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EON

ELECTRO-OPTICS NEWS

SPRING 2017 → VOLUME 4 → ISSUE 3

INSIDE THIS ISSUE

Reflections	→	1
Faculty Spotlight: Jay Mathews and Imad Agha Integrate Electronics and Photonics	→	2
EOP in Action	→	3
Complex Optical Fields Are Really Not All That Complex	→	3
Bringing Holography to Light	→	4
Books	→	5
Preliminary Exam Questions	→	5
Selected Journal Publications	→	6
Grants	→	7
Lasers Enable Localized Microstructure Engineering	→	7
Colloquial	→	7
Research by Sarah Krug Enables Digital Aperture Synthesis in Adaptive Optics	→	8
EOP Graduates December 2016	→	8



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REFLECTIONS



The Optical Society celebrated its 100th year in Rochester, the place it was founded. Here, the convention center, the venue for FiO, reflected from the downtown buildings.

Welcome to the Department of Electro-Optics and Photonics (EOP) at the University of Dayton (UD). As we are completing our first year as a department, rather than just a program, we look forward to another exciting year.

Last October, the Optical Society celebrated its centennial in Rochester, New York, at the Frontiers in Optics (FiO) meeting. Several of our faculty and students attended, including collaborators from other national and international institutions. A grand gathering of seven Nobel laureates was one of the highlights of the conference. Personally, I was humbled and honored to be with my nominee, Dr. Francis Yu, who received the prestigious Emmett Leith award.

With the agreements with Huazong University of Science and Technology (HUST) in Wuhan, China, and the Centro de Investigaciones en Optica (CIO) in Leon, Mexico, already in place, EOP has finalized another agreement for an exchange of students with China Jiliang University. The Jiliang agreement was made possible due to personal contacts between EOP faculty Qiwen Zhan and Jiliang. This fall, seven Bachelor's Plus Master's Program students will be joining our department from HUST, as well as one M.S. and one Ph.D. student from CIO. As part of the agreement with HUST, three of our faculty will be going to Wuhan to co-teach courses in optics. Andrew Sarangan, Imad Agha and Jay Mathews, along with our students Josh Burrow and Mike Buzbee, have been active in visiting universities and international conferences scouting promising students. We hope to recruit exceptionally qualified domestic students with the help of our strong funding partnerships with the Air Force Research Laboratory and other private companies in the area.

Our faculty and students continue to excel in their respective areas of research. Jay Mathews won the prestigious Air Force Office of Scientific Research CAREER

Continued on page 2

REFLECTIONS PARTHA BANERJEE CONTINUED

award to work on his unique research area of silicon optics. Andrew Sarangan and Joe Haus have published books within the last year. Qiwen Zhan recently guest-edited a special issue on *Complex Optical Fields in Chinese Optics Letters*, and I am guest-editing a special joint issue on digital holography in *Applied Optics* and the *Journal of the Optical Society B*. OPTONICUS, founded by Mikhail Vorontsov, continues to receive SBIRS and STTRs, and Paul McManamon's Exciting Technologies (ET) is active with its work on LIDAR and beam steering. Our students continue to be well placed after their graduation. For instance, Thomas Welsh (M.S., 2017) will be working with Ford on their autonomous self-driving cars guided by LIDAR. Mahmudunnabi Basunia (Ph.D., 2016) has been promoted to senior process engineer at Boeing in Charleston, where he has been involved with the 787 Program. Yun Zhao (M.S., 2016) joined Columbia University in the Ph.D. program as a research assistant.

