# International Year of Light 2015

## Symposium and Industrial Affiliates Program

UCF CREOL, The College of Optics and Photonics

# Advances in Optics & Photonics
# Industrial Affiliates Symposium

Celebrating the International Year of Light

## 12–13 March 2015

***Thursday, 12 March***

### Short Courses 9:00 AM–12:15 PM

9:00-10:30AM, CREOL Building, Room 102
**Functional Optical Metamaterials**
Instructor: Debashis Chanda, Asst. Professor, NSTC & CREOL, UCF

Metamaterials are artificially engineered materials with unique electromagnetic properties. Various new properties like negative refractive index, zero index, artificial magnetism, perfect absorption etc have been demonstrated which are not available in natural materials. However, to date no practical application has emerged based on such properties, primarily due to lack of control and fabrication challenges. The present course will cover the fundamental physics of a chosen set of metamaterials and demonstrate various control mechanisms to tune the optical responses dynamically in order to develop infrared detectors, bio-sensors and flexible displays based on practical large area fabrication techniques.

9:00-10:30AM, HEC Room 125
**Transition-Metal Solid-State Lasers**
Instructor: Kenneth L. Schepler, Research Professor, CREOL UCF

The course covers fundamental principles of transition-metal ion spectroscopy, semiconductor host materials, transition-metal infrared lasers and their applications. Performance of transition-metal infrared lasers such as $Cr^{2+}$:ZnSe/S and $Fe^{2+}$:ZnSe will be reviewed including cw, gain-switched, and modelocked operation. Recent advances in waveguide operation will also be reviewed. Broadband tunability and operation in a multitude of formats leads to applications which encompass infrared spectroscopy, sensing, imaging, free-space communications, infrared countermeasures and high-field effects.

10:45-12:15PM CREOL Building, Room 102
**Optical Fiber Communication**
Instructor: Guifang Li, Professor, CREOL, UCF

How does fiber optical communication support exponential growth in data traffic on the internet? This course describe key technological revolutions that have provide multiplicative growth of transport capacity of fiber-optic transmission systems in the last two decades. Space-division multiplexing, a focus of current research which could potentially provide the next 100x improvement in transmission capacity, will be presented.

10:45-12:15PM HEC Room 125
**Beam Synthesis & Dynamics**
Instructor: Demetrios Christodoulides, Pegasus Professor Cobb Family Endowed Chair, CREOL, UCF

The course will cover recent developments in beam shaping and synthesis techniques. Special emphasis will be given to optical diffraction-free patterns and accelerating beams. Possible applications of such wavefronts will be also discussed.

### Student Talks 1:30 PM–2:30 PM HEC125

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|---|---|---|
| 1:30 | Hybrid Integrated Photonic Platforms and Devices | Jeffrey Chiles, Student of the Year |
| | Carrier-Envelope Phase Locked Ultrahigh Power Lasers | Eric Cunningham |
| | Ultrafast Nonlinear Dynamics of Molecules | Matthew Reichert |
| | Transverse Mode Selection and Brightness Enhancement of a Fiber Laser using Transmitting Bragg Gratings | Brian Anderson |

### Poster Session, Lab Tours & Exhibits 2:30 PM–4:30 PM CREOL 102&103

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|---|---|
| Student poster session | CREOL rooms 102 & 103 |
| Exhibits | CREOL Lobby |
| Lab Tours | Tours start from CREOL lobby |

### Reception and Poster Awards Presentation 4:30 PM–5:00 PM CREOL Lobby

## *Friday, 13 March*

***Morning Session*** –UCF Student Union, Pegasus Ballroom

8:00 Continental Breakfast and Walk-in Registrations

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|---|---|---|---|
| 8:30 | Welcoming Remarks | Dale Whittaker<br>MJ Soileau | Provost and Vice President<br>Vice President for Research, UCF |
| 8:40 | Welcome and Overview | Bahaa Saleh | Dean & Director, CREOL, UCF |

## Technical Symposium

### Session I. Fiber Photonics – Guifang Li, Session Chair

| | | | |
|---|---|---|---|
| 9:15 | High Speed Optical Networks for Global Telecom Carriers | Tiejun Xia | DMTS, Verizon Communications |
| 9:45 | Multimaterial Chalcogenide Fibers for Mid-Infrared Applications | Ayman Abouraddy | CREOL, UCF |

10:05 BREAK & EXHIBITS

### Session II. Integrated Photonics and Sensors – Axel Schulzgen, Session Chair

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|---|---|---|---|
| 10:25 | Radio Frequency Photonics and Integration Technologies | Arthur Paolella | Harris Corp. |
| 10:55 | Novel Fibers and Fiber Devices for Sensing Applications | Rodrigo Amezcua | CREOL, UCF |

### Session III. Bioimaging – Aristide Dogariu, Session Chair

| | | | |
|---|---|---|---|
| 11:15 | Quantitative Phase Imaging: Metrology Meets Biology | Gabriel Popescu | UIUC |
| 11:45 | Scalable Large Field-of-View Fluorescence Microscopy | Shuo Pang | CREOL, UCF |

12:05 **LUNCH Served** Student Union

***Afternoon Session*** – UCF Student Union, Pegasus Ballroom

### Session IV. Mid IR – Peter Delfyett- Session Chair

| | | | |
|---|---|---|---|
| 1:00 | Monolithic QCL Arrays for Portable High Performance Spectroscopy | Mark Witinski | President, Eos Photonics |
| 1:30 | Frequency Combs for Ultrasensitive Molecular Sensing | Konstantin Vodopyanov | CREOL, UCF |

### International Year of Light -- Public Lecture

| | | | |
|---|---|---|---|
| 1:50 | Evolving Lasers to Solve Problems | Jeff Hecht | Science and technology writer |

2:45–3:30 **RECEPTION**

**Tiejun Xia**
**Verizon Communications**

**Abstract:** Global telecom carriers' main task is to meet networking traffic capacity demand growth from users all over the world and increase network efficiency continuously to deal with economic pressure. The carriers have been constantly introducing new technologies into their networks to accomplish the task. Deployment of 100-Gb/s optical transport systems with coherent detection is a significant milestone for the carriers since the system brought in a fiber capacity leap. A commercial 100-Gb/s system is able to provide 10 Tb/s capacity on a single strand of fiber, compared with less than 1 Tb/s provided by 10-Gb/s systems. Experiments in carrier network have proved that 40-50 Tb/s capacity is feasible for deployed single mode fiber. Beyond 100 Gb/s the likely next data rate will be 400 Gb/s with superchannel design (a channel with multiple optical carriers). Enhancement of optical network efficiency is supported by flexible optical functions, which have been gradually introduced in recent years. The key enabling technologies including wavelength tunable laser, flexible forward error correction (FEC) overhead, modulation adjustable transceiver, and colorless, directionless, contentionless, and flexible grid reconfigurable optical add/drop multiplexer (CDC-F ROADM). Moving forward, spatial division multiplexing (SDM) with multi-core and/or multi-mode fiber will further increase fiber capacity. The concept of software defined network (SDN) will be extended to optical layer to make multiple layer optimization a reality by separating control plane and data plane. New technologies, such as fast optical link establishment, will lead optical network to be more dynamic and more efficient.

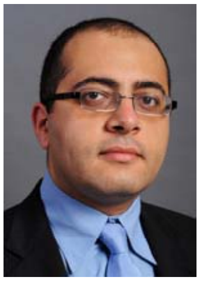
**Tiejun J. (TJ) Xia** is a key optics and photonics expert in Verizon, a global telecom carrier. He currently is a Distinguished Member of Technical Staff and leads technology development for optical signal transmission and transport network architecture. He also is an Adjunct Professor at Miami University in Ohio and was an Adjunct Professor at the University of Texas at Dallas from 2005 through 2009. In recent years Dr. Xia has led a series of high speed, high capacity, and flexible optical transmission studies in fiber networks and set several field channel speed and transmission capacity records for the industry. He has served on conference technical program committees (OFC/NFOEC, APOC, ACP, OECC, and LOIS). He serves on the executive board of directors of IEEE Dallas Section as Chief Innovation Officer. Dr. Xia has a Ph.D. degree in physics from CREOL (Center for Research and Education in Optics and Lasers) at the University of Central Florida, an M.S. degree from Zhejiang University, China, and a B.S. degree from the University of Science and Technology of China. Dr. Xia has written more than 20 invited papers, contributed more than 100 peer-reviewed technical papers, published three book chapters, given more than 30 invited talks, and holds more than 80 granted or pending U.S. patents. He is a Fellow of OSA. He won technology Leadership Award of MCI in 1999 and Telecom Leaders Circle Award of Verizon in 2008. In 2011, he was featured as "Verizon Innovator" on YouTube. He is the winner of CREOL Professional Achievement Award of UCF in 2013.

# *Multimaterial Chalogenide Fibers for Mid-Infrared Applications*



**Ayman Abouraddy**
**CREOL, The College of Optics & Photonics, UCF**

**Abstract:** There is currently broad interest in extending optical technologies beyond the traditional comfort zones in the visible and near-infrared wavelengths into the less-explored realms of the mid-infrared (MIR) – the next frontier for the optics and photonics community, where unexplored territory awaits to be reclaimed. The development of MIR fibers is a critical milestone towards this goal. Chalcogenide glasses offer a host of advantages that make them attractive candidates for MIR fibers: they have a broad transparency window in the MIR, a variety of compositions may be stably drawn in to fibers, and they have some of the highest reported nonlinear optical coefficients amongst glasses. I will review the burgeoning field of multimaterial chalcogenide fibers, and will focus on the recent achievements in my research group where we have developed several strategies to combine thermoplastic polymers with chalcogenide glasses at the preform stage. Within this overall approach, a macroscopic preform is prepared – typically through extrusion – in which these two distinct families of materials are combined, resulting in continuous drawing of robust chalcogenide fibers. The robustness of such fibers has enabled us to produce tapers with sub-micron diameter cores that we have exploited in infrared supercontinuum generation while exercising control over the fiber dispersion and using strong confinement effects (through large core/cladding index contrast) to enhance the optical nonlinearity.



