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REFLECTIONS *by Partha Banerjee*

Welcome to 2018! As the Department of Electro-Optics and Photonics (EOP) celebrates its second year, we have several exciting things from the past year to report.

In 2017, EOP graduated eight Ph.D. and eight M.S. students. Meanwhile, six students from the Huazhong University of Science and Technology (HUST) in Wuhan, China, came to EOP, with five of them being in the Bachelor's + Master's Program. Two of these students received scholarships from the Chinese government. Also, one M.S. and one Ph.D. student joined us from Centro de Investigaciones en Optica (CIO) in Mexico. Furthermore, under the joint agreement with HUST, three of our faculty taught courses in Wuhan last year. Courses co-taught at HUST include geometrical optics, solid-state physics and electro-optic devices.

As a new department, EOP developed and finalized its bylaws. Conditions and expectations for joint appointments have now been clearly enunciated. To date, Imad Agha, Andy Chong and Chenglong Zhao from Physics, and Monish Chatterjee and Russ Hardie from Electrical and Computer Engineering have received joint appointments with EOP.

Very recently, EOP overhauled its candidacy exam. A candidacy exam committee will oversee the exam; also, an oral exam component was added for those who score slightly lower than the passing score for the written exam.

Our faculty and staff continue to excel in their research and associated activities. The National Science Foundation (NSF) recently awarded Andy Chong \$300K for the "development of visible ultrafast mode-locked fiber lasers." Imad Agha, along with Andrew Sarangan, received a \$200K grant from NSF for collaborative

REFLECTIONS CONTINUED

research on “nanopatterning and temporal control of phase-change materials for reconfigurable photonics.” Joe Haus received an STTR Phase I subcontract from Aegis Technologies in Huntsville, Alabama, to work on an Air Force project titled “phase-change materials for optical limiting.” His collaboration with Quantum Screening, Inc., a biotechnology company in Pasadena, California, and Dr. Uttam Sinha from the Keck School of Medicine at the University of Southern California on sensing of cancer biomolecules in saliva is beginning to realize success. And, Mikhail Vorontsov recently received a \$900K Multidisciplinary Research Initiatives (MRI) grant for “novel characterization measurements and meteorological-driven modeling of turbulence for directed energy applications” from the High Energy Laser Joint Technology Office (HEL-JTO).

Finally, I would like to specially recognize two newcomers to the department (and the world): Samahah Falah, daughter of EOP Ph.D. students Farzia Karim and Md. Shah Alam, and Arwen Joanna, daughter of EOP Ph.D. student Antara Debnath Antu. Congratulations!

Best wishes to all and warm regards.

CRYSTALLOGRAPHY [101]



The jazz song, “Diamonds are a girl’s best friend,” introduced by Carol Channing in the original Broadway production of *Gentlemen Prefer Blondes* in 1949, made a long-lasting impression. While the Broadway hit did not make Billboard’s Top Ten, crystals, in general, are a hot commodity. “Most crystal-growing facilities in the United States have been closed,” says Edith Bourret-Courchesne, from Berkeley Labs, in the context of crystals for optical applications. You have to look to China or countries from the former Soviet Union to find such crystals. Currently, education in crystal growth is limited at universities in the U.S., and the U.S. now has a very mature workforce in this area.

The Department of Electro-Optics and Photonics at the University of Dayton is spearheading its efforts toward changing this through its new crystal growth facility. Dr. Paul McManamon, research professor in EOP and head of Exciting Technology (ET), a small company housed in Fitz Hall, encouraged the chairperson of EOP and the dean of the School of Engineering to invest in a crystal growth facility in an educational environment to develop new crystals and train the next generation of crystal growth specialists in the U.S. With support from Dean Eddy Rojas, EOP and ET, the new crystal growth facility is now operating in Fitz Hall room 580 (*see picture*). A few PMN-PT crystals have been grown and characterized, and efforts to produce a good optical quality crystal is now underway by improving the system and working out the quirks. Dr. Ujitha Abeywickrema (*right, in picture*), research engineer in EOP, and Cullen Bradley (*left, in picture*) from ET are the main people doing this work, and Dr. Ratnakar Neurgaonkar (R2), formerly from Rockwell and a specialist in crystal growth, is advising the group.