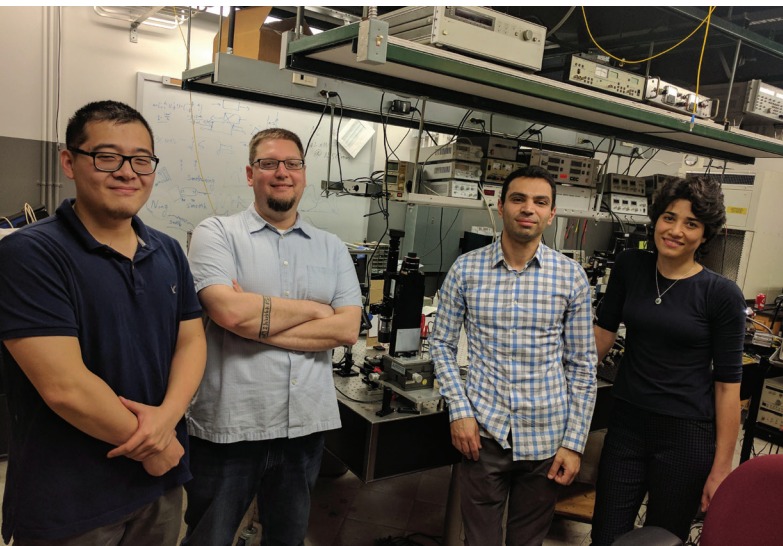
In other news, the local SPIE and OSA chapters are organizing a biweekly Students Presenting Optics Research Training Symposium (SPORTS) starting this spring semester. It is a great way for students to present their ongoing research to their peers in a relaxed atmosphere. The EOP advisory committee met for the second time this spring, and while felicitating the department on its achievements, commented on faculty teaching loads and the credit hours needed to obtain a doctoral degree.

Finally, I would like to recognize two newcomers to the department (and the world), Sara and John. Congratulations to the proud parents, Michelle and Jeff Kraczek, and Meghan and Brian Brophy.

Best wishes to all and warm regards,
Partha Banerjee, Chair, EOP

FACULTY SPOTLIGHT: JAY MATHEWS AND IMAD AGHA INTEGRATE ELECTRONICS AND PHOTONICS

The UD Silicon Photonics Lab, headed by Dr. Jay Mathews and Dr. Imad Agha, has recently started a three-year, \$360,000 project funded by Air Force Office of Scientific Research (AFOSR) for developing new infrared laser technology for the military and the silicon photonics industry. Silicon is an excellent material for electronics, but it has major flaws when used for photonic devices like photodetectors, LEDs and lasers. Because of the nature of silicon, it cannot absorb infrared light beyond 1100 nm, and it is an inefficient light emitter, so it cannot be used to produce lasers. Other materials, such as InGaAs and InSb are used to make these devices, which leads to very high costs for the components and limits their use in everyday products.



Jay Mathews (second from left) and Imad Agha (second from right) with graduate students Zairui Li (left) and Elaheh Ghanati (right) in the silicon photonics lab.

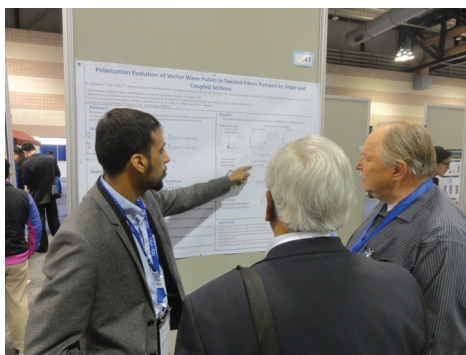
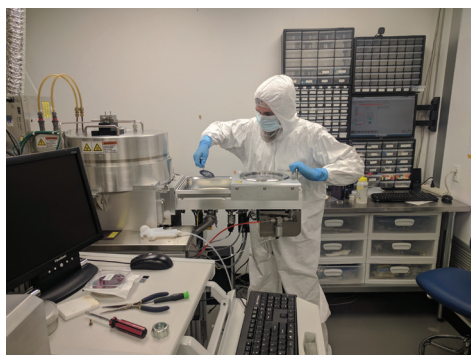
A silicon-compatible laser could impact a variety of military and civilian applications. Infrared lasers are used for targeting and acquisition of munitions and for free-space optical communications, and bringing the cost of these components down could lead to improved performance and significant cost savings for the military. On the civilian side, one possible pathway to next generation microprocessors for faster computers is the use of optical interconnects, where multiple processors are connected together on a single chip using light. This is like fiber optics but done on the chip itself. This scheme will require laser sources that are integrated onto a silicon chip and emit at wavelengths in the infrared. Fiber-optic communications could also benefit from Si-based laser sources, which would drastically reduce the cost of fiber-based communications for the Internet and computer networking.