**Ayman F. Abouraddy** is an associate professor of optics at CREOL, The College of Optics & Photonics, at the University of Central Florida. He joined CREOL as an assistant professor in September 2008 where he has since established facilities for fabricating new classes of polymer and soft-glass fibers for applications ranging from mid-infrared optics to solar energy concentration. He received the B.S. and M.S. degrees from Alexandria University, Alexandria, Egypt, in 1994 and 1997, respectively, and the Ph.D. degree from Boston University, Boston, MA, in 2003, all in electrical engineering. In 2003 he joined the Massachusetts Institute of Technology (MIT), Cambridge, as a postdoctoral fellow working with Prof. Yoel Fink (Materials Science & Engineering) and Prof. John D. Joannopoulos (Physics), and then became a Research Scientist at the Research Laboratory of Electronics in 2005. At MIT he pursued research on novel multi-material optical fiber structures, photonic bandgap fibers, nanophotonics, fiber-based optoelectronic devices, and mid-infrared nonlinear fiber optics. He is the coauthor of more than 60 journal publications and 120 conference presentations, holds seven patents, and has three patents pending.

**Arthur Paolella**
**Harris Corporation**

**Abstract:** The term "radio frequency (RF) photonics" is used to delineate a subset of photonic technology that is utilized to detect, distribute, process, frequency translate, and switch optical signals in the RF, microwave, and millimeter wave frequency regions. RF photonics can provide high performance at a lower size, weight, and power (SWAP) than traditional electrical systems. The implementation of RF photonics technology is paramount to meet the demands of future Department of Defense (DoD) and commercial systems. Military and commercial systems are requiring more data throughput, larger operating bandwidths, higher operating frequencies, better sensitivity, and better image processing with higher resolution. These requirements must be achieved at a lower cost and reduced SWAP consumption. To achieve these objectives, a strong investment in photonic components, manufacturing, and, in particular, photonic integrated circuits (PICs) is paramount for creating a successful marketplace and providing the U.S. a strategic technological advantage.

In 2002 Dr. Paolella founded Artisan Laboratories Corporation a small high technology business that developed products for the communications, test and measurement markets. From 2000 to 2002, he was Director, Advanced Photonic Development and Photonic Transport, Motorola Broadband Communications Sector. From 1996 to 2000, he was at Lockheed Martin Commercial Space Systems, Communications Product Division as a Project Manager / Senior Staff Engineer. Dr. Paolella started his professional career at the US Army Research Laboratory, Ft. Monmouth, NJ in 1982. He became Group Leader, Microwave Photonics Team in 1988; a new research team and technology direction that he started at the Army.

Dr. Paolella received his Ph.D. in Electrical Engineering, in June 1992 from Drexel University, Philadelphia, Pa. He is a Fellow of the Institute for Electrical and Electronic Engineers (IEEE). He has published over 50 publications in journals and magazines and written two book chapters along with 20 patents in the area of microwaves and optics.

**Rodrigo Amezcua**
**CREOL, The College of Optics & Photonics, UCF**

**Abstract:** Fiber optics are currently used for sensing in a broad range of industrial applications; including temperature, strain, pressure and acoustic waves. Besides fiber Bragg gratings based point sensors, multimode interference based sensors have shown to be a useful tool in fiber optics sensing. With the goal to extend the applications of fiber sensors to harsh environments we have developed a versatile sensing platform based on multicore fibers. In this talk I will give an overview of our current research activities on new fibers and fiber devises for sensing applications.

**Rodrigo Amezcua** joined the College of Optics and Photonics (CREOL) and the Townes Laser Institute in February 2011 as an Assistant Research Professor. He obtained his PhD degree from the Optoelectronics Research Centre (ORC) at the University of Southampton. His Ph.D. was on the development of photonic crystal fibers. After completing his doctoral research, Rodrigo was employed as a post-doctoral researcher with Prof. Jonathan Knight at the University of Bath, UK. At the University of Bath, he developed novel photonic crystal fiber fabrication methods that lead to fibers with significantly improved optical properties. He has extensive experience in the design and fabrication of photonic crystal fibers for several applications; including fiber lasers, supercontinuum generation, nonlinear microscopy and sensing. Before joining CREOL, he worked at Powerlase Photonics, fabricating high-power diode pumped solid-state lasers.

**Gabriel Popescu**
**ECE, University of Illinois at Urbana-Champaign**

**Abstract:** Most living cells do not absorb or scatter light significantly, i.e. they are essentially transparent, or phase objects. Phase contrast microscopy proposed by Zernike in the 1930's represents a major advance in intrinsic contrast imaging, as it reveals inner details of transparent structures without staining or tagging. While phase contrast is sensitive to minute optical path-length changes in the cell, down to the nanoscale, the information retrieved is only qualitative. Quantifying cell-induced shifts in the optical path-lengths permits nanometer scale measurements of structures and motions in a non-contact, non-invasive manner. Thus, quantitative phase imaging (QPI) has recently become an active field of study and various experimental approaches have been proposed.

Recently, we have developed Spatial Light Interference microscopy (SLIM) as a highly sensitive QPI method. Due to its sub-nanometer pathlength sensitivity, SLIM enables interesting structure and dynamics studies over broad spatial (nanometers-centimeters) and temporal (milliseconds-weeks) scales. I will review our recent results on applying SLIM to basic cell studies, such as intracellular transport and cell growth. I will end with a discussion on using SLIM for label-free diagnosis of blood and biopsies.

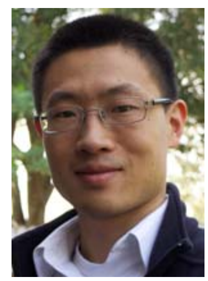
**Gabriel Popescu** is an Associate Professor in Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, and directs the Quantitative Light Imaging Laboratory (QLI Lab) at the Beckman Institute for Advanced Science and Technology. He authored book, edited another book, 110 journal publications, 120 conference presentations, 24 patents, gave 110 invited talks. Professor Popescu received the B.S. and M.S. in Physics from University of Bucharest, in 1995 and 1996, respectively. He obtained his M.S. in Optics in 1999 and the Ph.D. in Optics in 2002 from the School of Optics/ CREOL (now the College of Optics and Photonics), University of Central Florida. Dr. Popescu continued his training with the G. R. Harrison Spectroscopy Laboratory at M.I.T., working as a postdoctoral associate. He joined University of Illinois at Urbana-Champaign in August 2007. Prof. Popescu received the 2009 NSF CAREER Award, was the 2012 Innovation Discovery Finalist selected by the Office of Technology Management Office, UIUC, and was elected as the 2012-2013 Fellow of the Center for Advanced Studies at UIUC. Dr. Popescu is an Associate Editor of Optics Express and Biomedical Optics Express, and Editorial Board Member for Journal of Biomedical Optics. He is an OSA and SPIE Fellow. Dr. Popescu founded Phi Optics, Inc., a start-up company that commercializes quantitative phase imaging technology.

# *Scalable Large Field-of-view Fluorescence Microscopy*

**Shou Pang**
**CREOL, The College of Optics & Photonics, UCF**

**Abstract:** Longitudinal imaging can provide valuable information for many key biological processes in living cells. A large field-of-view (FOV) is often required in such imaging application to capture the migration and division of a large population of cells. However, conventional fluorescence microscope objective lenses have a limited FOV less than 1 mm2, and attempting to achieve a large FOV based on refractive lens is not scalable; the increased FOV demands more optical surfaces for aberration compensation, which unavoidably lead to complex and expensive. Fluorescence Talbot microscope has ~100 times larger field-of-view than a conventional 20x microscope and can scale up easily. In this talk we discuss the implementation and various add-on modules to expand the microscopy system based on Talbot effect.

Sean Pang received his PhD degree in Electrical Engineering from Caltech. He finished his master study in Biomedical Engineering at Texas A&M University and undergraduate in Optical Engineering at Tsinghua University. His research interest is focused on developing imaging platforms for biological research, medical diagnosis, and industrial imaging applications in both visible and X-ray regimes**.**



# *Monolithic QCL Arrays for Portable High Performance Spectroscopy*

**Mark Witinski**
**Eos Photonics**

**Abstract:** This presentation presents the spectroscopic concepts and results enabled by arrays of Distributed Feedback (DFB) QCLs, with each element at a slightly different wavelength than its neighbor. In optical systems, such as standoff detectors and in situ gas analyzers, this increases analyte sensitivity and selectivity by broadening spectral source coverage and by allowing for extremely fast all-electronic wavelength tuning with no moving parts. The QCL array is also an increasingly essential solution to the power scaling of QCLs. The data show how monolithic and all-electronic tuning enables next-generation spectroscopes that are not only more robust and miniature than those that utilize external cavity-tuned lasers, but that are inherently more stable in terms the shot-to-shot amplitude and wavelength parameters. This enhanced stability increases signal to noise for a given configuration (pathlength, averaging time, concentration, etc…). Some discussion of how to maximize the benefits of high speed, highly reproducible tuning is presented, including detector, preamplifier, and digitization considerations for both backscattered and closed path configurations. Time permitting, preliminary results on monolithic beam combining of QCLs for both power scaling and for improved spectroscopic integration will be discussed.



**Mark F. Witinski** completed his doctorate in physical chemistry at Cornell University in 2006, where his work centered on using molecular beams and laser spectroscopy to examine the dynamics of molecular collisions, particularly those involving free radicals. He then spent six years as a Postdoc/Research Associate in the laboratory of Prof. Jim Anderson at Harvard. There, he was focused on innovative approaches to Mid-IR spectroscopy using Quantum Cascade Lasers such as the detection of stable carbon isotopes using Off-Axis Integrated Cavity Output Spectroscopy (ICOS) and wavelength modulated laser spectroscopy. After Harvard, Dr. Witinski worked for 5 months as a Fulbright Scholar in the Amazon rainforest studying the fluxes of carbon into and out of the forest canopy. Dr. Witinski is a co-founder and President of Eos Photonics. He focuses primarily on QCL integration, systems development and strategic partnerships..

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**Konstantin Vodopyanov**
**CREOL, The College of Optics & Photonics, UCF**

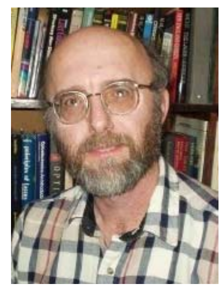
**Abstract:** I will present a new technique for extending octave-wide frequency combs to the highly desirable yet difficult-to-achieve mid-IR "molecular fingerprint" spectral range. The technique is based on subharmonic optical parametric oscillation (OPO) in GaAs that can be considered as a reverse of the second harmonic generation. The frequency comb of a pump laser is transposed to half of its central frequency and simultaneously spectrally augmented, thanks to the enormous gain bandwidth near OPO degeneracy and massive cross-coupling between the laser and the OPO frequency comb lines. With this source we demonstrate massively-parallel trace molecular detection and achieve part-per-billion sensitivity levels. Our present focus is both biomedical and security applications of the mid-IR spectral comb.

