CREOL • UCF COLLEGE OF OPTICS AND PHOTONICS VOL. 11, NO. 1 • FALL 2010

Highlights

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

DEAN'S CORNER

BAHAA SALEH, Ph.D.

As you may have observed, our website has a new look and a number of added features. The website lists all academic, research, and outreach events and activities of the faculty and the students, organized for easy access and archived for future reference. One new feature is a taxonomy for the various research activities, organized by technologies (e.g., lasers, fibers, etc), each with its own applications (e.g., laser material processing, fiber optic sensing, and so on), and these activities may also be listed by faculty. This should help our industrial affiliates identify experts in a particular technology or assist our graduate students in identifying possible research advisors. Another new feature in the website is the Spotlight, which highlights noteworthy stories.

One recent spotlight is a report about Dr. Zenghu Chang, our most recent addition to the faculty who is featured in this newsletter. Dr. Chang was recognized in the July

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Optical Airy Beams and Bullets

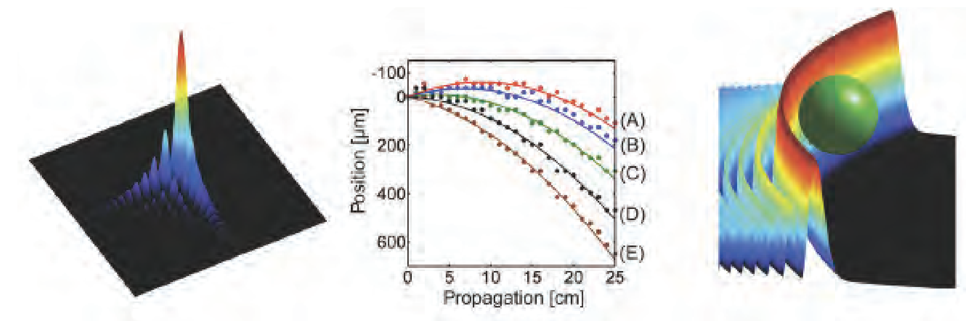

Figure 1. (left) Intensity profile of a 2D Airy beam; (middle) ballistic trajectories (After Optics Letter, Vol. 33, pp. 204-209, 2008); (right) an Airy beam circumventing an obstacle.

Strategies to overcome the often undesirable consequences of diffraction and dispersion have been systematically explored since the early days of lasers. It is well known that under the combined actions of these two ubiquitous physical processes any localized wave packet tends to broaden in space and time. The diffraction behavior of the Gaussian family of beams—the predominant modes of optical laser resonators—was the first to be considered in great detail. The same applies to their higher-order cousins, the so-called Gauss-Hermite and Gauss-Laguerre beams. Yet, it was not until the pioneering work of Durnin, Miceli, and Eberly in the mid-eighties, that it was first realized that diffraction effects can be "postponed" at will through the use of Bessel beams—perhaps the best known example of a diffraction-free field configuration. Over the years, this early work sparked considerable theoretical and experimental activity and paved the way toward the discovery of other interesting two-dimensional (2D) non-diffracting solutions. Even though at first sight these propagation-invariant beams may appear dissimilar, they in fact share common characteristics. Most importantly, they are all generated from an appropriate conical superposition of plane waves, wherein all waves share the same propagation constant along the direction of propagation. For

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INSIDE THIS ISSUE

Optical Airy Beams and Bullets *(continued from page 1)*

this very reason, their intensity pattern remains invariant during propagation. Of course, in practice, all these non-spreading beams are normally truncated by an aperture and as a result they eventually diffract. If the geometrical size of the limiting aperture greatly exceeds the comparatively narrower spatial features of the ideal propagation-invariant fields, the diffraction process is considerably "slowed down" over the intended propagation distance and hence for all practical purposes these beams are called "diffraction-free". These days non-diffracting beams are widely used in many and diverse areas of science and technology ranging from biophotonics and sensing to atomic physics and nonlinear optics.

Yet, up until now, no one-dimensional (1D) diffraction-free wave was known to exist. Interestingly, the answer to this quest came from the curious world of quantum mechanics. In 1979, Berry and Balazs noted that, the Airy wavepacket represents a unique, non-spreading accelerating solution to the force-free quantum mechanical Schrödinger equation. The realization that these same solutions can be observed within the discipline of optics came only recently from CREOL. In fact, in this realm, the beam's acceleration takes on a whole new meaning. It implies that during propagation the intensity features of an Airy beam can self-bend even in free space, and this without violating any physics. Remarkably, these beams can follow parabolic trajectories in a way formally analogous to the ballistics of projectiles (like cannon balls) moving under the action of gravity.