Recently, Matt Whittaker, manager of high temperature growth at the Cleveland branch of Gooch and Housego, formerly known as Cleveland Crystals, as well as Prof. Alp Sehirlioglu from Case Western, visited the EOP department with the goal of establishing long-term collaborations in crystal growth.

McManamon’s group has also started looking at growing relatively thin-film PMN-PT crystals for beam steering applications. Kyle French, an M.S. student in EOP, will be working on this process, while Dr. Abtin Ataei, a Ph.D. student in EOP, will use these crystals for non-mechanical beam steering.

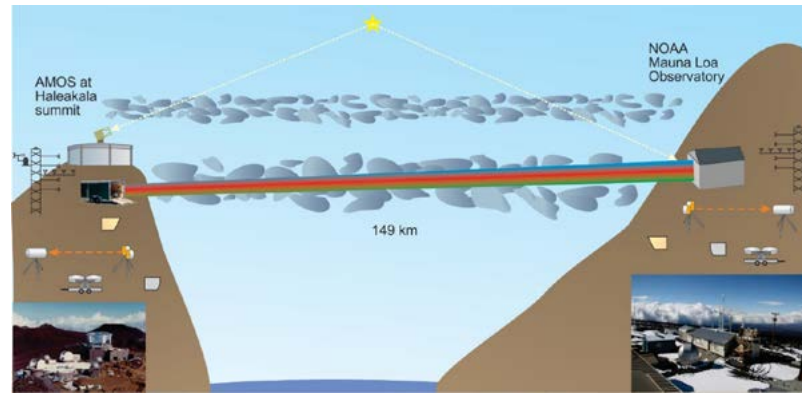
With the training of future crystal growers in mind, a short course on crystal growth, characterization and applications will be offered in the summer of 2018 by R2. In the near future, it is our hope that a crystal science certificate program will be developed.

JUST SIT RIGHT BACK AND YOU'LL HEAR A TALE . . .

. . . A TALE OF A LASER BEAM *(through atmospheric turbulence)*

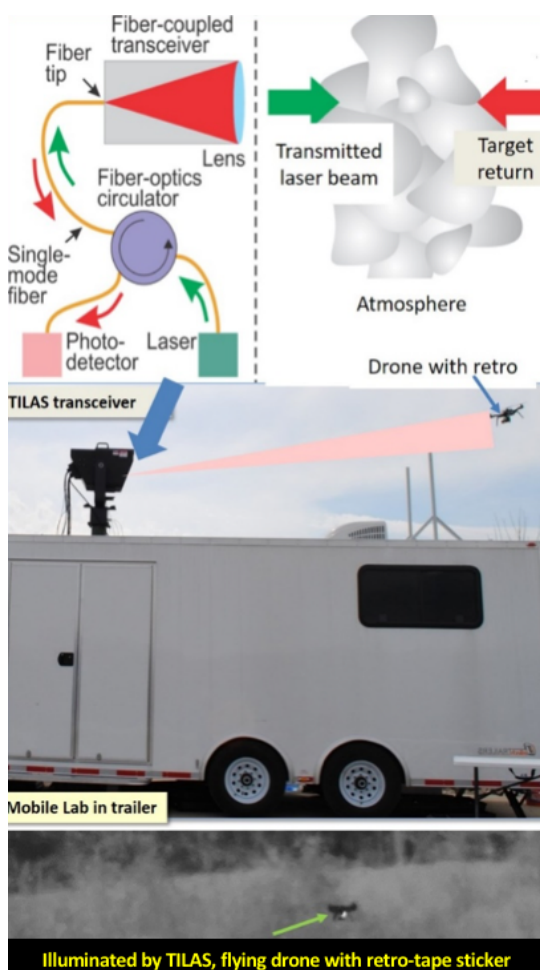
In the '60s hit TV series *Gilligan's Island*, a scientist, Dr. Boris Balinkoff, who lived on a nearby island, saw smoke signals from the castaways and rescued them. Free space communication has since improved by leaps and bounds.