**Konstantin L. Vodopyanov** obtained his MS degree from Moscow Institute of Physics and Technology ("Phys-Tech") and accomplished his PhD and DSc (Habilitation) in the Oscillations Lab. of Lebedev Physical Institute (later General Physics Inst.), led by Nobel Prize winner Alexander Prokhorov. He was an assistant professor at Moscow Phys-Tech (1985-90), Alexander-von-Humboldt Fellow at the University of Bayreuth, Germany (1990-92), and a Royal Society postdoctoral fellow and lecturer at Imperial College, London, UK (1992-98). In 1998, he moved to the United States and became head of the laser group at Inrad, Inc., NJ (1998-2000), and later director of mid-IR systems at Picarro, Inc.,CA (2000-2003). His other industry experience includes co-founding and providing technical guidance for several US and European companies. In 2003 he returned to Academia (Stanford University, 2003-2013) and is now a 21st Century Scholar Chair & Professor of Optics at CREOL, College of Optics & Photonics, Univ. Central Florida. Dr. Vodopyanov is a Fellow of the American Physical Society (APS), Optical Society of America (OSA), SPIE - International Society for Optical Engineering, UK Institute of Physics (IOP), and a Senior Member of IEEE. He has > 350 technical publications and is member of program committees for several major laser conferences including CLEO (most recent, General Chair in 2010) and Photonics West (Conference Chair). His research interests include nonlinear optics, laser spectroscopy, mid-IR and terahertz-wave generation, ultra broadband frequency combs and their biomedical applications.

# Evolving Lasers to Solve Problems

**Jeff Hecht**

**Abstract:** Soon after he helped Ted Mainam make the first laser, Irnee D'Haenens jokingly called the laser "a solution looking for a problem." That became a running joke in early days of lasers, because the few lasers then available were not well-matched to many applications. But that changes as the young technology evolved. The more we learned about laser science, the better we could design lasers to match the needs of potential applications. Similarly, people could take these newly developed lasers and adapt them to solve other problems. A sterling example is the blue diode laser, developed to play HD Video disks, and then adapted to make bright blue LEDs that laid the foundation for solid-state lighting. Another is how the fiber amplifier, developed for fiber-optic communications, was adapted to make industrial fiber lasers. This talk will describe how lasers and their applications have evolved in the past and will continue to evolve in the future.



Jeff Hecht is a science and technology write and a contributing editor for Laser Focus World, and has written extensively on lasers, photonics and fiber optics for more than 30 years. His books include Understanding Fiber Optics, Understanding Lasers, City of Light, The Story of Fiber Optics, Beam: The Race to Make the Laser, and The Laser Guidebook. He received a B.S. in electrical engineering from Caltech, and is a senior member of the Optical Society of America and a life member of IEEE.

# Exhibitors

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# Student of the Year Presentation

## Hybrid Integrated Photonic Platforms and Devices

**Jeffrey Chiles**

The mid-infrared (3-8 μm) region of optical spectrum offers numerous possibilities in the fields of remote sensing, materials processing, and precision medical surgery. So far, most mid-infrared optical systems have been relying on bulky free-space optics. However, integrated photonics enables extremely compact and reliable designs to be achieved at low cost. We have developed two novel platforms to meet this need. The first is the all-silicon-optical-platform (ASOP), which offers ultra-broad optical transparency from 1.2 to 8.5 μm. The second is silicon-on-lithium niobate (SiLN), the first silicon-based mid-infrared compatible platform to exhibit second-order nonlinearity. The results of recently demonstrated mid-infrared optical modulators built on SiLN technology will be presented, as well as future prospects for nonlinear photonic devices built on these platforms.

**Jeff Chiles** is a PhD student in Dr. Fathpour's Integrated Photonics and Energy Solutions (IPES) Laboratory. His research focuses on mid-infrared integrated photonic devices, platforms and fabrication techniques. He is the first author of two journal articles, has co-authored 6 additional journal articles, and has presented his work at OFC, CLEO, and the IEEE Photonics Society Summer Topicals 2014, where he won second-place in the student poster presentation competition. He is a recipient of the Trustees Doctoral Fellowship of UCF.

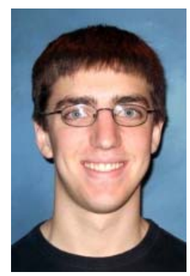
# Student Presentations

## Carrier-envelope phase locked ultrahigh power lasers

Isolated attosecond pulses are powerful tools for studying electron dynamics in atoms and molecules, but their usefulness is limited by low pulse energies. While it has been shown that a high-power laser using generalized double optical gating (GDOG) can increase the available photon flux in an extreme ultraviolet (XUV) continuum, such systems in general operate at repetition rates too slow for locking the carrier-envelope phase (CEP). Without CEP stabilization, isolated attosecond pulses can be generated by every shot of the driving laser, but the CEP fluctuations alter the flux of each pulse. This variability is unacceptable when initiating nonlinear XUV dynamics or dressing states in an attosecond pump–attosecond probe scheme. In an effort to make these high-energy lasers more suitable for high-field experiments and attosecond pulse production, we introduce a method for locking the CEP of a high-energy, low repetition-rate CPA system.

**Eric Cunningham** joined Prof. Zenghu Chang's Attosecond Science and Technology group in 2011 after earning BS and MS degrees in physics at Brigham Young University. While at UCF, he has been a recipient of the Graduate Dean's Fellowship, the Army Research Office Graduate Mentoring Fellowship, and the Graduate Research Excellence Fellowship.

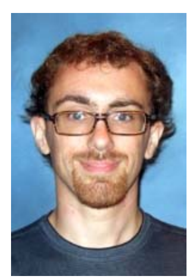
## Ultrafast Nonlinear Dynamics of Molecules



Understanding of the temporal dynamics of the nonlinear refraction is important for nonlinear photonics applications such as ultrafast time-resolved imaging [1], soliton propagation [2, 3], filamentation and supercontinuum generation [4], slow light [5], and all-optical switching [6]. Molecular systems exhibit large noninstantaneous nonlinear refraction that arise from induced motions of the nuclei. Here we present a thorough experimental study of the ultrafast nonlinear refractive dynamics of liquid carbon disulfide. Carbon disulfide is the most popular material for applications of nonlinear optical liquids, and is frequently used as a reference standard for NLO measurements. However, its nonlinearity varies by over an order of magnitude depending on pulse duration [7]. The application of our recently developed beam deflection technique [8] provides complete determination of the ultrafast response function, including absolute magnitudes, temporal dynamics, and symmetry properties of each mechanisms' contribution [9]. The response function allows prediction of any nonlinear refractive measurement on CS2, and establishes it as a proper reference material. This experimental approach may also applied by a wide variety of other materials, including molecular gases such as air.

**Matthew Reichert** is a Ph.D. candidate at CREOL in his fifth year of study. He received Bachelor of Science in Optical Engineering from Rose-Hulman Institute of Technology in 2010 and a Master of Science in Optics from CREOL in 2012. In addition to ultrafast nonlinear dynamics of molecules, his research has included the development and application of nonlinear spectroscopic techniques, and investigating the possibility of using GaAs for a two-photon semiconductor laser.

## Transverse Mode selection and brightness enhancement of a fiber laser using transmitting Bragg gratings



Increasing the dimensions of a waveguide provides the simplest means of reducing detrimental nonlinear effects, but such systems are inherently multi-mode, reducing the brightness of the system. Furthermore, using rectangular dimensions (giving 'ribbon' like shape) allows for improved heat extraction, as well as uniform temperature profile within the core. We propose a method of using the angular acceptance of a transmitting Bragg grating (TBG) to select the fundamental mode of a fiber laser resonator. This angular filter provides a simple method of increasing the brightness of a resonator without increasing the cavity length or requiring high intensity on a small aperture. We demonstrate numerical models and experimental results of an Yb-doped fiber with dimensions of 107.8 μm x 8.3 μm and a 4.7 mrad TBG with beam quality improvements from M2 = 11.3 to M2 = 1.45, while reducing the slope efficiency from 76% to 53%, overall increasing the brightness by 5.1 times.

**Brian Anderson** received his B.S. in physics from the University of Washington in 2009, and has been studying in the CREOL PhD program since 2010. Since then, he has participated in two internships with the AFRL in Albuquerque, NM and has received the DEPS HEL scholarship in 2013 and 2014. His current research interests include phase modulation in fiber amplifiers, beam combining, and transverse mode selection using VBGs. He hopes to graduate in the summer of 2015.

# Posters

## Poster 1

### Mode selection in a ribbon fiber using transmitting Bragg gratings

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Increasing the dimensions of a waveguide provides the simplest means of reducing detrimental nonlinear effects, but such systems are inherently multi-mode, reducing the brightness of the system. Furthermore, using rectangular dimensions (giving 'ribbon' like shape) allows for improved heat extraction, as well as uniform temperature profile within the core. We propose a method of using the angular acceptance of a transmitting Bragg grating (TBG) to select the fundamental mode of a fiber laser resonator, and as a means to increase the brightness of multi-mode fiber laser. Numerical modeling is used to calculate the diffraction losses needed to suppress the higher order modes in a laser system with saturable gain. The model is tested by constructing an external cavity resonator using an ytterbium doped ribbon fiber with core dimensions of 107.8μm by 8.3μm as the active medium. We show that the TBG increases the beam quality of the system from M2 = 11.3 to M2 = 1.45, while reducing the slope efficiency from 76% to 53%, overall increasing the brightness by 5.1 times.

## Poster 2

### Characterization of a Seven-Core Fiber Laser Based on Supermode Interference

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We have assembled a monolithic multicore fiber (MCF) laser based on a gain section of Yb-doped seven-core fiber. At the operation wavelength near 1030 nm, each core is single-mode and strong coupling between the cores results in the propagation of supermodes. The propagation of these supermodes results in supermode interference (SMI). By temperature control of the fiber Bragg grating (FBG) serving as the high reflector in the cavity, the ability to tune across multiple SMI periods was demonstrated.

