frequency could be tuned throughout the entire visible spectrum. This kind of tunable nanoscale optical antenna could lead to improved biosensing schemes, nanoscale optical sources, nanoscale display pixels, and nonlinear optical switching elements. In a related example, it was experimentally demonstrated that one can achieve controlled excitation of propagating surface plasmons by placing shape-optimized ellipsoidal metal nanoparticles near a metal surface. This structure effectively acts as a planar nanostructured antenna that converts an incident visible or near-infrared beam into a propagating surface mode, or vice versa (Phys. Stat. Sol. Rapid Research Letters 4, 280 (2010), see http://goo.gl/3Nxp8). Such controlled conversion of incident light into surface modes is actively being investigated by many research groups for enhancing the efficiency of thin film solar cells.

A final example is the use of localized plasmons in the enhancement of nonlinear optical response. Through numerical simulation it was demonstrated that closely spaced metal nanoparticles can strongly enhance the nonlinear optical refraction and absorption in metal-dielectric composites. Interaction between coupled nanoparticles in such structures leads to additional field enhancements, enhancing the nonlinear optical response by well over three orders of magnitude compared to that of the materials that make up the composite (Opt. Express 17, 15032 (2009), see http://goo.gl/EERJ). These examples show that it is now possible to engineer the optical response of materials by structuring at the nanoscale.

Students working on a plasmonics simulation project in course OSE6650 'Optical Properties of Nanostructured Materials'.



Simulated electric field enhancement in a two-dimensional array of closely spaced silver nanoparticles. The large electric field in between the particles leads to strongly enhanced nonlinear refraction and absorption.

Plasmonics opportunities at CREOL

Thanks to recent investments in nanotechnology, CREOL is well set-up for a broad range of nanophotonics research areas, including plasmonics. The CREOL building houses a Class 100 cleanroom, meaning that a cubic foot of cleanroom air contains fewer than 100 particles larger than 0.5 µm. This allows users to handle nanophotonic devices with minimal risk of contamination of the small device elements. The cleanroom houses an advanced electron beam lithography system that is able to define nanostructures with sizes well below 50 nm. Students as well as external visitors can supply computer-generated patterns that can be replicated in resist layers. After further processing through, e.g., deposition, etching, and even selective area growth, these patterns yield a wealth of different metallic and dielectric nanostructures.

Aside from requiring dedicated nanofabrication tools, the design and analysis of plasmonic structures requires advanced electromagnetic analysis. While early work in plasmonics typically focused on relatively simple systems that could be evaluated using analytical calculations, ever more complex structures are being considered that require the use of numerical simulation tools. For this purpose the NPNO group at CREOL uses CST Studio, a software suite that can be used to design realistic three-dimensional nanophotonic structures using CAD layout design tools, followed by frequency domain or time domain electromagnetic analysis. Using this software, meaningful simulations can be done on standard desktop computers on structures spanning several cubic microns or on much larger periodic structures such as nanostructured gratings.