Fast forward 50 years: A target-in-the-loop-atmospheric sensing (TILAS) approach developed by Dr. Mikhail Vorontsov, professor and Wright Brothers Endowed Chair in EOP, will be tested over an extended-range (149 km) propagation path between a trailer with polychromatic laser beacons located at the AFRL atmospheric optics sensing (AMOS) facilities on Haleakala summit (Maui Island, HI) and an instrumentation shed with a receiver telescope and sensing modules at the National Oceanic and Atmospheric Administration (NOAA) Observatory at the Mauna Loa summit (Big Island, HI).



The Extended-Range Comprehensive Atmospheric Optics Sensing (ERCAOS) experimental trial is a part of the ongoing Phase II STTR ERASS contract (UD/Optonicus). ERCAOS experimentations will be performed by the team of researchers and engineers from the University of Dayton (UD), Optonicus, AFRL (/RD, /RYMT, and /RDSS) and on-site contractors during two weeks in October 2018.

The EOP Intelligent Optics team has recently proposed a TILAS concept for *in-situ* remote sensing of laser beam and turbulence characteristics along the target line of sight, including the scintillation index and refractive index structure parameter. The TILAS concept is based on the integral invariant (interference metric), which couples the complex amplitudes of counter-propagating optical fields in the refractive and turbulent atmosphere. It was shown that the interference metric could be measured using a single-mode, fiber-based laser transceiver system. The TILAS transceiver consists of a transceiver telescope and an optical train solely based on a single-mode fiber and fiber elements that are used for (a) delivery of a collimated Gaussian beam generated at the fiber tip to the transceiver telescope pupil and (b) delivery of the target-return optical wave to the fiber-coupled photo-detector. In the TILAS transceiver, the separation of the outgoing (transmitted) and return (received) waves propagating in the fiber-optics train is performed using the single-mode, fiber-optics circulator.



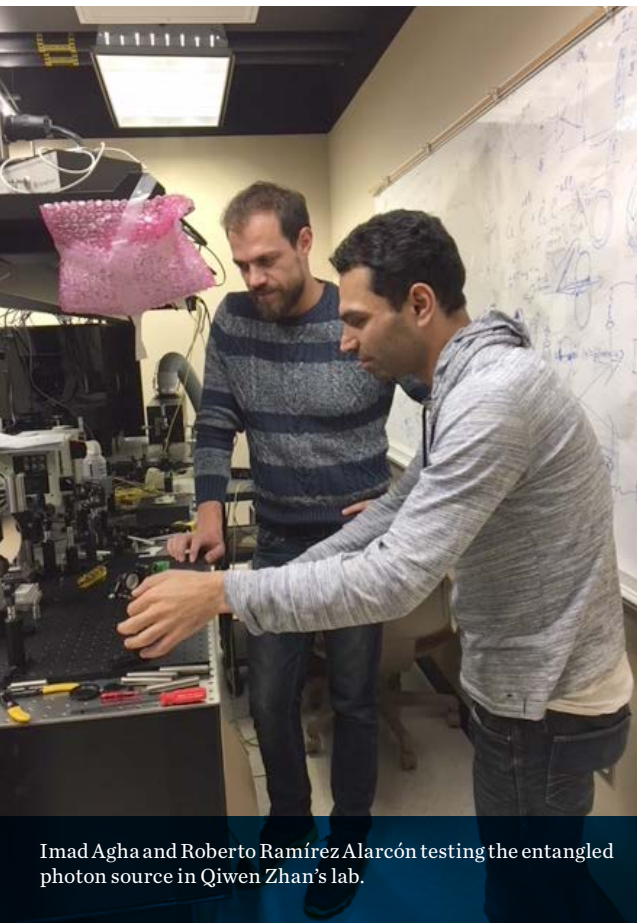
The TILAS measurements allow remote evaluation of intensity scintillations of the laser beam that is scattered off a small size retro-reflector (or a retro-tape sticker) at the other-end of a laser beam propagation path, as well as retrieval of the path integrated refractive index structure parameter from these measurements.

The TILAS concept may be used to examine the validity of the Kolmogorov turbulence theory as well as to develop physics-based models of the atmosphere.