Utilizing the FBG's reflectivity tuning, measurements were made of the laser spectrum, threshold power, and slope efficiency for varying wavelengths along the SMI interference period. Temporal measurements showing an unstable Q-switched regime of pulse trains were also taken. To stabilize these pulse trains, single-mode fiber was used to increase nonlinearities in the cavity, and regular pulse trains were observed. Comparison of the increased cavity length with the original characterization is presented.

## Poster 3

### Thermal Mode Instability

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Thermal mode instability (TMI) has recently emerged as a critical phenomenon limiting high average power scaling in fiber laser amplifiers. During TMI, interference arises between two or more transverse modes along the fiber amplifier. This interference leads to a periodic variation in gain inversion and temperature distribution- effectively producing a long period grating that can transfer energy between the interfering modes. This poster summarizes ongoing experimental efforts to more thoroughly understand this phenomenon and develop mitigation techniques.

## Poster 4

### Quantum Beats in Attosecond Transient Absorption of Krypton Autoionizing States

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The development of attosecond transient absorption spectroscopy (ATAS) has allowed probing of electron dynamics in atoms with few-femtosecond to sub-cycle time scales. Recently, the contribution of quantum beating to the two-color multi-photon excitation process has been proposed and demonstrated in the attosecond transient absorption experiment in the bound state of atoms. Here we performed an attosecond transient absorption experiment with krypton atoms, the attosecond pulse launched electronic wave packets composed of multiple bound excited states and spin-orbit coupling induced autoionization states of krypton atoms. Quantum beats were observed in the autoionizing states near the ionization threshold. Recurrences were observed in the autoionizing states with periods of 5 – 10 fs. The relative phase among these autoionizing states can be retrieved from the ATAS measurement, thus allowed the reconstruction of the valence state wave packets of krypton.

## Poster 5

### Hybrid Integrated Photonic Platforms and Devices for the Mid-Infrared

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The field of integrated optics has seen vast growth since its beginnings decades ago. The promise of mass-manufacturable, compact, and reliable systems has driven much of this growth. The use of silicon as an optical platform has been established for several decades, the silicon-on-insulator (SOI) platform being the most popular. For the pursuit of integrated photonics in the mid-infrared (3-8 μm), however, the SOI platform is inadequate due to the oxide-induced absorption and the poor performance of free carrier modulation in this regime. We have developed two novel platforms to address these shortcomings. The first is the all-silicon-optical-platform (ASOP) which offers ultra-broad optical transparency from 1.2 to 8.5 μm. The second is silicon-on-lithium niobate (SiLN), the first silicon-based mid-infrared compatible platform to exhibit second-order nonlinearity. The results of recently demonstrated mid-infrared optical modulators built on SiLN technology will also be presented.

## Poster 6

### Guided Cellular Motion Using Linearly Polarized Light

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Ever since the seminal work of Beth more than 75 years ago, we have known that the polarization of electromagnetic fields can induce torques when incident on the proper materials. Extending this application into the biological realm, it has been shown that rod shaped subcellular actin rods will align in the polarization direction of linearly polarized optical radiation. This ability to direct actin movement is of key importance to controlled cell guidance, as actin filamentation plays a crucial role in determining the direction of cellular motion. We show here that by aligning actin rods and filaments using linearly polarized light, subcellular actin activity, not only aligns, but shows preferential movement along the direction of polarization. The implication that cells could be guided in a preferred direction *in vivo* using non-invasive optical forces, presents exiting applications in accelerated wound healing, controllable apoptosis, and many other interesting macro-scale biological phenomena.

## Poster 7

### Carrier-envelope phase locked ultrahigh power lasers

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Isolated attosecond pulses are powerful tools for studying electron dynamics in atoms and molecules, but their usefulness is limited by low pulse energies. While it has been shown that a high-power laser using generalized double optical gating (GDOG) can increase the available photon flux in an extreme ultraviolet (XUV) continuum, such systems in general operate at repetition rates too slow for locking the carrier-envelope phase (CEP). Without CEP stabilization, isolated attosecond pulses can be generated by every shot of the driving laser, but the CEP fluctuations alter the flux of each pulse. This variability is unacceptable when initiating nonlinear XUV dynamics or dressing states in an attosecond pump–attosecond probe scheme. In an effort to make these high-energy lasers more suitable for high-field experiments and attosecond pulse production, we introduce a method for locking the CEP of a high-energy, low repetition-rate CPA system.

## Poster 8

### Atmospheric Pressure Chemical Vapor Deposition: An Enabling Technology for Manufacturing Silicon Solar Cells

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Atmospheric pressure chemical vapor deposition (APCVD) is a versatile manufacturing process that offers much promise in enabling significant efficiency gains and cost reductions for crystalline silicon (c-Si) solar cells. In this presentation, recent results on the deposition and subsequent processing of functional oxide films using an in-line, high throughput APCVD system will be reported. The materials deposited in this work include aluminum oxide, titanium oxide, silicon oxide, and doped silicon oxide. These oxide films and film stacks can be utilized for doping (e.g., emitter and surface field formation), surface passivation, and photon management on the front and rear side of c-Si solar cells. Experimental data regarding the microstructure, optical properties, and electronic properties of the films will be presented, along with the impact of these films on cell efficiency and other relevant cell parameters. Implications of these results for standard and novel c-Si cell architectures will be covered.

## Poster 9

### Three Dimensional Polarization-Sensitive Spatially-Variant Self Collimating Photonic Crystal for Beam Bending

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A three dimensional spatially-variant self-collimating photonic crystal (SVPC) with high polarization sensitivity that can control the spatial propagation of electromagnetic waves was fabricated and characterized. The orientation of the SVPC unit cell was changed as a function of position to make use of the directional phenomena of self-collimation to tightly bend a mid-infrared (MIR) unguided beam through a 90º angle without significant diffuse scattering caused by the bend. Other geometrical attributes of the SVPC lattice were maintained constant throughout the structure. Multi-photon direct laser writing was used to fabricate the SVPC in the photo-polymer SU-8. Optical characterization of the SVPC lattice was performed using light having a vacuum wavelength of $\lambda 0$ = 2.94 μm. BOE-etched optical fibers were scanned across the different faces of the structure to measure the relative intensity of light emanating from those surfaces. The results show that the SVPC lattice effectively bends vertically polarized MIR light through a turn with a radius as small as $6.4\lambda 0$ while transmitting the horizontal polarization straight through. This work provides a new solution and scheme for integrated photonic applications.

## Poster 10

### Bi-directional pump configuration for increasing thermal modal instabilities threshold in high power fiber amplifiers

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We present a time dependent computer model for modal instabilities (MI) in high power fiber amplifiers based on beam propagation method. Three regimes of temporal dynamics that are characteristic of the transfer of energy between the fundamental mode and higher order mode are captured and applied to predicting the threshold of these instabilities in absence of any frequency offset between the interfering modes. Simulation results show an increase of the instabilities threshold by a factor of approximately %30 in the case of bi-directional pump scheme with respect to the forward pump configuration. Furthermore, we estimated the MI threshold applying a coupled-mode model of thermally induced instabilities which also takes account of gain saturation to its first order approximation, and obtained reasonably good agreement with respect to our beam propagation simulation results.

## Poster 11

### Quantum-dots enhanced liquid crystal displays

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"LCD vs. OLED: who wins?" is recently a hot topic. LCD has advantages in lifetime, power consumption, resolution, and cost, but OLED is superior in response time, color saturation, viewing angle, and flexibility. To outperform OLED in color vividness, LCD camp has developed quantum dot (QD)-based backlight. The advantages are threefold: 1) It greatly widens the LCD color gamut to 120% in CIE 1931 color space (in comparison, OLED is 100%), 2) it is easy to achieve perfect white point, and 3) it improves the optical efficiency by 15%. Meanwhile, our group developed a new quasi-collimated backlight and freeform diffusers to enlarge viewing angle, eliminate color shift and grayscale inversion, keep high transmittance, high contrast ratio and low ambient reflection, and manipulate display luminance distribution. Potential applications of such a new system include privacy display, multi-view display, and Lambertian-like display.

## Poster 12

### Improving Energy Harvesting using Plasmonic Optical Horns

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Energy harvesting is an attractive means for decreasing the costs of materials and devices used for photovoltaics and related applications. One potential way to harvest infrared energy is to use plasmonic horns. These devices would harvest energy over a wide aperture and funnel it to a smaller-area photovoltaic device. Horns with arbitrary shape and sizes were fabricated by multi-photon direct laser writing, metallized by electroless deposition, and then optically characterized. Preliminary data are presented to show the potential of these devices.

## Poster 13

### Achromatic phase elements based on a combination of surface and volume diffractive gratings

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Phase masks are important optical elements that have been utilized for several decades in a large variety of applications. Recently, we demonstrated a new type of phase masks fabricated by encoding phase profiles into volume Bragg gratings, allowing these holographic elements to be used as phase masks at any wavelength capable of satisfying the Bragg condition of the hologram. Here, we present a new method of true achromatization of this type of phase masks that removes the need for angle tuning and is implemented by combining this holographic phase masks approach with a pair of surface diffraction gratings.

## Poster 14

### Plasma Density of Laser Filament

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A femtosecond laser pulse with peak power above 3.2 GW in air will self-focus, generating a plasma that causes the beam to defocus. The ensuing competition between Kerr self-focusing and plasma defocusing results in a weakly ionized plasma channel and laser "filament" that is nearly non-diffracting for distances much greater than the Rayleigh length. Several applications of filamentation have been suggested, such as kilometer range LIDAR, remote generation of terahertz radiation, stand-off sensing, and guided discharge of clouds. In order to characterize the plasma generation during filamentation, we have constructed an interferometric system to give direct temporally and spatially resolved measurements of the plasma density. In our pump-probe setup, the pump beam is focused to induce filamentation and plasma generation. The probe beam first passes through a spatial filter and an adjustable delay line, to clean the beam and vary the delay between pump and probe. Next it intersects with the filamenting beam at a small angle, to increase the interaction length and thus the overall phase change experienced by the beam. Finally the probe beam

enters a folded wavefront, Mach-Zehnder interferometer, and the intersection point is magnified and imaged to a CCD. Our Abel inversion code extracts the phase from the interferogram and determines the electron density of the filament cross-section as a function of radius, using the central lineout of the phase. By varying the delay and the filament collapse location, we can create a temporal and spatial profile of the filament.