One possible solution to the silicon photonics problem is to grow a new material on top of silicon, one that has better optical properties and can be used for photonic devices. To that end, the UD Silicon Photonics group is looking at using germanium-tin

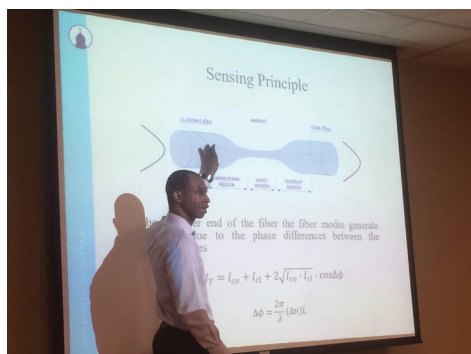
(GeSn) alloys, which are grown directly on silicon, for making infrared lasers. Unlike silicon, GeSn alloys can absorb infrared light in the intended range, and these materials are much more efficient at light emission, so it should be possible to make lasers from them. Recently, the UD group demonstrated stimulated emission, which is a first step to making a laser, in waveguide structures made from GeSn. This exciting result prompted Dr. Mathews to submit a grant proposal to AFOSR, for which he was given a Young Investigator Award and the funding to implement the project.

Dr. Mathews, in collaboration with Dr. Agha, will be leading the effort to produce GeSn lasers. Dr. Mathews and Dr. Agha, assistant professors with the Department of Physics, joined UD in the fall of 2013. Their research initiative will fund two Ph.D. students from the Department of Electro-Optics and Photonics, Zairui Li and Elaheh Ghanati, for three years. Zairui completed his master's degree in electro-optics in 2015, and his thesis work was the basis of the preliminary GeSn results, so his Ph.D. will be a major expansion of that work. Elaheh is new to the research group, and she is now starting her Ph.D. research.

EOP IN ACTION



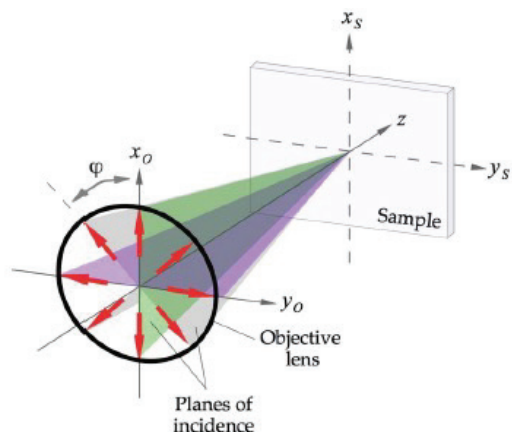
Left: Dave Lombardo at the Nanofabrication facility at EOP in the Science Center. Middle: Mohammed Alamanee explaining his poster on vector wave pulses in twisted fibers to Govind Agrawal from the University of Rochester at the OSA FiO, while Joe Haus looks on. Right: Mohammed featured in one of the giant electronic billboards at the OSA FiO reception.



Left: Diego Garcia presenting his work on tapered fiber sensors at the special Stander Symposium in March in Fitz Hall in honor of Peter Powers. Middle: EOP student, Joshua Burrow, posing in front of his OSA/SPIE Student Chapter poster at the OSA FiO in Rochester, 2016. Right: Sarah Krug presenting her research on LIDAR at the weekly SPORTS symposium organized by the student chapter of SPIE and OSA in Fitz Hall.

COMPLEX OPTICAL FIELDS ARE REALLY NOT ALL THAT COMPLEX

This would be what Qiwen Zhan, professor of electro-optics and photonics, fellow of OSA and SPIE, author of the book *Vectorial Optical Fields*, World Scientific (2013) and an authority in the area, would probably say to his students in his polarization course. Dr. Zhan has written numerous articles in the area of polarization optics and vector field engineering, and he recently guest-edited a special issue on the topic in *Chinese Optics Letters*.