Early in 2007, our group explored the possibility of experimentally realizing such non-spreading accelerating Airy beams in optics. To do so we exploited the fact that the Fourier transform of an exponentially truncated Airy wavepacket is a Gaussian beam modulated with a cubic phase. For the Airy synthesis, a broad, high quality Gaussian wavefront from an Argon-ion continuous-wave laser was used. A spatial light phase modulator was then employed to impose the cubic-phase modulation and the Airy beam was then generated through a lens transformation, as illustrated in Fig.1.

Even though exponentially truncated, Airy waves can still exhibit their key characteristics. More specifically, they resist diffraction while their main intensity maxima or lobes tend to self-bend along parabolic paths. Experimental results confirming this behavior are shown in Fig. 1. Their ballistic behavior persists over long distances until eventually diffraction takes over. In this manner an Airy beam could in principle change its direction thus avoiding an object in its path (Fig. 1). Another intriguing feature associated with this class of waves is their very ability to self-heal during propagation. In other words, Airy packets can regenerate their features even if a portion of them has been blocked. This clearly makes them ideal for applications in hazy or turbulent environments.

Indeed in 2008, Dholakia's group from St. Andrews University demonstrated optical particle trapping and clearing in micro-fluidic systems (Fig.2). Different from other arrangements, the Airy beam not only attracts particles via gradient forces but it also propels them using its own radiation pressure along curved trajectories often exceeding 10 degrees.

This is done without inducing any fluid flow—a useful attribute for particle manipulation in biology and colloidal science. In another important step forward, Ady Arie's team from Tel Aviv University produced Airy waves using three-wave mixing effects in quasi-phase matched structures where a cubic phase was already imprinted. Clearly such developments may open new avenues for new wavelength generation and all-optical control of Airy beam trajectories, especially under high power conditions.

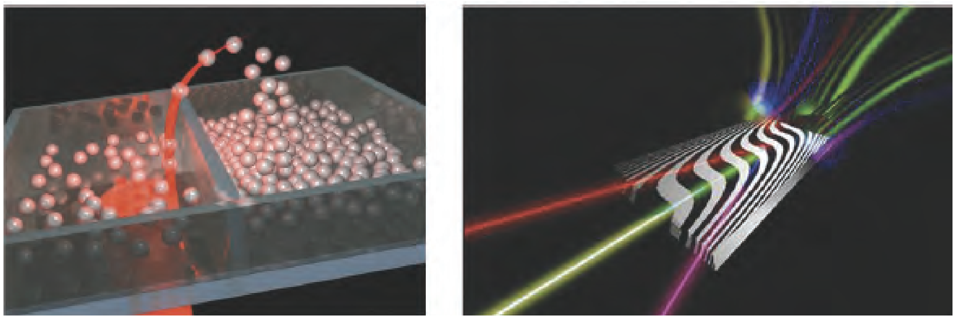


Figure 2. (left) Particle snow-blowing using Airy waves (After website of Prof. Kishan Dholakia); (right) generating Airy beams in quasi-phase matched nonlinear crystals. (After website of Prof. Ady Arie).

Early in 2009, we saw first experiments in extreme nonlinear optics using ultra-intense Airy beams. This work was carried out by Jerry Moloney's group (University of Arizona) in collaboration with CREOL. In this regime, the forces exerted on electrons exceed the binding attraction of the nucleus and hence several nonlinear interactions come into play. These range from plasma channel generation and filament stabilization to terahertz and extreme wavelength generation. On many occasions, highly directive secondary emissions may also provide valuable information as to the content of such atmospheres and are thus useful for remote spectroscopies. Thus far, the use of standard Gaussian and Bessel waves prohibited any spatial resolution at the output as should be naturally expected from "straight" beams. This problem was effectively overcome using the self-bending characteristics of Airy beams, as shown in Fig. 3.