# Poster 15

## On-Chip PT-Symmetric Microring Lasers

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Microring resonators represent one of the most promising structures for on-chip laser sources. Due to their high quality factors, small footprints, and simplicity of fabrication, microrings are already widely popular for passive applications such as sensing and optical communications. However, utilization of such resonators in designing laser cavities is still rather challenging, because of the fact that they support several longitudinal and transverse modes within the gain bandwidth afforded by semiconductors. This multimode operation has a critical effect on the spectral purity and beam quality of these lasers, causing spatial and temporal fluctuations in the emitted power. Thus enforcing single mode laser operation is a necessary step in utilizing microring resonators as an integrated light source. Although several methods have been proposed in the literature to address this issue, there is still a need for a novel and versatile approach for laser design without imposing extra demands in terms of complexity and fabrication.
Using a PT-symmetric arrangement, here, we present the first experimental demonstration of stable single-mode operation of a micro-ring cavity, which normally tends to support several transverse and longitudinal modes for the same amount of pump power. Along these lines, an identical but lossy partner has been coupled to the active ring in order to form the PT-symmetric arrangement. By engineering the distance between the pair, all undesired modes have been kept below the PT-symmetry breaking threshold. Therefore, only the fundamental mode oscillates in the symmetry-broken regime, dominating the emission spectrum with high stability and enhanced efficiency.

# Poster 16

## Spatial Dependence of the Interaction between a Single Aerosol and Laser Filament on its Reformation

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A femtosecond laser pulse with a peak power above 3 GW in air can create structures called filaments that propagate long distances without diffraction by achieving a dynamic balance between the Kerr self-focusing and plasma defocusing effects. The interaction of a laser filament with an aerosol shows a self-healing behavior of the filament characterized by a rupture of the plasma channel followed by a refocusing of the pulse as a filament. This study shows the dependence of the survival and reformation of the filament on the position of the aerosol within the filament and quantifies the importance of the carrier field around the plasma channel.

# Poster 17

## Filament-Filament Interaction

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A femtosecond laser pulse with a peak power above 3 GW in air can create structures called filaments that propagate long distances without diffraction by achieving a dynamic balance between the Kerr self-focusing and plasma defocusing effects. Increasing the power of the laser pulse leads to the formation of multiple filaments, which can be manipulated by controlling the phase of the laser pulse. Such filaments can be arranged in array patterns to create a transient optical waveguide in air or to control and enhance the terahertz radiation produced by the filaments. In order to better understand these structures and better control them for applications, we study the interaction between two filaments using interferometry to control the phase, position, and energy of the two filaments relative to one another. This detailed study of the filament-filament interaction and how various parameters affect the interaction will further improve the understanding of more complex filament arrays and structures.

# Poster 18

## Tailoring Photon Statistics in Disordered Photonic Lattices by Variation of deterministic Structured Illumination

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Coherent light transmitted through a finite disordered structure with disorder-immune symmetry of chiral type exhibits photon statistics that depend strongly on the illumination spatial distribution and its symmetries. We show that for point illumination, a thermalization bandgap exists such that the light always emerges with super-thermal statistics no matter how small the disorder level. At a fixed disorder level, structured coherent illumination may be varied to enable deterministic tuning of the photon statistics in a compact device –from sub-thermal to super-thermal. This is implemented via controlled symmetry breaking realized by sculpting the amplitude or phase of the illumination coherent field. We experimentally demonstrate this prediction by use of two-point coherent illumination and observing Hanbury-Brown and Twiss correlation and the photon number distribution as a function of the illumination relative phase difference.

# Poster 19

## Control of surface reactivity in borosilicate glasses using thermal poling

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The ability to control surface reactivity at different scales will enable key properties needed for future "smart substrates". Within this objective, we aim to design a borosilicate glass substrate with tailored physical and chemical properties at a sub-micron scale via thermal poling. During the treatment, alkali elements diffuse in the glass toward the cathode, leaving an alkali depleted layer under the anode. By carefully selecting glass compositions, two effects can be combine (i) structural changes and (ii) implementation of a static electric field. Using Raman and infrared spectroscopy, we were able to investigate the network reorganization in the borate network as a result of the process. Location of the electric field has been characterized by micro-Second Harmonic Generation (μSHG). It was observed that formation of the new charged borate structure makes the glass surface extremely hygroscopic.

# Poster 20

## A Mid-IR OPCPA laser system

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A Mid-IR OPCPA laser operating at 1 kHz is being developed for generating isolated attosecond pulses in the water window. A broadband Mid-IR seed covering a wavelength range of 1.2 μm to 2.3 μm is generated by intro-pulse difference frequency generation driven by white-light pulses from a gas filled hollow-core fiber using Ti:Sapphire laser output. Such seed, with an 800 nJ pulse energy, is stretched to 4ps by an IR acousto-optic programmable dispersive filter (Dazzler) to frequency-match with chirped Ti:Sapphire laser pulses for broadband amplification inside BIBO crystals. With two-stage OPCPA amplification and a total of 2.7 mJ pumping energy, 200 μJ Mid-IR laser pulses from 1.2 μm to 2.3 μm are achieved. With a bulk of fused silica for pulse compression and Dazzler for phase correction, we anticipate a few-cycle Mid-IR laser source.

# Poster 21

## Negative Curvature Hollow Core Fiber

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We show a numerical study of the hollow core negative curvature fibers (HCNCFs). These fibers consist of a hollow core surrounding by a circular arrangement of capillaries tightly packed. This arrangement creates a boundary of negative curvature with respect to core of the fiber. As a result light is strongly confined in the core with low interaction with the cladding. In these fibers the total losses, including leakage, material and bending, can be lower than that of conventional solid fibers. On the other hand, we show the importance of optimizing the capillary thickness and the separation distance between them to reach optimum low loss mode of operation

in high power transmission lines for near and mid infrared applications.

## Poster 22

### Gap-Plasmon Enhanced Gold Nanoparticle Photoluminescence

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Plasmon resonances of metal nanostructures have been studied widely as a means to enhance numerous optical effects due to their strong electromagnetic field enhancement and subwavelength resonance volume. Single molecule detections, nonlinear mirrors, and light beam shaping are a few examples of applications that plasmon resonances play a crucial role. A gap-plasmon resonance is a type of resonance mode found in closely spaced metal nanostructures that can provide extreme electric field enhancement. This field enhancement can be several orders of magnitude higher than observed in isolated metal nanostructures. We have studied the effect of *gap-plasmon resonance enhanced photoluminescence* of individual gold nanoparticles on an $Al_2O_3$ coated gold film under 532 and 633 nm excitation wavelength. The enhanced gold photoluminescence spectra are compared with thaose from a reference gold film at both wavelengths, and show a clear peak near the measured gap-plasmon resonance wavelength of the gold nanoparticle. A peak photoluminescence enhancement of 28 000 is observed. The measured photoluminescence enhancement spectra for both excitation wavelength are reproduced using numerical calculations without any free parameters. The calculations suggests the local photoluminescence enhancement as high as one million in the gold volume near the gap between the particle and the gold film. The photoluminescence enhancement is explained as the result of a combined effects of a gap-plasmon enhanced e–h pair generation rate at the excitation wavelengths and the wavelength-dependent plasmon enhanced emission efficiency.

## Poster 23

### Extremely Low-Loss Chalcogenide Integrated Photonics with Chlorine Plasma Etching

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The chalcogenide glasses are promising materials for integrated photonics due to their transparency in mid-infrared and high optical nonlinearity. We present a novel method for the fabrication of high-performance chalcogenide-based integrated photonics on silicon substrates based on chlorine plasma etching to produce low loss waveguides. Using this fabrication method, microring resonators with intrinsic Q-factors as high as 450,000 and a corresponding propagation loss as low as 0.42 dB/cm are demonstrated. Furthermore, we have utilized the chlorine plasma etching process to demonstrate the first fiber-to-waveguide grating couplers in chalcogenide photonics with high power coupling efficiency of 37% for transverse-electric polarized modes. The new process is a significant improvement to previous fluorine-based etching recipes, exhibiting 3-fold decrease in the propagation loss. The design of devices utilizing the high optical nonlinearity is underway.

## Poster 24

### Scanning 3-D mid-IR imaging of buried structures in an uncooled wide bandgap photodiode using extremely nondegenerate two-photon absorption

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In extremely nondegenerate (END) two-photon absorption (2PA) in semiconductors, there is several orders of increase in the magnitude of the 2PA coefficient over the degenerate case. Based on this phenomenon, we can get 2PA to be strong enough in pin photodetectors to provide sensitive detection of mid IR radiation. We demonstrate a scanning gated 3-D mid-IR imaging technique using mid-IR femtosecond pulses (~ 5 µm) in an uncooled GaN p-i-n photodetector. A 3-axis automated scanning system records the delay of the mid-IR signal pulse and gate pulse, which corresponds to various levels of the depths of the object. We observe a depth resolution (~ 2 µm) smaller than vacuum wavelength of light (~ 5 µm) in buried semiconductor structures. The method is nondestructive and could be used for inspection and diagnosis of buried structures in various IR transparent materials. This technique also enables 3-D imaging in the long-wave-IR.

# Poster 25

## Heterogeneous Microring and Mach-Zehnder Modulators Based on Lithium Niobate and Chalcogenide Glass on Silicon Substrates

Ashutosh Rao, Aniket Patil, Jeff Chiles, Marcin Malinowski, Spencer Novak, Kathleen Richardson, Payam Rabiei, Sasan Fathpour*
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Submicron thin films of lithium niobate are bonded onto silicon dioxide thermally grown on silicon substrates, and rib-loaded with an index-matched $Ge_{23}Sb_7S_{70}$ chalcogenide glass. This novel platform is used to demonstrate single-mode lithium niobate microring modulators with grating couplers, and Mach-Zehnder modulators in the telecom C band at 1550 nm. The chalcogenide rib loading region facilitates high optical waveguide confinement, yielding devices smaller than conventional diffused lithium niobate waveguides. A waveguide propagation loss of 1.2 dB/cm is extracted from microring modulators with 200 µm radius, with a corresponding quality factor, Q, of $1.2 \times 10^5$, a tuning rate of 0.4 GHz/V, and extinction ratio of 13 dB. The 6-mm long Mach-Zehnder modulators have a $V_\pi.L$ of 3.8 V.cm and a 15 dB extinction ratio. The reduction in size, compared to conventional lithium niobate modulators, will enable dense integration of these devices, a key requirement for components for short reach optical interconnects and higher order advanced modulation schemes.