Radial polarization state of light focused by an objective lens. For any azimuthal angle (ϕ), the electric field is always in the plane of incidence. Adapted from G. López-Morales, V.-M. Rico-Botero, R. Espinosa-Luna, and Q. Zhan, "Refractive index measurement of dielectric samples using highly focused radially polarized light," *Chinese Opt. Lett.* 15, 030004 (2017). López-Morales, Rico-Botero, and Espinosa-Luna are from CIO, Leon, Mexico. Espinosa-Luna was visiting scholar at EOP in 2015. CIO will send MS and Ph.D. students to EOP at UD starting Fall 2017.

There is considerable and increasing interest in tailored optical fields with complex amplitude, phase and polarization spatial distributions, as well as specifically designed temporal waveforms. Potential applications include accurate measurements of refractive index, novel nanotechnology investigations and biomedical experiments, remote sensing of an object's rotational orientation, micromachining, photon-phonon conversion-based signal-processing, new types of optical tweezers with lateral pulling forces which allow for the full control of biological samples with complex geometric shapes, etc. Researchers continue to invent new types of complex optical fields along with the tools to generate and characterize them and use them for innovative applications.

BRINGING HOLOGRAPHY TO LIGHT

While 3D technologies that make headlines are not truly holographic, modern holographic techniques are furthering advances in important applications such as metrology, biomedical imaging and true 3D display.

“A lot of people abuse the word ‘holography,’” says James Fienup, professor of optics and electrical and computer engineering at the University of Rochester. “It’s kind of a catchy thing.” A notorious example is the so-called “Tupac hologram,” which stunned audiences at the 2012 Coachella Music Festival by appearing to show the rapper Tupac Shakur performing on stage years after he had been killed. In fact, the effect didn’t use holography at all; rather, it repurposed a classic magician’s trick called Pepper’s Ghost, an illusion created through the clever use of carefully angled mirrors.

To most people, a hologram is any virtual object appearing in 3D form—even the images created using the simple stereoscopic effects seen through plastic 3D glasses. “That’s not the scientific definition,” says David Fattal, CEO of LEIA, an HP spinoff that has been developing a 3D display for smartphones. True holography, in the scientific sense, refers to a process that uses wave interference effects to capture and display a three-dimensional object. The method, which goes back to the 1960s, uses two beams of coherent light, typically lasers. “You shine a laser on something, and the light scattered from that comes to your holographic sensor, and you also shine on that same sensor a beam from the same laser that hasn’t struck the object,” explains Fienup. “You interfere those two together and you capture the whole electromagnetic field.” In fact, the “holo” in holography means “whole”.

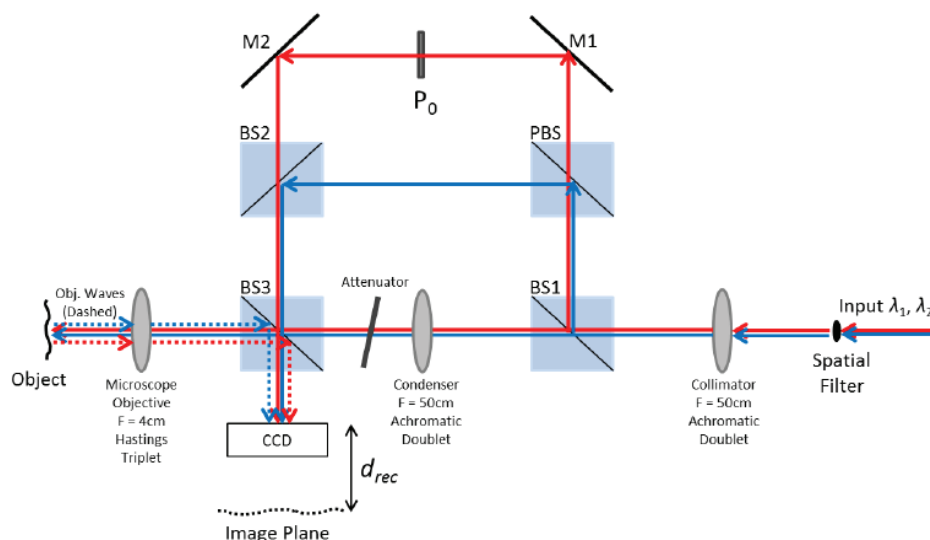
The key to getting the whole electromagnetic field—including the impression of depth—is holography’s capture of phase information, or the degree to which the light wave from the reference beam is out of step with the wave from the object beam. “What that provides are these interesting characteristics of three-dimensionality,” says Raymond Kostuk, professor of electrical and computer engineering and of optical sciences, at