The TILAS concept development is a part of the recently received JTO-HEL MRI grant. During the proposed five-year effort, the team plans to experimentally validate this new atmospheric sensing concept using direct atmospheric TIL measurements of laser beam intensity scintillation characteristics over a 7 km propagation path at the UD testbed between Fitz Hall and the VA hospital across town. For field experiments, the team uses the mobile laser lab in a trailer developed under the DARPA/MTO Sea Hawk contract. The mobile lab has target-tracking capabilities. The UD/Optonicus team has already demonstrated tracking and laser illumination of a flying drone using the Sea Hawk mobile laser lab during a set of field experiments performed at the Navy testing facilities in Crane, Indiana, in summer 2016.

Top: Schematic of TILAS laser transceiver based on the single-mode fiber optical setting. **Middle:** Photo of laser lab in trailer with fiber-array laser head lifted above the trailer's roof to track a flying drone seen on the right (Crane, IN, June 2016). **Bottom:** Image of a flying drone with a small retro-tape sticker. The bright glint at the retro-sticker location is caused by illumination of the drone by the laser beam from the trailer. The image is taken by the fine tracker CCD—a part of the laser head.

ENTANGLED, TWISTED AND STRUCTURALLY POLARIZED



Imad Agha and Roberto Ramírez Alarcón testing the entangled photon source in Qiwen Zhan's lab.

Photons have many unique, and at times, seemingly bizarre properties. Photon pairs can be generated in the so-called quantum entangled states, leading to “spooky action at a distance.” Recently, scientists learned how to add a new “twist” to photons by creating photons with orbital, angular momentum states. In parallel, technologies have been developed to structure photons in polarization offering additional degrees of freedom to the photon states. Combining these latest findings together certainly will lead to exciting new discoveries. In an international collaborative effort, Prof. Qiwen Zhan (UD EOP), Prof. Imad Agha (UD EOP and Physics) and Prof. Roberto Ramírez Alarcón (Centro de Investigaciones en Óptica - CIO, Mexico) are doing just that. Entangled photon sources have been built up and will be coupled to the patented vectorial optical field generator developed in Prof. Zhan's lab. Mr. Carlos Sevilla, UD-CIO master's degree program student and co-advised by researchers from UD EOP and CIO, is working on this project. He will experimentally implement the generation and detection of entangled, twisted and structurally polarized photons and study the effects arising from atmospheric turbulence. The findings will have applications in quantum communications, cryptography, metrology and quantum computing.



DID YOU KNOW?



Two of Qiwen Zhan's papers were among the top 100 most cited articles among all the papers published in *Optics Express* in the past 20 years. For more information, see *Optics Express* 20th anniversary website: <https://www.osapublishing.org/oe20/>:

41. Q. Zhan, “Trapping metallic Rayleigh particles with radial polarization,” *Opt. Exp.* **12**, 3377-3382 (2004).

51. Q. Zhan and J. R. Leger, “Focus shaping using cylindrical vector beams,” *Opt. Exp.* **10**, 324-331 (2002).

NANO-PHOTONICS & NANO-MANIPULATION LAB WELCOMES STUDENTS FROM CIO AND HUST



Chenglong Zhao (third from right) with graduate students Farzia Karim (left front), Yuwen Li (left), Ana Sanchez Solis (second from left), Md Shah Alam (second from right), and Yujie Yang (right).

Dr. Chenglong Zhao welcomes Ana Sanchez Solis from Centro de Investigaciones en Optica (CIO) in Mexico, and Yuwen Li and Yujie Yang from Huazhong University of Science and Technology (HUST) in China, to the Nano-photonic & Nano-manipulation (NPNM) lab. Through our agreements with HUST and CIO, EOP has received six Bachelor's Plus Master's Program students as well as one M.S. and one Ph.D. student from CIO.

The NPNM lab, led by Dr. Zhao, is dedicated to developing cutting-edge nanotechnologies for additive nano-manufacturing, reconfigurable optical devices and ultra-sensitive bio-sensing. In the lab, Ana will develop a novel “hot-bubble” technology for temperature sensing and quantum-dot synthesis. And, Yuwen and Yujie will work on reconfigurable micro-lens and nonlinear plasmonics, respectively.