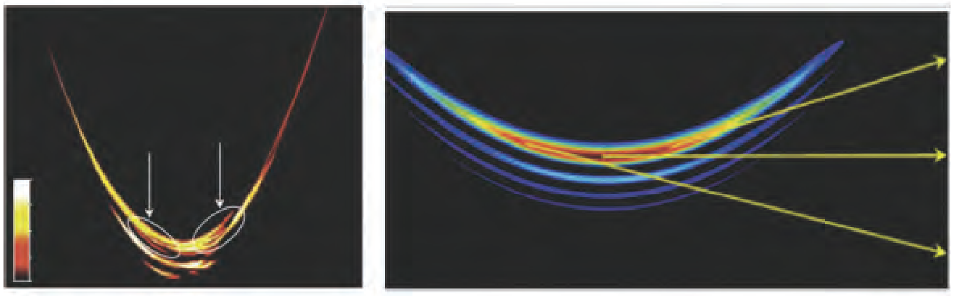


Figure 3. (left) Curved plasma channel induced by an Airy beam. Arrows indicate positions of secondary emissions, (After Science, Vol.324,p.229,2009); (right) angularly resolved emissions (After Optics and Photonics News, Vol.21, p.42, September 2010).

The possibility of generating optical bullets, that is optical wavepackets that are simultaneously impervious to the effects of both dispersion and diffraction, has been another problem that has preoccupied the optics community for several years. Ideally, such light bullets should be versatile, i.e., they should be capable of withstanding any level of diffraction and dispersion irrespective of whether the material dispersion is normal or anomalous. The only way to circumvent this problem is to disengage space and time. Earlier this year, in collaboration with Frank Wise's group from Cornell University, we reported the first observation of a new class of versatile three-dimensional linear light bullets, which combine Bessel beams in the transverse plane with temporal Airy pulses, (Fig.4). As such, their evolution does not depend critically on the material in which they propagate. Temporal self-healing and free acceleration, which are signatures of Airy packets, were also demonstrated experimentally. These spatiotemporal waves are possible for either sign of dispersion and do not require any diffraction/dispersion equalization. This family of robust and versatile waves is potentially useful for ultrafast probing or imaging in media with poorly known or dynamically varying properties.

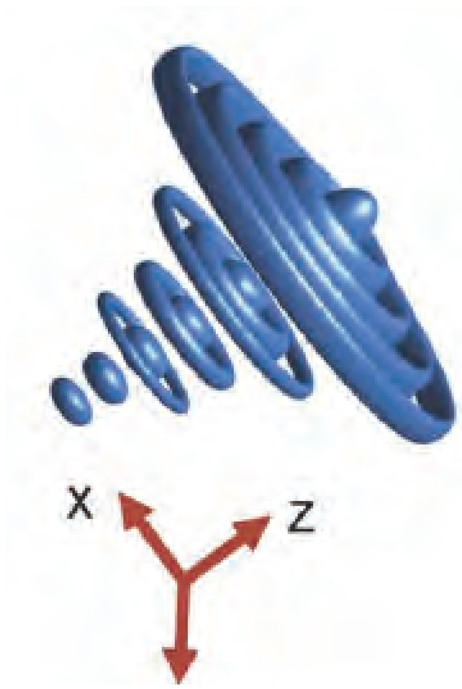


Figure 4. An Airy-Bessel optical bullet.

Undoubtedly this field is still evolving. The idea of accelerated energy flows is new in optics and may still lead to surprises. As for what the future may hold in this area, well this is left to the fiery imagination of young graduate students!

George Siviloglou, John Broky, Aristide Dogariu, and Demetrios Christodoulides

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

2010 issue of the famed journal Nature Photonics, which highlighted a new method that he invented for simplifying the generation of isolated attosecond optical pulses, called double optical gating (DOG).

Another spotlight noted an announcement by the Optical Society (OSA) that Dr. David Hagan has been named editor-in-chief of a new journal, Optical Materials Express (OME). To be launched in Spring 2011, OME will be a bimonthly, rapid-publication, peer-reviewed, open-access, online publication focusing on materials for optics and photonics applications, their synthesis/preparation, optical properties, and mechanisms and characterization.

Success of our faculty in obtaining federal funding in support of their research is also highlighted in the Spotlight. A mid-July Spotlight reported that teams from the Townes Laser Institute, which is led by Dr. Martin Richardson, were awarded three contracts from the High Energy Laser Multidisciplinary Research Initiative (MRI) of AFOSR/JTO totaling approximately $5 million.

The September issue of Optics and Photonics News featured articles by two CREOL faculty. An article by Dr. Demetrios Christodoulides and his colleagues describes those remarkable beams and bullets of light that follow ballistic paths without diffraction or dispersion (see front page). The other article by Dr. William Silfvast reflects on whether one of the hallmarks of the laser—population inversion—may occur naturally as part of the normal atmospheric process of lightning discharge! It is interesting to read about such notions as the celebrations of LaserFest, the 50th anniversary of the first demonstration of the laser, approach its end. The college joined the celebrations with a number of our own events, but we are pleased to have received from SPIE a number of large posters depicting the history of the laser, which were used at various meetings and conferences in 2010. Five 4' by 8' panels covering the five decades are now permanently posted on the second floor of the CREOL building. When you visit us next, please make sure to take a look.