the University of Arizona, who is using holography to develop more efficient processes for solar energy conversion and cheaper methods of ovarian cancer detection. By capturing phase and amplitude (intensity) information, holography shows more than do photographs, which capture information only about the intensity of the light. Much of this process is now often done computationally, using CCD or CMOS cameras and algorithmic reconstruction. “Instead of recording on film, you record on the CCD camera, and then you store the information on a computer as a matrix,” explains Partha Banerjee, professor of electro-optics and photonics, and electrical and computer engineering at the University of Dayton. To reconstruct the image, you process that matrix using well-known diffraction equations, which model how light waves propagate from one place to another—from the

original object to the light sensor. “That’s digital holography,” says Banerjee, who has used holography to capture the shape of raindrops or ice particles as they strike airplanes to determine the three-dimensional characteristics of dents created from such impact. One of the most popular applications of digital holography these days, says Banerjee and other experts, is in digital holographic microscopy (DHM), which aims at getting

precise pictures of microscopic objects, particularly living cells and tiny electronic components such as the transistors printed on silicon wafers.

For example, Laura Waller, professor of computer science and electrical engineering at the University of California, Berkeley, runs a Computational Imaging Lab that designs DHM tools for biological imaging, creating hardware and software simultaneously. “We’ve carefully designed our optical system so we’re getting enough information about the phase into our measurement,” she says, “and because we know the wave-optical physics model of the microscope, we can throw [the data we capture] into a non-linear, non-convex optimization problem so we can solve for the phase from these measurements.” Living cells are completely transparent, but they are thick enough to delay the phase of a light beam; by measuring phase delays, researchers can map the shapes and densities of cells.

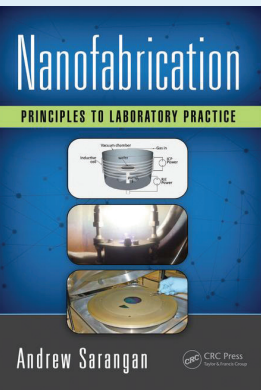


Multiwavelength DHM configuration. From Williams *et al.*, *Proc. SPIE* **9006**, 90060K.1-90060K.9 (2014).

Adapted from the original article by Marina Krakovsky, Comm. ACM **59**, 13-15 (2016). Based in San Francisco, Marina Krakovsky is the author of *The Middleman Economy* (Palgrave Macmillan), and regularly writes for *Discover*, *New York Times Magazine*, *Scientific American*, *Stanford Magazine*, *Washington Post*, *Wired*, and more.

BOOKS

Andrew Sarangan, *Nanofabrication: Principles to Laboratory Practice*, CRC Press, Boca Raton, FL (2016)

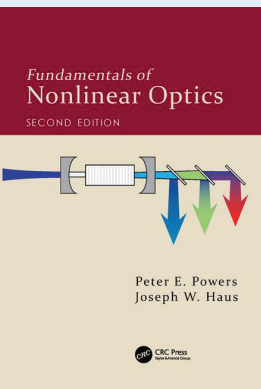


This book is designed to introduce typical cleanroom processes, techniques, and their fundamental principles. It is written for the practicing scientist or engineer, with a focus on being able to transition the information from the book to the laboratory. Basic theory such as electromagnetics and electrochemistry is described in as much depth as necessary to understand and explain the current practice and their limitations. Examples from various areas of interest are covered, such as the fabrication of photonic devices including photo detectors,

waveguides, and optical coatings, which are not commonly found in other fabrication texts.

As Dr. Sarangan states in the Introduction, he developed this book with the hope that it fills the gap between academic research and laboratory practice, and that it is a companion for those starting out to work in a cleanroom. The book is written from the perspective of electrical engineering and photonics, with examples, calculations and pictures from his own lab. Dr. Greg Peake from Sandia National Labs writes in his review: “Dr. Sarangan has done an excellent job of providing a practical text for scientists and technologists interested in the principles of nanofabrication. This book would serve as a relatively comprehensive reference text for anyone beginning the journey of creating solutions in the science of very small things.”