# Poster 26

## Extremely Nondegenerate Two-Photon Gain: Potential for Two-Photon Semiconductor Lasers

Matthew Reichert, David J. Hagan, Eric W. Van Stryland*
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A two-photon gain (2PG) based laser, where two-photons simultaneously stimulate the emission of another two, has been a goal of nonlinear optics since shortly after the invention of the laser. This process is the inverse of two-photon absorption (2PA), just as one-photon (linear) stimulated emission is the opposite of one-photon absorption. The 2PA coefficient $\alpha_2$ in direct-gap semiconductors may be enhanced by orders of magnitude when using extremely nondegenerate photon pairs. This enhancement also applies to 2PG which may open the possibility for semiconductor-based two-photon lasers. We present experimental measurements via a modified pump-probe technique, with a third pulse to optically excite a population inversion, in a thin sample of GaAs. We have evidence for the first time of nondegenerate two-photon gain in optically excited bulk GaAs with pump-probe experiments. Analysis of a GaAs based two-photon semiconductor lasers including competing processes, both free-carrier and three-photon absorption, is presented.

# Poster 27

## Plasmonic photo-capacitive spectral imager

F. K. Rezaie[1,*], C. W. Smith[1,2], M. Lodge[1,2], J. Nath[1], D. Maukonen[1], J. W. Cleary[3], M. Ishigami[1,2], I. O. Oladeji[4], R. E. Peale[2]
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Electronic detection of surface plasmon polaritons (SPPs), which are resonantly excited as a function of angle and wavelength, enables a potentially ultra-compact means of spectral imaging. Individual sensing elements comprise a prism to couple light to SPPs and a close-coupled photo-capacitor to detect the SPPs. The photo-capacitor comprises a silicon substrate, a layer of silicon oxide, and a transparent conductor. The latter may be graphene, thin evaporated metal, or a transparent conducting oxide such as $SnO_2$:F. Exposure to light only at the SPP resonance wavelength and angle of incidence generates electron-hole pairs in the semiconductor. The electrons accumulate at the semiconductor-oxide interface, inducing a current in the transparent conductor, which is amplified and recorded. Biasing the transparent conductor enables electronic modulation of the photoresponse. A spectral imager based on this approach would have no moving parts and no external spectrometer or interferometer, making it compact, light-weight, and attractive for airborne and satellite platforms. Applications include defense, Earth science, and planetary exploration.

# Poster 28

## Extraordinary Light Absorption on Graphene

Alireza Safaei*[1,2], Michael Leuenberger[1,2,3], Debashis Chanda[1,2,3]
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Graphene is one of the most widely studied 2D material. It possesses very high mobility and fast carrier relaxation time making it suitable material for ultrafast optoelectronic devices for visible to far-IR domain. However, since the band structure of graphene doesn't have band gap, the conduction and valence bands touch each other at Dirac point. It means that the absorption in all regions of wavelength (visible to IR) is very small for monolayer graphene (~2.3 %). Such low optical absorption prevents use of graphene as an efficient optical material.

Various strategies based on stacking of multiple graphene sheets to increase absorption cross-section has been studied previously without significant improvement in absorption. We developed a different strategy where a patterned graphene sheet is attached to an optical cavity. The excitation of propagating (SPP) and localized (LSP) surface plasmons on patterned metal surface is a well-known phenomenon. Any material like graphene having free electron plasma supports surface plasmon resonance. The localized surface plasmon can be excited on the edges of a nanostructured graphene which enhances absorption of the incident radiation. The coherant interaction between incident and back reflected light in the cavity enhances graphene absorption by many fold. The key aspect of the proposed system is that we could excite localized surface plasmon resonance (LSPR) on the edges of the nanohole pattern (defind by nanohole diameter) which results in strong absorption (~60%) due to strong coupling between graphene LSPR and optical cavity modes at quaterwave condition . At this point, the coherent excitation by both incident and back reflected light creates stronger localized surface plasmon resonance inducing higher absorption.

# Poster 29

## Properties of direct laser written nano-structures in multi-layered chalcogenide glasses

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Arsenic trisulfide (As2S3) is a chalcogenide (ChG) material with excellent infrared (IR) transparency (620 nm to 11 μm), an optical bandgap at 2.35 eV (λ ~ 517 nm), low phonon energies, and large nonlinear refractive indices. Multi-photon direct laser writing (DLW) can be used to photo-pattern nano-structures in thin films of thermally deposited As2S3. After photo-patterning, the unexposed regions of the film can be dissolved in a polar solvent, leaving behind a free-standing As2S3 nano-structure. In this work we investigated the properties and processing of single-layered films of thermally deposited As2S3 and multi-layered films of As2S3 deposited onto an underlying thin film of arsenic triselenide (As2Se3). The As2Se3 serves as an anti-reflection (AR) layer which reduces reflection of the incident laser beam back into the focal volume during laser patterning. By eliminating the back-reflection we are able to fabricate smaller nano-structures in the As2S3 layer with sub-wavelength features, cylindrical shapes, and increased substrate adhesion. The multi-layer films were used to fabricate large arrays (250 μm × 250 μm) of homogeneous nano-structures with a 500 nm pitch and dimensions as small as 120 nm. This work opens new routes to ChG based electronics and optical devices such as detectors, sensors, photonics waveguides, and acousto-optics.

# Poster 30

## Plasma Temperature Measurements in the Context of Spectral Interference

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In Atomic Emission Spectroscopy (AES), Laser-Induced Breakdown Spectroscopy (LIBS) is a technique used to obtain the elemental composition of samples. LIBS relies on firing a high-powered laser pulse onto the surface of a sample so that a plasma is induced. The laser-induced plasma (LIP) emits light from excited ions, which results in an emission spectrum of the elements composing the sample. This emission spectrum can be characterized by its temperature. Temperature measurements are important in LIBS because it helps in characterizing if the LIP is under equilibrium conditions. Plasma characterization outside equilibrium conditions is cumbersome because of the complex processes that occur within the plasma, and its inhomogeneous and transient nature.

We introduce here a novel approach to calculating the plasma temperature from unresolved spectra. By assuming that the plasma is in Local Thermodynamic Equilibrium (LTE), the Boltzmann plot (BP), Saha-Boltzmann plot (SBP), or Multi-Elemental Saha- Boltzmann plot (MESBP) methods can be used to measure plasma temperature. A MatLab code is written to analyze simulated spectra and perform the BP, SBP, and MESBP so that a plasma temperature is calculated. The basic framework for the BP, SBP, and MSBP are developed in Matlab and produces accurate results for single elemental spectra.

The temperature algorithm will also be implemented in a new algorithm developed in UCF for quantitative interference analysis and probabilistic line assignment in under-resolved LIBS spectra. This work is funded by the National Institute of Justice for the quantification of error rates when analyzing trace evidence.

## Poster 31

### Monolithic Mode-Locked Lasers Based on High Finesse Silicon Ring Resonators

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The rapid depletion of natural resources and increased emission of green-house gases are the motivation behind the development of solar energy based environment friendly devices. One of these environment friendly devices is called Luminescent Solar Concentrators (LSCs). The LSCs are based on the phenomenon of enhanced light guiding, resulting in improved solar energy harvesting and thus efficient solar cells. In this work an anisotropic Rhodamine-B dye of varied concentration was intercalated in Somasif mica and a fluorescent dye/mica hybrid was developed. This hybrid was then dispersed in a UV-curable mixture of WR-5500 and SR-350, optimized to minimize any scattering and reabsorption losses. The dye/mica hybrid was then suspended in the resin mixture and rotated at 25 rpm in a 1 T magnetic field for 10 minutes and cured for 20 minutes with a Xe lamp under a magnetic field. The hybrid material was aligned so that the axis of the mica particles was perpendicular to the applied magnetic field. The alignment was then confirmed by UV/Vis measurement using vertical and horizontal polarizers. XRD studies were performed in order to determine the orientation of the Rhodamine-B dye in Somasif mica. This work opens new possibilities of research in the field of LSCs which can use aligned anisotropic dyes to efficiently concentrate the light to produce cheaper and efficient solar devices.

## Poster 32

### Engineered Structures of Laser Filaments

Robert Short*, Nicholas Barbieri, Matthieu Baudelet, Martin Richardson

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We investigated techniques for the creation of arrays of laser filaments using a multi-terawatt femtosecond laser system. The filament arrays are created by modifying the wavefront of the Gaussian laser beam prior to filamentation. Such arrays have applications as microwave and optical waveguides. Supported by the Army Research Office.

## Poster 33

### Barium Chloride Scintillator Ceramics

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Barium chloride is a recently discovered scintillator material with high brightness and high energy resolution for use in gamma ray spectroscopy. Its low hygroscopicity compared to other halide scintillator materials marks a potential for using bulk ceramic processing techniques to fabricate large-scale plates at a much lower cost than growing single crystals. We present a new method of intermediate-temperature and high-pressure compaction of powders using a custom built press. Both commercially available powders and spray dried powders, synthesized in house, are tested in compaction experiments. Samples exhibit translucency with scattering brought about by birefringence at grain boundaries and residual porosity. Performance of europium doped samples is measured by optically excited luminescence, pulsed x-ray excited luminescence, and thermoluminescence. Optical measurements have provided evidence of problematic oxygen defects attributed to the processing environment, which can be carefully controlled to yield higher quality ceramics.

# Poster 34

## Resonantly Pumped Thulium-doped Photonic Crystal Fiber Amplifier

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Ultra-large mode area thulium-doped photonic crystal fibers (Tm:PCF) have enabled the highest peak powers to date in 2 micron fiber based laser systems. However, Tm:PCFs slope efficiency is limited to <50% when pumped with 790 nm laser diodes. Pumping at 1550 nm with erbium/ytterbium-doped fiber (Er/Yb:fiber) lasers is an alternative that improves slope efficiency to ~70%; however such pump lasers are themselves relatively inefficient. A more attractive approach that has been demonstrated to enable slope efficiencies over 90% in thulium-doped step-index fiber amplifiers is resonant pumping (or in-band pumping) using another high power thulium fiber laser operating at a shorter wavelength. This approach offers several advantages including higher overall electrical to optical efficiency than pumping with Er/Yb:fiber and significantly lower heat loads in the final amplifier than diode pumping at 790 nm. This poster describes ongoing efforts to apply resonant pumping to Tm:PCF in order to improve efficiency and facilitate high power scaling in ultra-large mode area systems.