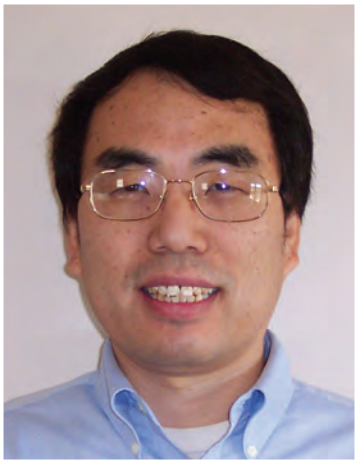
We are always proud of the academic and scholarly accomplishments of the faculty and the students and the leadership roles they play within the optics and photonics community worldwide. We are equally proud of our alumni and industrial partners and future spotlights will report their success stories.

Bahaa Saleh, Dean

CREOL,
The College of Optics and Photonics

WELCOME ZENGHU CHANG, PH.D., PROFESSOR OF PHYSICS AND OPTICS

Dr. Zenghu Chang joined UCF in the Fall of 2010 and founded the Florida Attosecond Science and Technology laboratory located in the new physical science building. The lab is supported by both the Townes Laser Institute at CREOL, and the Department of Physics.



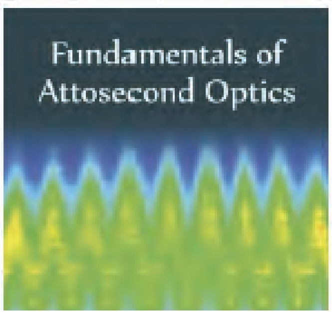
Zenghu Chang, Ph.D.

Dr. Chang's new book on "Fundamentals of Attosecond Optics" will be published in February 2011. And he is the author of a chapter on "Attosecond Optics" in the 3rd edition of the Handbook of Optics.

Since 2007, Dr. Chang has been the leading principal investigator of a $6.25 million, multi-university research program on attosecond optics supported by the Army Research Office.

Dr. Chang was born in Shaanxi Province, China. He received his doctorate at the Chinese Academy of Sciences Xi'an Institute of Optics and Precision Mechanics before joining the Rutherford Appleton Laboratory in the United Kingdom. From 1996 to 2000, he worked in the Center for Ultrafast Science at the University of Michigan, and in 2001 joined Kansas State University and was the Ernest K. and Lillian E. Chapin Professor of Physics prior to joining UCF.

Dr. Chang has made numerous pioneering contributions to attoscience—the generation and applications of ultrashort (quintillionth of a second) optical pulses. He and his colleagues studied high harmonic generation,



which is closely related to attosecond physics and extended the generated coherent radiation to the "water window", paving the way for applications in biological imaging. His group demonstrated the extension of harmonic cutoff wavelengths by using long-wavelength driving pulses from optical parametric amplifiers. This approach is now pursued by many groups.

Since the first demonstration of attosecond pulse generation in 2001, very few laboratories had access to such unique light source. By using a polarization gating approach, Chang showed that using a few-cycle pulse is the key to the generation of attosecond pulses. In the process of finding a technique that can generate single attosecond pulses using longer driving pulses, he proposed a novel method called double optical gating (DOG). Using this technique, his group generated isolated 140 attosecond pulses using 28 femtosecond lasers. Since such lasers are more accessible than the few-cycle lasers used in the past, his DOG method has allowed more researchers to enter the arena of attosecond science.

RESEARCH

Attosecond and zeptosecond optics

Atomic and molecular dynamics

Femtosecond high power laser

PROFESSIONAL ACTIVITIES

Chair of the attoscience technique group, Optical Society of America

Co-chair, 2nd international conference on attosecond science, 2009

HONORS AND AWARDS

Fellow, American Physical Society

Mercator Professorship, German Science Foundation (DFG), 2007

Hubert Schardin Gold Medal, 22nd International Congress on High Speed Photography and Photonics, 1996

AWARDS & HONORS

Faculty Awards

Demetrios Christodoulides received the UCF Research Incentive Award in recognition of his outstanding research efforts. The award fosters collaborative funded research, promotes research enterprise and national recognition and assists faculty in developing professional expertise in research collaborations.