Peter E. Powers and **Dr. Joseph W. Haus**, *Fundamentals of Nonlinear Optics 2nd Ed.*, CRC Press, Amsterdam (2017).



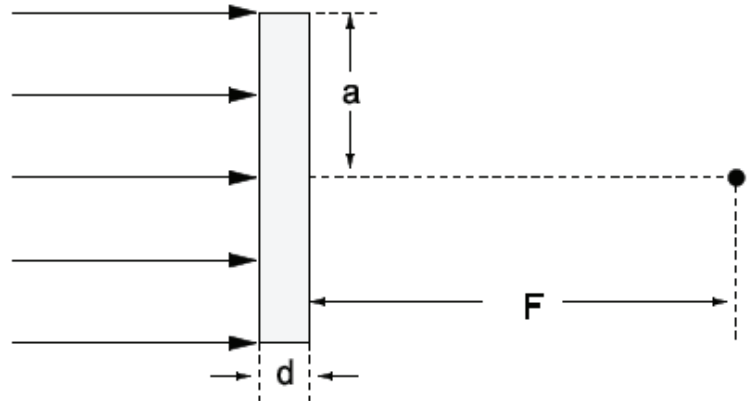
This fully revised 2nd edition enables the reader to understand and use the basic principles related to many phenomena in nonlinear optics and provides the mathematical tools necessary to solve application-relevant problems. The second edition expands the earlier treatment and includes a new chapter on quantum nonlinear optics, a thorough treatment of parametric optical processes covering birefringence, tolerances and beam optimization to design and build high conversion efficiency devices, treatment of numerical methods to solving

sets of complex nonlinear equations, an extended treatment of four-wave mixing and solitons, and coverage of ultrafast pulse propagation including walk-off effects.

Dr. Anderson Gomes from Universidade Federal de Pernambuco (UFPE), Brazil, writes: “Professor Joe Haus has done a magnificent academic job of completing the second edition of this already excellent introduction . . . even in the absence of Prof. Peter Powers, the basic concepts were kept and touched up, and the revised chapters and new chapter, which brings to the nonlinear optics community and newcomers the expanding area of quantum nonlinear optics, updates the book. Great work!”

PRELIMINARY EXAM QUESTIONS

1. The index of refraction of optical media can be varied by diffusing in impurities. If the index of refraction is increased then it is possible to make a lens from an optical component having a constant thickness. Given a disk of radius a and thickness d , determine the radial variation of the index of refraction $n(r)$ to order r^2 which will produce a converging lens with focal length F using the assumption that the radius $a = F$ and also that the lens is thin.



Adapted from University of Wisconsin, Madison, Qualifying exam, Spring 2015.

2. For a system consisting of two thin lenses, the image distance after the second lens is

$$s_{i2} = \frac{f_2 d - (f_1 f_2 s_{o1}) / (s_{o1} - f_1)}{d - f_2 - (f_1 s_{o1}) / (s_{o1} - f_1)}$$

Here, f_1 and f_2 are the focal lengths of the two lenses, d is the distance between the two lenses, and s_{o1} is the object distance in front of the first lens. Derive expressions for

- (a) the back focal length,
- (b) the front focal length, and
- (c) the effective focal length of the two-lens system as $d \rightarrow 0$.

Adapted from Columbia University, Qualifying exam, 2017.