# Poster 35

## Multi-Parameter Sensing using Seven-Core Fiber

Amy Van Newkirk*, Guillermo Salceda-Delgado, Enrique Antonio-Lopez, Rodrigo Amezcua-Correa, Axel Schülzgen,
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We have developed a novel multi-parameter sensor using a multicore fiber (MCF) spliced between two single mode fibers. The fiber chain creates a supermode interference pattern in the MCF that translates into a periodic modulation in the transmission spectrum. The spectrum shifts with changes in temperature, strain, displacement etc., and can be easily monitored in real time.

Multiple testing setups were developed, and the sensitivity of the devices to temperature, strain, and acoustic waves was measured. We have also investigated the dependence of the sensitivities on the outer diameter of the fiber sensors, observing sensitivity increases of more than 10x through etching of the fiber cladding. Additionally, a method for separating temperature and strain spectral shifts was developed, allowing for simultaneous measurement of both quantities, using a single transmission spectrum. These simple fiber sensors have shown to be extremely versatile in their applications, as well as robust, operating in temperatures of up to 1000°C.

# Poster 36

## Chiral Light-Matter Interaction

Abraham Vázquez-Guardado[1,2,*], Debashis Chanda[1,2,3]
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Chiral elements are abundant in nature, from amino acids, proteins, and sugars to DNA material. They are present in two configurations called enantiomers. One is the mirror image of the other but they cannot be superimposed onto each other, just like our hands. These chiral biomolecules have same physical properties, such as density, molecular weight and electronic/vibrational transition energies. Nevertheless it is the interaction with other chiral elements that an enantiomer can be probed and differentiated from its twin. Circular polarized light is an example of an electromagnetic chiral element in the form of left or right-handedness. Under this chiral light-matter interaction an enantiomer will preferentially interact with its electromagnetic counterpart. This preferential interaction has led to the circular dichroism spectroscopy technique, which is a differential measurement in the extinction of left and right circularly polarized light propagating in a chiral environment. This technique is a powerful analytical method but its main drawback lays in the small molecular cross sections that yield to extremely small signals. Plasmonic resonances, which are coherent oscillation of free electrons in a metal, are strong candidates to overcome this problem for different reasons. First, at the plasmonic resonance there is a strong near field around the metallic scatterer. Second, the field configuration, when excited appropriately, can generate strong rotating near field. Third, if the plasmonic metallic particle is chiral its interaction with light can mediate strong interaction with chiral molecule.

# Lab Tours

## Labs & Facilities

The main facilities of the College are housed in a state-of-the art 104,000 sq. ft. building dedicated to optics and photonics research and education.

## Facilities

**Nanophotonics Systems Fabrication Facilities.** A 3,000 ft2 multi-user facility containing Class 100 and Class 1000 cleanrooms and a Leica 5000+ e-beam lithography instrument capable of 10-nm resolution. These facilities are used for fabrication and study of nanostructured materials and nanophotonic integrated circuits. The facility equipment includes a Suss MJB-3 and MJB-4 aligners, 2 Plasma-Therm 790 RIE systems with silicon and III-V etching capabilities, a Temascal and V&N E-beam evaporators, along with an atomic force microscope, a profilometer, aa rapid thermal annealer, a bonder, a scriber and microscope. The Laboratory is designed and operated as a multi-user facility, with availability to companies and other outside users. Rm 180.

**Optoelectronic Fabrication Cleanroom.** 800 sq. ft. multiuser facility consisting of class 100 and class 10,000 cleanrooms. Used in the development of optoelectronic semiconductor devices. The facility equipment includes a Suss MJB-3 aligner, a Plasma-Therm 790 RIE/PECVD, an Edwards thermal evaporator, along with a bonder, a scriber and microscope. Rm 211

**Scanning Electron Microscope (SEM) Facility.** Vega SBH system built by Tescan is a tungsten-filament scanning electron microscope. The system is designed with a fully electronic column and is capable of imaging from 1–30 keV with nanometer scale resolution. Additionally, the system is equipped with the state of the art sample positioning stage with 5 nm resolution and a full scale travel of 42 mm. The shared SEM is ideal for checking the fidelty of travel of 42 mm. The shared SEM is ideal for checking the fidelty of the microfabrication routinely performed in the CREOL cleanroom. Rm 176

**Cary Spectra-Photometer and Microscope.** Cary 500 is Spectrophotometer that is capable of measuring light absorption in both transmitted and reflected light in the UV, visible and near IR spectrum. Rm 159

**Zygo Facility.** Rm 211B. Shared facility administered by Martin Richardson.

**Machine Shop.** Has two modern Sharp LMV milling machines and a 16–50G lathe capable of achieving the tolerances required for the instruments used in CREOL. Classes are offered to qualify research scientists and students to safely modify and construct instruments critical to their research. Rm A106. Richard Zotti.

## Faculty Laboratories

Room

### Ayman Abouraddy

- Optical Fiber Characterization and Mid-infrared Nonlinear Fiber Optics — A114
- Optical Fiber Draw Tower — A105
- Thin-film Thermal Evaporation — 216
- Multi-material Fiber Preform Fabrication — A302
- Optical Characterization Lab — 244

### Rodrigo Amezcua Correa

- Micro Structured Fibers and Fiber Devices — A119
- Fiber Preform Fabrication — 130
- Fiber Optic Draw Tower — A105

## Michael Bass

- Laser Spectroscopy, Optical Fibers and New Materials 157
- Laser Calorimetry and Novel Diode Pump Configurations 158
- Microscopy, Electronics, Wave Propigation Studies 175

## Zenghu Chang

- FAST Lab PS140

## Demetri Christodoulides

- Nonlinear Guided Wave Lab 203

## Peter Delfyett

- Femtosecond Semiconductor Lasers & Dynamics 252
- Frequency Comb technology 254
- Photonic Analog to Digital Converter Technology 255
- Microwave Photonics 256
- Laser Radar Technology and Systems 245A
- Advanced Optical Signal Processing Technology 244A
- Quantum Dot Semiconductor Laser Laboratory 243A

## Dennis Deppe

- MBE Lab 180C
- PL Lab 146

## Aristide Dogariu

- Photonic Diagnostics in Random Media 142, 144,155

## Sasan Fathpour

- Integrated Semiconductor Photonic Device Characterization Laboratory 202
- Nano-Photonics System Fabrication Facility 180
- Device Processing Laboratory 261

## Romain Gaume

- Optical Ceramic Labs OML 123,125,126

## Leon Glebov

- Volume Holographic Elements: recording 153
- Photo-thermo-refractive glass: X-ray analysis 156
- Photo-Thermo-Refractive Glass: metrology, photoinduced processing 151
- Photo-Thermo-Refractive Glass: Melting 152
- Volume Bragg semiconductor lasers, spectral beam combining 154
- Volume holographic elements: high power applications (with Boris Zeldovich) 249
- Photo-Thermo-Refractive Glass: Grinding, polishing 240

## David Hagan and Eric Van Stryland

- Femtosecond Laser/OPA lab (300-11,000 nm) and spectrofluorometer-Dual Arm Z-scan, beam deflection, 2-photon fluorescence 227
- Nanosecond Tunable OPO (400-1,500 nm) – Z-scan, optical limiting 236
- Picosecond tunable OPA lab (400nm–16microns) – Z-scan, pump-probe 230
- Femtosecond Laser/OPA (300nm-11microns)- WLC Z-scan, beam deflection, pump probe 233
- Nanosecond OPO and near-field microscopy 246

## Mercedeh Khajavikhan

- Photoluminescence Characterization 243
- Nanophotonics Lab 253

## Aravinda Kar

- Laser Advanced Manufacturing; Laser Synthesis of Materials;
  Laser Processing of Wide Bandgap semiconductors; LED, Sensors, Detectors and Solar Cells
  Modeling and Simulation for materials processing and materials synthesis 263, 264

## Pieter Kik

- Nanophotonics Characterization Lab 247
- Spectroscopic Ellipsometry Lab 242

## Stephen M. Kuebler

- Nanophotonic Materials Lab PS332

## Guifang Li

- Optical Fiber Communications 246A, 248

## Patrick LiKamWa

- MQW Integrated Photonics 220, 223

## Shou Pang

- Optical Imaging System Lab 251
- X-ray Imaging Lab 242A

## Kathleen Richardson

- Infrared materials manufacturing 177
- Mid-infrared optical property measurement lab 258
- Glass and Glass Ceramic Lab OML-217
- Physical property measurement Lab OML-129
- Optical Fabrication Lab OML-123

## Martin Richardson

- Northrop Grumman Extreme Ultraviolet Photonics Lab 140, 143
- Multi-TW Femtosecond Laser Interaction Facility; New Solid State Laser Development;
- Secure Laser Test Range SLTR 140
- High Intensity femtosecond laser interactions 140, 112–117
- Laser Spectroscopy & Sensing Lab 140, 123 & 123A, 112- 117
- Fiber Laser Development Lab 143
- X-ray microscopy 123
- Laser Materials Processing 141
- High Intensity CEP Laser 117
- Laser Tissue Interaction Lab 262
- Thin disk laser development

## Bahaa Saleh

- Quantum Optics Lab 204

## Axel Schülzgen

- Fiber Optics Lab 201
- Fiber Optics Sensor Lab A109
- Fiber Optic Draw Tower A105
- Fiber Preform Lab, OML Building 128

## Winston Schoenfeld

- Photovoltaic Characterization Lab 156
- Nanophotonics Fabrication Facility 180
- Wide Band Gap Characterization Lab A112
- Oxide MBE Lab 180B

## Photonics Incubator

The Photonics Incubator is part of the UCF Business Incubation Program and is located within the facilities of the College. It is one of the ways that the College fulfills one element of its mission, namely to "Aid the development of Florida's and the nation's high technology industries." Companies in the Photonics Incubator have ready access to the CREOL faculty, graduate students, laboratory facilities and other excellent UCF resources including the staff of the Office of Research and Commercialization and the Venture Lab. The following is a list of 2014 clients:

**LC Matter Corp.** (Sebastian Gauza, www.lcmatter.com, ) offers custom design and manufacturing of liquid crystal materials and its polymeric composites. Applications include military electronically driven laser devices, optical telecommunication and entertainment systems.