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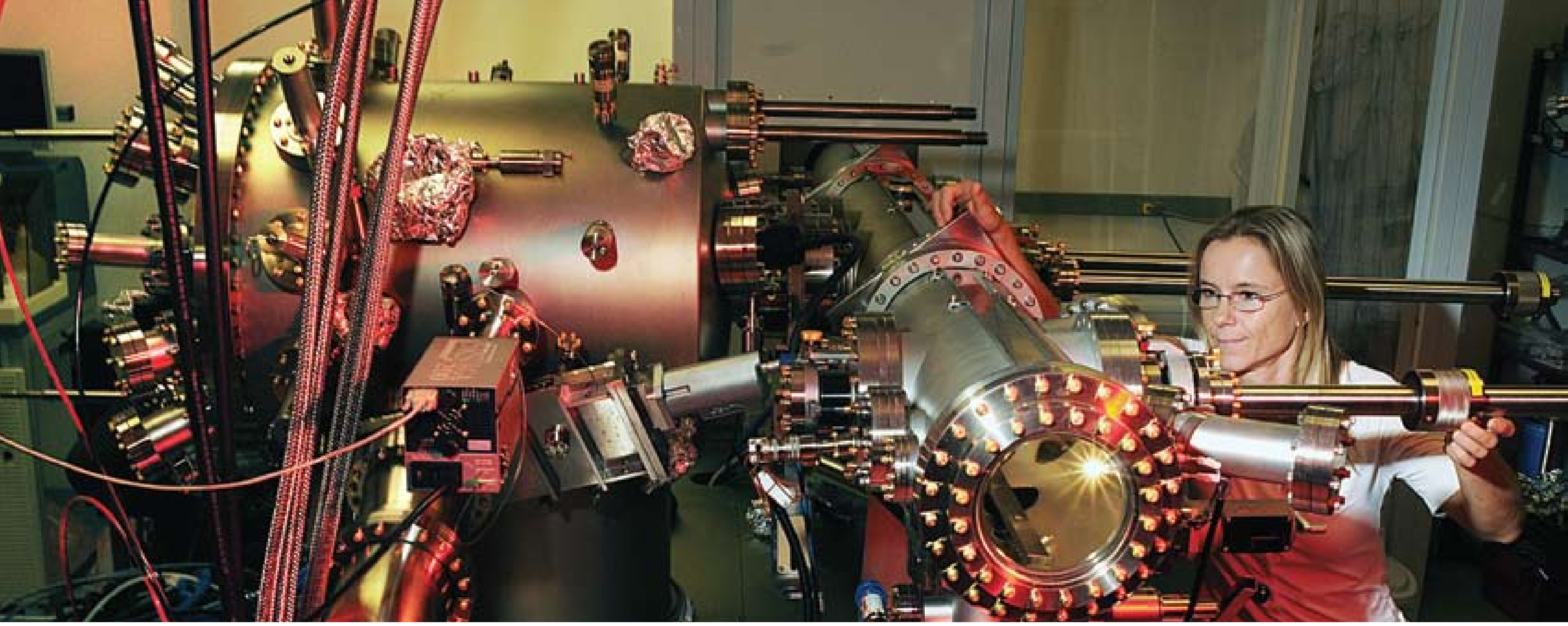


Research in the III-V epitaxial growth facility

DEAN'S CORNER *(CONTINUED FROM PAGE 1)*

for his work with Dr. Peter Delfyett on the generation of low-noise chirped pulses using a semiconductor laser in a theta configuration with an intra-cavity etalon. At the end of the day, I had the general feeling that our research and partnership with industry continue to be vigorous and exciting. We are now planning for the 2012 IAD, which will be a two-day event celebrating CREOL's 25th anniversary and featuring a longer technical symposium with talks by the CREOL founders.

Another important event of the year is Commencement. It was indeed a pleasure seeing 5 Ph.D. students and 9 M.S. students receiving their degrees at the 2010 Fall and 2011 Spring commencements. Last year, 23 Ph.D. and 18 M.S. students graduated. We are very proud to see our alumni list grow, and we make every effort to stay connected with our alumni network via reunions at technical meetings and invitations to our special events.

Perhaps the most pleasure I have during the year comes from hearing the good news about faculty receiving prestigious accolades. Since the last Highlights, Prof. S.T. Wu received the 2011 Society of Information Display (SID) Slottow-Owaki Prize *in recognition of his exceptional contribution to the education and training of graduate students and professionals in the field of information display*. Prof. Peter Delfyett received the APS Edward A. Bouchet Award *for his significant scientific contributions in the area of ultrafast optical device physics and semiconductor diode based ultrafast lasers, and for his exemplary and continuing efforts in the career development of underrepresented minorities in science and engineering*. Prof. Demetri Christodoulides received the OSA R. W. Wood Prize *for contributions in nonlinear and linear beam optics, which initiated new areas, among them the discovery of optical discrete solitons, Bragg and vector solitons in fibers, nonlinear surface waves, and the discovery of self-accelerating optical (Airy) beams*.

Other great days are those when I hear that a faculty candidate that we have been recruiting for months has accepted our offer. Indeed, one of the significant actions taken by the College is the addition of new faculty in order to keep up with the rapidly changing technology and meet our educational mission. Since the last *Highlights*, Dr. Rodrigo Amezcua, an expert in optical fibers from the University of Southamton, UK, joined our faculty at the rank of Research Assistant Professor (see an article on Dr. Amezcua on page 5). This is part of the plans of the Townes Laser Institute to expand research in fiber optics, which is pursued by Drs. Ayman Abouraddy, Martin Richardson, and Axel Schülzgen. Also, Dr. Romaine Gaume, an expert in optical ceramics currently at Stanford University, is expected to join the faculty this Fall at the rank of Assistant Professor, with a joint appointment at the NanoScience Technology Center.