SELECTED JOURNAL PUBLICATIONS

1. Y. Zhao, D. Lombardo, **J. Mathews**, and **I. Agha**, "All-optical switching via four-wave mixing Bragg scattering in a silicon platform," *APL Photonics* **2**, 026102 (2017).
2. M. Basunia, **P. P. Banerjee**, U. Abeywickrema, T.-C. Poon, and H. Zhang, "Recursive method for phase retrieval using transport of intensity and its applications," *Appl. Opt.* **55**, 9546-9554 (2016).
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4. H. Li, X. Huang, Q. Cao, Y. Zhao, P. Li, C. Wan, and **A. Chong**, "Generation of three-dimensional versatile vortex linear light bullets," (*Invited Paper*) *Chinese Opt. Lett.* **15**, 030009 (2017).
5. L. Wang, A. Chong, and **J. W. Haus**, "Numerical modeling of mode-locked fiber lasers with a fiber-based saturable-absorber," *Optics Commun.* **383**, 386-390 (2017).
6. J. E. Slagle, **J. W. Haus**, S. Guha, D. G. McLean, D. M. Krein and T. M. Cooper, "Degenerate frequency two-beam coupling in organic media via phase modulation with nanosecond pulses," *J. Opt. Soc. Am. B* **33**, 180-188 (2016).
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8. A. Belardini, M. Centini, G. Leahu, D. C. Hooper, R. Li Voti, E. Fazio, **J. W. Haus**, A. Sarangan, V. K. Valev, and C. Sibilia, "Chiral light intrinsically couples to extrinsic/pseudo-chiral metasurfaces made of tilted gold nanowires," *Scientific Rep.*, **6**, 31796 (2016).
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10. L. Wang, A. Chong, and **J. W. Haus**, "Numerical modeling of mode-locked fiber lasers with a fiber-based saturable-absorber," *Optics Commun.* **383**, 386-390 (2017).
11. V. Molebny, **P. F. McManamon**, O. Steinvall, T. Kobayashi, and W. Chen, "Laser radar: historical prospective—from the East to the West," *Opt. Engr.* **56**, 031220 (2017).
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13. S. E. Krug and **D. J. Rabb**, "Digital phase correction of a partially coherent sparse aperture system," *J. Opt. Soc. Am. A* **34**, A47-A55 (2017).
14. J. Duran and **A. Sarangan**, "Fabrication of ultrahigh aspect ratio silicon nanostructures using self-assembled gold metal-assisted chemical etching," *J. Micro Nanolith, MEMS MOEMS* **16**, 014502 (2017).
15. **T. Weyrauch**, **M. Vorontsov**, J. Mangano, V. Ovchinnikov, D. Bricker, E. Polnau, and A. Rostov, "Deep turbulence effects mitigation with coherent combining of 21 laser beams over 7 km," *Opt. Lett.* **41**, 840-843 (2016).
16. **M. A. Vorontsov**, S. L. Lachinova, and A. K. Majumdar, "Target-in-the-loop remote sensing of laser beam and atmospheric turbulence characteristics," *Appl. Opt.* **55**, 5172-5179 (2016).
17. **M. A. Vorontsov**, and **T. Weyrauch**, "High-power lasers for directed-energy applications: Comment," *Appl. Opt.* **55**, 9950-9953 (2016).
18. J. Chen, C. Wan, L. Kong, and **Q. Zhan**, "Experimental generation of complex optical fields for diffraction limited optical focus with purely transverse spin angular momentum," *Opt. Express* **25**, 8966-8974 (2017).
19. **Q. Zhan**, and A. Forbes, "Complex optical fields," Editorial for special issue on complex optical fields, *Chinese Opt. Lett.* **15**, 030001 (2017).
20. G. Lopez-Morales, V. M. Rico-Botero, R. Espinosa-Luna, and **Q. Zhan**, "Refractive index measurement of dielectric samples using highly focused radially polarized light," (*Invited paper*) *Chinese Optics Letters* **15**, 030004 (2017).
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29. **C. Zhao**, "Practical guide to the realization of a convertible optical trapping system," *Opt. Express* **25**, 2496-2510 (2017).
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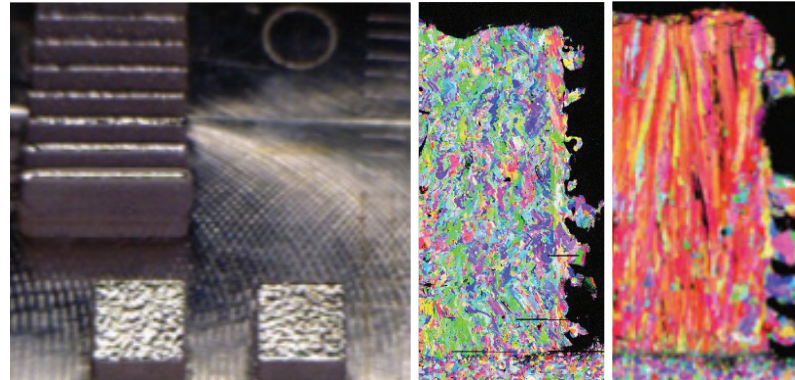
GRANTS