**Plasmonics, Inc.** (David Shelton, www.plasmonics-inc.com) is developing tunable infrared metamaterials which are engineered composites with unique refractive-index characteristics. Metamaterials with tunable resonances have wide ranging potential for optical devices, modulators, and sensors.

**sdPhotonics LLC** (Dennis Deppe, Sabine Freisem) is an emerging leader in the development of high power laser diode technologies that provide improved power, efficiency, brightness and reliability.

**Partow Technologies, LLC**, (Payam Rabiei) is developing compact high-speed lithium niobate modulators for data-center and telecommunication applications. The company technology is based on nano-waveguides made in thin film lithium nionbate on silicon substrates. The devices can fit into small form factor transceivers used in data-centers and in telecommunication coherent systems.and reliability.

# Tours

**TOUR A** **Start times:** **2.30 pm** and **3.15 pm**

**A105** **Fiber Draw Tower** ★ **Featured in talk**
Ayman Abouraddy
http://MultiOFD.creol.ucf.edu

**A119** **Micro-Structured Fibers and Devices Lab** ★ **Featured in talk**
Rodrigo Amezcua Correa
http://mof.creol.ucf.edu

**153** **Optical Glass Sciences & Photo-Induced Processing Lab**
Leonid Glebov
http://ppl.creol.ucf.edu/

**TOUR B** **Start times:** **2.30 pm** and **3.15 pm**

**258** **Townes MWIR Metrology Lab**
Kathleen Richardson
http://gpcl.creol.ucf.edu

**243/253** **Plasmonics and Applied Quantum Optics Lab**
Mercedeh Khajavikhan
http://paqo.creol.ucf.edu/

**201** **Fiber Optics Lab**
Axel Schülzgen
http://fol.creol.ucf.edu

**TOUR C** **Start times:** **2.30 pm** and **3.15 pm**

**145/147** **Mid-IR Frequency Combs Lab** ★ **Featured in talk**
Konstantin Vodopyanov
http://mir.creol.ucf.edu

**227** **Femtosecond Lab**
David Hagan and Eric Van Stryland
http://nlo.creol.ucf.edu

**259** **Liquid Crystal Displays**
Shin-Tson Wu
http://lcd.creol.ucf.edu

# Building Map

## First Floor

# Building Map

## Second Floor

# Industrial Affiliates Program

Membership in the Industrial Affiliates (IA) program provides to industrial corporations, organizations, and individuals many benefits, most of which are also of mutual benefit to the College of Optics and Photonics. One of these mutual benefits is the regular communication and contact the program provides between the research faculty and students at the College and the IA member company's engineers and scientists who are developing new technologies and products for their business. Other benefits include:

- Establishing a close association with this leading institute in optics, lasers, and photonics
- Exposure to the latest research and developments in cutting edge technologies
- Availability of sophisticated measurement, test, and calibration facilities
- Early notice of students approaching graduation (the next generation of experts in the field) and access to their CVs
- Ability to post job openings on the College's website (exclusive benefit for IA members)
- Close interactions with the faculty, each of whom are leaders in their fields
- Opportunity to make presentations about the member's company and products to the faculty and students of the College
- Access to the College's periodic newsletter, Highlights, and monthly e-Highlights
- Notification of seminars at the College
- Opportunity for free presentation space at the annual Industrial Affiliates Day meeting
- Several Web-based benefits, including linkage to the company's web site from the College website
- For companies who donate equipment, getting their hardware/software in the hands of some of the leading researchers—faculty and students—in the field provides visibility to future customer prospects and information on its impact in leading-edge research
- Demonstration by the company of its support of the College, its research programs, and its effective corporate cooperation and partnership activities

In addition, we use many mechanisms to give visibility to our Industrial Affiliates that can be valuable to them in marketing their products. Wherever possible, the level of the membership is indicated. Examples of current practices include:

- Listing in the CREOL Highlights quarterly newsletter
- Special recognition at the annual Industrial Affiliates Day
- Listing in other publications, where appropriate, including on the website (with a link to the company's website)
- Company name plaque prominently displayed in the entrance lobby of the CREOL building.

There are also many intangible benefits that accrue from association with this dynamic research and education institution. Among these are facilitated access to and collaboration with other specialized facilities within the University of Central Florida and the central Florida area. In addition to resources in the Center for Research & Education in Optics & Lasers (CREOL) the Florida Photonics Center of Excellence (FPCE), and the Townes Laser Institute, UCF facilities include the following major research centers:

- Nano-Sciences & Technology Center (NSTC)
- Advanced Materials Characterization Facility (AMPAC)
- Materials Characterization Facility (MCF)
- Biomolecular Science Center
- Institute for Simulation and Training (IST)
- Center for Distributed Learning
- National Center for Forensic Science (NCFS)
- Florida Solar Energy Center (FSEC)
- Florida Space Institute (FSI)

The College's faculty and students play leading roles in both local and international professional associations and can provide effective introductions to the extensive network of industry and expertise to which CREOL, The College of Optics & Photonics, connects. Through the IA program, members can also readily connect with other optics, photonics, and industrial organizations through local Florida organizations in which the College maintains an active participation, including the Florida Photonics Cluster (FPC), the Laser Institute of America (LIA), Florida High Technology Corridor Council (FHTCC), the UCF Technology Incubator — ranked #1 in the US in 2004 — and a large family of laser and optics companies in the Central Florida region.

# Industrial Affiliates Members

## Life Members

Cobb Family Foundation
Northrop Grumman Corporation
Nufern
Memoriam Members: *Dr. Arthur H. Guenther and Dr. William C. Schwartz*

## Medallion Members

Breault Research
Lasersec Systems Corp.
Northrop Grumman Laser
Optical Research Assoc.
Paul G. Suchoski, Jr

## Senior Members

AFL Global
Amplitude
Coherent, Inc.
CST of America
DataRay Inc.
Edmund Optics
ER Precision Optical
LAS-CAD GmbH
LightPath Technologies
Lockheed Martin
Newport Corporation
Open Photonics
Ophir-Spiricon
Optimax Systems
Radiant Zemax, LLC
Tektronix
TRUMPF, Inc.
V & N
Zygo Corporation

## Affiliate Members

Aerotech, Inc.
ALIO Industries
Analog Modules
Applied Image Inc.
Asphericon
Block Engineering, LLC
eVision, LLC
Fike Corporation
Finisar
FLIR Systems, Inc.
Gentec-EO, Inc.
Gooch & Housego, LLC.
Harris Corporation
HORIBA Jobin Yvon
IRadiance Glass, Inc.
JENOPTIK Optical Systems Inc.
Kaufman & Robinson
Laser Institute of America
Lee Laser
Ocean Optics
Optigrate Corp.
OIDA
Photonics Online
Photonics Spectra
Plasmonics
Plasma-Therm
Princeton Instruments
QPC Lasers/Laser Operations, LLC
Q-Peak, Inc.
R-Soft Design Group
SCD.USA, LLC
Sciperio, Inc.
SPIE- The Int'l Society for Optics & Photonics
StellarNet, Inc.
Teledyne ODI
The Optical Society
Tower Optical Corporation
Thorlabs
TwinStar Optics, Coatings & Crystals
ULVAC Tech. Inc.
Vytran, LLC
Yokogawa Corporation of America
Zomega Terahertz Corp.

# Why Florida?

All high-tech companies benefit from Florida's business environment, which emphasizes innovation, collaboration, and talent formation for today's global markets. From start-ups focused on turning the latest academic research into commercially viable products and technologies, to established industry giants, Florida has what high-tech companies need.

## Florida Photonics Industry Cluster

Florida's photonics cluster is the 4th largest in the US, with over 270 companies employing over 5,700 professionals focused on the design, development, manufacturing, testing, and integration of photonics products and related systems. The photonics and optics cluster in Florida spans a very broad range of industry sectors, including lasers, fiber optics, optical and laser materials, thin film coatings, optical components, optoelectronic fabrication and packaging, and photonic systems integrators, addressing almost all applications from energy to medicine to defense. The state's colleges and universities have established interdisciplinary programs and centers focusing on pho-tonics/optics, which graduate over 100 photonics specialists (AS to PhD) each year. The Florida Photonics Cluster, a 501c(6) trade association, (www.floridaphotonicscluster.com) is dedicated to serving the industry and to making Florida the place to go for photonics solutions.

## Innovation Economy

Nowhere else is the spirit of innovation more evident than in the State of Florida, which has the reputation as the "Innovation Hub of the Americas". The state's pro-business, pro-technology climate, combined with easy trade access to key growth regions of the Americas, as well as the rest of the world, provide a fertile environment for establishing and growing businesses. Some of the unique resources available to entrepreneurs include the Florida Virtual Entrepreneur Center (www.flvec.com), GrowFL (www.growfl.com), and several business incubators (www.floridahightech.com/region.php) including the rapidly growing and award-winning UCF Business Incubator (www.incubator.ucf.edu).

## Top Quality of Life & Great Place for Photonics

Since 2001, Florida has earned top rankings in Harris Poll's "most desirable place to live" survey, so it's no surprise why Florida has become a top destination for high-tech industry, and in particular for the photonics industry. The University of Central Florida houses CREOL, The College of Op-tics and Photonics, and in addition to CREOL, the College houses the Townes Laser Institute and the Florida Photonics Center of Excellence. In addition, the Florida Photonics Cluster, several vigorous university incubators, proactive regional and state-level economic development organizations, and a dynamic grouping of cutting-edge companies form a photonics hub focused on advancing Florida's photonics industry.

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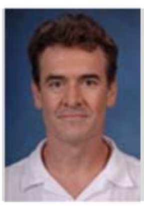

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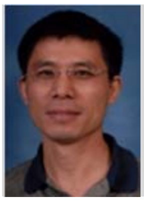

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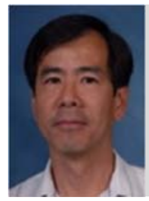

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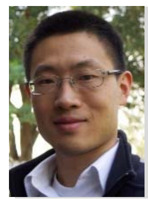

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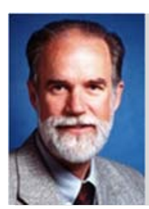

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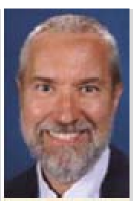

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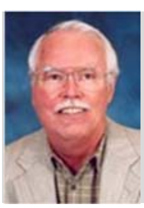

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# Notes

*Thank you for attending!*

We look forward to seeing you at our next
CREOL Industrial Affiliates Day
March 11-12, 2016

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