I will certainly keep you up to date with the good news in each of our future *Highlights*. We would also like to share our alumni success stories with the faculty, students, alumni, and industrial partners. Please keep us updated!

Bahaa Saleh, Dean

CREOL,
The College of Optics & Photonics

WELCOME RODRIGO AMEZCUA, PH.D., RESEARCH ASSISTANT PROFESSOR OF OPTICS

Dr. Rodrigo Amezcua joined CREOL, The College of Optics & Photonics in February 2011, as a Research Assistant Professor of Optics and member of the and Townes Laser Institute (TLI). Rodrigo is working on the establishment of the TLI Optical Fiber Facility, together with Drs. Axel Schülzgen and Ayman Abouraddy.

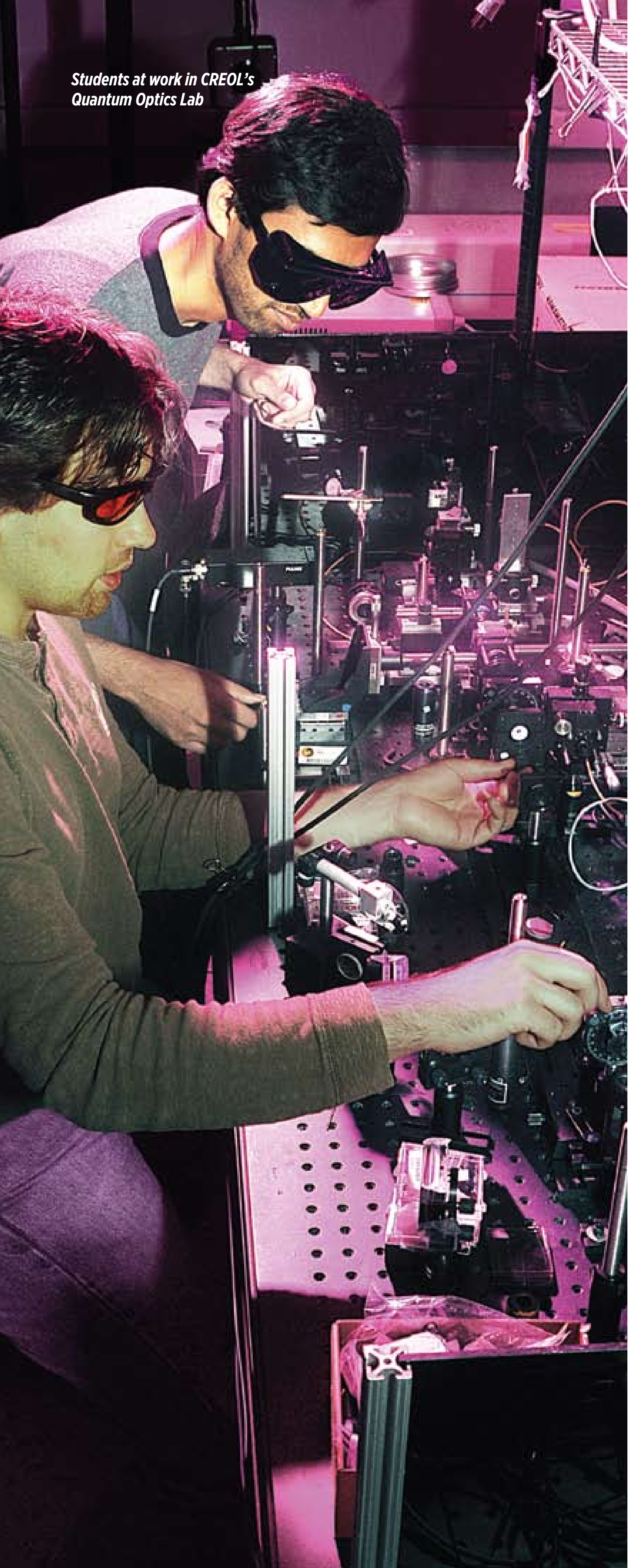
Rodrigo's research group will focus on the study of the interaction of light and matter in micro- and nano-structured optical fibers. He is looking forward to his first summer in Florida, when the new students and the new fiber drawing tower will arrive at CREOL. "I believe that there will be a lot of excitement once we pull the first fibers from the new tower" said Rodrigo.