Dr. Chenglong Zhao received a subcontract from the Air Force Research Laboratory to fabricate a single photon source for quantum devices. He also received the 2017 Summer Research Fellowship from the University of Dayton.

LASERS ENABLE LOCALIZED MICROSTRUCTURE ENGINEERING

Location specific (spatially localized) microstructure engineering has been a dream for additive manufacturing (AM) of metallic alloys because of its impact on the material properties and the overall performance of AM build parts. For the first time, laser-based AM is demonstrated to enable on-demand control of microstructure (morphology and crystallography) using a multi-beam fiber laser array system developed by the team of OPTONICUS and the EOP Intelligent Optics Laboratory. By precision control of seven Gaussian beams powers and locations at powder material (Ni-based superalloy IN718), 10 mm cubes (see figure) with columnar and equiaxed microstructures were built by laser powder bed fusion technique. The microstructure diagnostics, performed by the Material Resources LLC using high resolution scanning electron microscopy (see figure) confirmed the changing of the dendrite growth direction and morphology. Such a drastic change in morphology and crystallography demonstrates the ability to build metal components with on-demand microstructure using multi-beam adaptive coherent fiber array laser technology under development at OPTONICUS and EOP labs. The ability of fast control of spatiotemporal distribution of laser power (adaptive beam shaping) with the multi-beam fiber array laser systems promises true microstructure engineering with AM for various metallic alloys.

10 mm cubes built from Ni-based superalloy IN718 powder using 7-beam fiber array. The beams were overlapped (left) and in line (right) during the powder bed selective laser melting process. The corresponding grain structure crystal orientation maps obtained with for the left with the electron backscatter diffraction imaging technique demonstrate equiaxed (left) and columnar (right) microstructures.



COLLOQUIUM

Dr. Roberto Morandotti from Institut national de la recherche scientifique (INRS) in Canada, a SPIE visiting lecturer, presenting his talk on quantum states at a colloquium in EOP.



RESEARCH BY SARAH KRUG ENABLES DIGITAL APERTURE SYNTHESIS IN ADAPTIVE OPTICS



Aperture synthesis and adaptive optics approaches have long been researched but have typically required one of two items: high speed deformable mirrors and wavelength accuracy path length compensation, or coherent laser sources for illuminating the object of interest. These requirements drive costs limiting aperture synthesis implementations to world class optical interferometers for passive illumination, or short range experiments using coherent laser sources with a limited field of view. Working with EOP graduate faculty Dave Rabb at the Sensors Directorate, Sarah Krug has identified an approach to allow digital aperture synthesis using partially coherent illumination, documenting the concept in her thesis (M.S., EOP, 2016) and building on it in her Ph.D. research. Their work has been recently published in the *Journal of the Optical Society of America A*. The concept uses an anamorphic (also referred to as non-homothetic) pupil relay in order to isolate the effects of inter-aperture phase errors. The relay will use gratings to cause a constant shift of the spatial frequency content that arises from the interference of the multiple apertures, resulting in a sparse spatial frequency content, which can be digitally separated and corrected, first for phase errors and then for

the shift in the spatial frequency. This allows for multiple apertures to be phased with dramatically relaxed requirements on the path length matching without requiring coherent illumination, simplifying the path to highly multi-aperture beam combination. The apertures can then be smaller than atmospheric seeing limitations, replacing deformable mirrors for large telescopes with an array of smaller telescopes, which can be digitally corrected. This has applications not only for larger scale optical interferometers, but also for smaller scale telescopes seeking diffraction limited performance without the expense and complexity of a conventional adaptive optics system.



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CONGRATULATIONS!



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