Dr. Zhao, assistant professor in physics with a joint appointment in EOP, joined UD in the fall of 2015. He also supervises two EOP Ph.D. students, Md Shah Alam and Farzia Karim, who are in their third year of Ph.D. study. Shah has successfully developed a nano-manufacturing platform that allows for the additive manufacturing of metallic nanostructures under ambient conditions. Farzia is developing an ultra-sensitive bio-sensing system with Dr. Yvonne Sun, Department of Biology, and Dr. Erick S. Vasquez, Department of Chemical and Materials Engineering, for the rapid identification of foodborne bacteria.

SELECTED JOURNAL PUBLICATIONS

1. Z. Gao, M. M. R. Hussain, D. de Ceglia, M. A. Vincenti, **A. Sarangan, I. Agha**, M. Scalora, **J. W. Haus**, and P. Banerjee, “Unraveling delocalized electrons in metal induced gap states from second harmonics,” *Appl. Phys. Lett.* **111**, 161601 (2017). [yes, there is another P. Banerjee!]

2. J. A. Burrow, R. Yahiaoui, **A. Sarangan, I. Agha, J. Mathews**, and T. A. Searles, “Polarization-dependent electromagnetic responses of ultrathin and highly flexible asymmetric terahertz metasurfaces,” *Opt. Exp.* **25**, 32540-32549 (2017).

3. **P. P. Banerjee**, U. Abeywickrema, and A. Kota, “Selected recent advances in the theory and applications of photorefractive materials,” *Asian J. Phys.* **26**, 137-145 (2017).

4. U. Abeywickrema, **P. P. Banerjee**, A. Kota, S. Swiontek, and A. Lakhtakia, “High-resolution topograms of fingerprints using multiwavelength digital holography,” *Opt. Eng.* **56**, 034117-1 – 8 (2017).

5. **P. P. Banerjee**, W. Osten, P. Picart, L. Cao, and G. Nehmetallah, “Digital holography and 3D imaging,” *Appl. Opt.* **56**, DH1-DH4 (2017).

6. S. McDaniel, F. Thorburn, A. Lancaster, R. Stites, **G. Cook**, and A. Kar, “Operation of Ho:YAG ultrafast laser inscribed waveguide lasers,” *Appl. Opt.* **56**, 3251-3256 (2017).

7. S. A. McDaniel, P. A. Berry, **G. Cook**, D. Zelmon, S. Meissner, H. Meissner, and X. Mu, “CW and passively q-switched operation of a Ho:YAG waveguide laser,” *Opt. Laser Tech.* **91**, 1-7 (2017).

8. F. Thorburn, A. Lancaster, S. McDaniel, **G. Cook**, and A. K. Kar, “5.9 GHz graphene based q-switched mode-locked mid-infrared monolithic waveguide laser”, *Opt. Exp.* **25**, 26166-26174 (2017).

9. D. Hobbs, B. Macleod, E. Sabatino, S. Mirov, D. Martyshkin, M. Mirov, G. Tsoi, S. McDaniel, and **G. Cook**, “Laser testing of anti-reflection microstructures fabricated in zinc selenide and chromium-ion doped zinc selenide laser gain media,” *Opt. Mat. Exp.* **7**, 3377 – 3388 (2017).

10. S. McDaniel, F. Thorburn, A. Lancaster, R. Stites, **G. Cook**, and A. Kar, “Operation of Ho:YAG ultrafast laser inscribed waveguide lasers,” *Appl. Opt.* **56**, 3251-3256 (2017).

11. H. Kim, R. S. Hay, S. A. McDaniel, **G. Cook**, N. G. Usechak, A. M. Urbas, K. N. Shugart, H. Lee, A. H. Kadhim, D. P. Brown, B. Griffin, G. E. Fair, R. G. Corns, S. A. Potticary, F. K. Hopkins, K. L. Averett, D. E. Zelmon, T. A. Parthasarathy, and K. A. Keller, “Lasing of surface-polished polycrystalline Ho: YAG (yttrium aluminum garnet) fiber,” *Opt. Exp.* **25**, 6725-6731 (2017).