Aristide Dogariu and **Winston Schoenfeld** are 2009/2010 UCF Teaching Incentive Program (TIP) Award recipients

David Hagan is the Editor of OSA's new journal Optical Materials Express (OME). OME will launch in Spring 2011 with bi-monthly issues, joining OSA's diverse portfolio of 14 peer-reviewed optics journals. The journal is a peer-reviewed, rapid-publication, open-access, online publication that focuses on materials for optics and photonics applications, their synthesis/preparation, optical properties, mechanisms and characterization.

David Hagan and **Winston Schoenfeld** are 2009/2010 recipients of the College Excellence Awards for Research and Graduate Teaching respectively.

Bahaa Saleh was elected to the Laser Institute of America (LIA) Board of Directors.

William Silfvast is one of the 20 "Laser Luminaries" for 50th anniversary year of the laser. According to SPIE: "Silfvast is renown for the number of new lasers he discovered. As a doctoral student he produced laser action for the first time in the vapor of nine elements. He also has done notable work in metal vapors, and demonstrated over 100 recombination lasers and laser action in laser-produced plasmas."

Shin-Tson Wu, is the 2010 recipient of the Joseph Fraunhofer/Robert M. Burley Prize for exceptional contribution to optical engineering through liquid crystal displays, tunable photonics devices and adaptive focus lenses. The Fraunhofer Award recognizes significant accomplishments in the field of optical engineering. The award, a silver medal and a certificate, is made possible by an endowment from the Baird Corporation. The accompanying prize of $3,000 honors the memory of Robert M. Burley, who exemplified many of the highest attributes of the optical engineer and was the first recipient of the Fraunhofer Award. Dr. Wu is also now a Pegasus Professor which is an award given to professors who contribute excellence in teaching, research and service to the UCF community. Dr. Wu's contributions to UCF and to the science of liquid crystal display (LCD) technology have been prolific. He has published six books, more than 350 peer-reviewed journal papers, and more than 140 conference papers. He and his team have earned 66 patents.

Student Awards & Honors

Florian Fournier, **Linghui Rao**, and **Charles Williams** received 2010 SPIE Educational Scholarship in Optical Science and Engineering.

David Haefner received the 2010 CREOL Student of the Year Award.

Timothy McComb (PhD. Optics, 2009) received the 2009 UCF Award for Outstanding Dissertation. Tim's dissertation, entitled "Power Scaling of Large Mode Area Thulium Fiber Lasers in Various Spectral and Temporal Regimes" was written under the supervision of Martin Richardson.

Dimitrios Mandridis received the 2010 IEEE Graduate Student Fellowship Award. This award is provided to outstanding IEEE Photonics Society student members pursuing graduate education. Ten fellowships of $5,000 each are awarded in the Americas.

Christina Willis received a 2010 Directed Energy Professional Society Scholarship.

GRADUATES
FALL 2009– SUMMER 2010

Ph.D.	Dissertation Area
Anderson, Troy	*Laser processing of chalcogenide glasses*
Bickel, Nathan	*Multimode interference semiconductor waveguides*
Choi, Jiyeon	*Volumetric diffractive optical elements*
Demir, Abdullah	*Lithographic lasers and quantum-dot laser diodes*
El-Ganainy, Ramy	*Dielectric nano-suspensions*
Fournier, Florian	*Freeform reflector with extended sources*
Ghoshal, Amitabh	*Integrated nanophotonic devices*
Haefner, David	*Near-field optics*
Hageman, William	*Fiber and solid-state lasers*
Jabbour, Toufic	*Diffractive optical elements*
Kim, Ji-Myung	*Quantum dot mode-locked semiconductor lasers*
Krenz, Peter	*Antenna-coupled infrared sensors*
Li, Xiaoxu	*WDM optical fiber systems*
Mares, Jeremy	*Novel wide-bandgap oxide semiconductors*
McComb, Timothy	*Large mode area Thulium fiber lasers*
Reza, Syed	*MEMS for sensing and signal processing*
Savchyn, Oleksandr	*Silicon-sensitized erbium excitation in silica*
Schmid, Tobias	*Alignment of astronomical telescopes*
Shavitranuruk, K	*Quantum dot laser diodes*
Sheikh, Mumtaz	*Optical sensors*
Siviloglou, Georgios	*Accelerating optical Airy beams*
Song, Qiong	*Fast response dual-frequency LCDs*
Srinivasan, Pradeep	*Space-variant micro-optic structures*

M.S.

Abruna, Ernesto
Eskridge, Gregory
Fisher, Matthew
Han, Seong Il
Legesse, Henock
Marraccini, Philip
Melino, Marco
Rao, Linghui
Shahen, Mohamed
Wadsworth, Samuel

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