Rodrigo Amezcua, Ph.D.

Rodrigo was born in Mexico City, Mexico. In 2003, he obtained a Mexican government scholarship and joined the Optoelectronics Research Centre at the University of Southampton in the United Kingdom to undertake his doctoral studies. At Southampton, he was involved in a variety of projects based on the theoretical analysis and numerical modeling of photonic crystal fibers (PCF).

In March 2007, he joined the Centre for Photonics and Photonic Materials as a post-doctoral researcher with Prof. Jonathan Knight at the University of Bath, UK. His position at Bath was part of a large-scale European research effort between leading technology companies, start-ups and research centers for the development and exploitation of photonic crystal fibers. Rodrigo's research focused on the design and fabrication of hollow-core photonic bandgap fibers for applications including ultrafast lasers, nonlinear microscopy and sensing. During his time at Bath he came up with a method to fabricate the fiber designs proposed during his PhD. These advances in hollow-core photonic bandgap fiber technology not only made their production far easier and faster than previously, but also led to improved fiber performance.

Prior to joining CREOL, Rodrigo was with Powerlase Photonics, a laser company just outside of London, where he worked on high-power diode-pumped solid state lasers for the semiconductor industry.



Students at work in CREOL's Quantum Optics Lab

Surface Plasmon Nanophotonics

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The simulations provide researchers with predicted field distributions, predicted field enhancement, absorption spectra, radiation patterns, and many other technologically relevant properties. The optimized structures can then be fabricated, for example, by use of CREOL's ebeam lithography system.

Nanophotonic and plasmonic devices can be analyzed using modern optical analysis techniques. The Nanophotonic Characterization Laboratory houses a fiber coupled microscope capable of detecting scattering spectra of individual plasmon resonant silver nanoparticles smaller than 60 nm in diameter. In addition, a near-field scanning optical microscope is available. This instrument can image optical fields with a resolution that far exceeds the diffraction limit, by combining confined illumination through a nanoscale aperture with a nanometer-precision scanning stage. A separate setup enables the analysis of guided plasmon waves through leakage radiation microscopy and spectroscopy. Picosecond excitation of metallic nanostructures for nonlinear optical applications is possible in a customized inverted optical microscope, thanks in part due to the support of CREOL Affiliate Ophir-Spiricon. These dedicated tools provide both spectral and high-resolution spatial information on locally prepared nanostructures, enabling direct comparison of simulated properties with real-world performance.

In order to prepare students for research in nanophotonics, CREOL offers the course 'Optical Properties of Nanostructured Materials,' which has a strong focus on plasmonics. The course covers all important aspects of metal nanophotonics, ranging from nanoscale integrated plasmon waveguides to plasmon-enhanced biosensing applications. Thanks to the generous support of CREOL Industrial Affiliate *Computer Simulation Technology* (CST), up to ten CREOL Graduate students annually carry out numerical simulation projects that highlight key aspects of plasmonic structures. The availability of a hands-on plasmonics course is rare, and given the pervasiveness of plasmonics in many research areas the acquired knowledge will undoubtedly benefit students in their future careers. For more information on nanophotonics at CREOL, please visit the CREOL website, or go directly to the website of the Nanophotonics and Near-field Optics Group (http://kik.creol.ucf.edu).

GRADUATES
FALL 2010– SUMMER 2011

Ph.D.	Dissertation Area
Michael Hemmer	*Few-cycle pulses amplification for attosecond science applications: modeling and experiments*
Clarisse Mazuir	*Design, Fabrication, and Testing of High-Transparency Deep Ultra-Violet Contacts Using Surface Plasmon Coupling In Subwavelength Alumninum Meshes*
Ibrahim Ozdur	*Low Noise, Narrow Optical Linewidth Semiconductor-Based Optical Comb Source Aand Low Noise RF Signal Generation*
Brian Slovic	*Infrared Phased-Array Antenna-Coupled Tunnel Diodes*
Ty Olmstead	*Photodisruption In Ocular Tissue Near And At The Boundary Between The Anterior Chamber and Crystalline Lens*

M.S.

Bae, Janghwan

Banaei, Seyed Esmaeil

Bermudez, Alexander

Coletta, Jason

Dillard, Alexander

Kyle, Douglass

He, Sihui

Mora, Manuel

Nersisyan, Artsveni

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Photonics Spectra

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