12. B. E. Schumm and **M. P. Dierking**, “Wave optics simulations of synthetic aperture ladar performance through turbulence,” *J. Opt. Soc. Am. A* **34**, 1888-1895 (2017).

13. A. J. Stokes, **M. P. Dierking**, and **D. J. Rabb**, “Interferometric synthetic aperture ladar using code division multiple access apertures,” *Appl. Opt.* **56**, 5003-5012 (2017).

14. D. Garcia Mina, **J. W. Haus**, A. Chong, A. Khanolkar, **A. Sarangan**, and K. Hansen, “Bi-tapered fiber sensor using visible to near infrared light,” *Sensors Actuators A Phys.* **263**, 285–290 (2017).

15. N. Korneev, M. Almanee, B. Ibarra-Escamilla, M. Duran-Sanchez, H. Santiago-Hernández, O. Pottiez, **J. W. Haus**, and E. A. Kuzin, “Nonlinear self-polarization of Raman amplified light in fibers,” *J. Opt. Soc. Am. B* **34**, 1644-1648 (2017).

16. G. S. He, M. Liu, **J. W. Haus**, M. T. Swihart, and P. N. Prasad, “Strong stimulated Mie scattering from plasmonic CuS nanocrystals in toluene or pentane,” *IEEE J. Sel. Top. Quant. Electron.* **23**, 1-6 (2017).



SELECTED JOURNAL PUBLICATIONS CONTINUED

17. L. A. Herrera-Piad, **J. W. Haus**, D. Jauregui-Vazquez, J. M. Sierra-Hernandez, Estudillo-Ayala, Y. Lopez-Diequez, and R. Rojas-Laguna, "Magnetic field sensing based on bi-tapered optical fibers using spectral phase analysis," *Sensors* **17**, 2393 (2017).

18. **P. McManamon**, P. Banks, J. Beck, D. Fried, A. Huntington, and **E. Watson**, "A comparison: Flash lidar detector options," *Opt. Eng.* **56**, 031223 (2017).

19. V. Molebny, **P. McManamon**, O. Steinvall, T. Kobayashi, and W. Chen, "Laser radar: Historical perspective, from the east to the west," *Opt. Eng.* **56**, 031220-031220 (2017).

20. C. Wan, D. Lombardo, **A. Sarangan**, and **Q. Zhan**, "High efficiency geometric-phase polarization fan-out grating on silicon," *Opt. Exp.* **25**, 24559-24565 (2017).

21. J. M. Duran and **A. Sarangan**, "Fabrication of ultrahigh aspect ratio silicon nanostructures using self-assembled gold metal-assisted chemical etching," *J. Micro/Nanolithography, MEMS, MOEMS* **16**, 14502 (2017).

22. V. A. Kulikov and **M. A. Vorontsov**, "Analysis of the joint impact of atmospheric turbulence and refractivity on laser beam propagation," *Opt. Exp.* **25**, 28524-28535 (2017).

23. Z. Yang, and **M. A. Vorontsov**, "Impact of atmospheric turbulence and refractivity on the modulation transfer function of incoherent imaging system," *J. Opt.* **19**, 125601 (2017).

24. S. L. Lachinova, **M. A. Vorontsov**, G. A. Filimonov, D. A. LeMaster, and M. E. Trippel, "Comparative analysis of numerical simulation techniques for incoherent imaging of extended objects through atmospheric turbulence," *Opt. Eng.* **56**, 071509 (2017).

25. C. Wan, G. Rui, J. Chen, and **Q. Zhan**, "Detection of photonic orbital angular momentum with micro- and nano-optical structures," *Front. Optoelectron.* **3**, 1-9 (2017).

26. Y. Yu, H. Huang, M. Zhou, and **Q. Zhan**, "Creation of a multi-segmented optical needle with prescribed length and spacing using the radiation pattern from a sectional-uniform line source," *Scientific Rep.* **7**, 10708 (2017).

27. J. Chen, C. Wan, L. Kong, and **Q. Zhan**, "Tightly focused optical field with controllable photonic spin orientation," *Opt. Exp.* **25**, 19517-19528 (2017).

28. X. Wang, L. Gong, Z. Zhu, B. Gu, and **Q. Zhan**, "Creation of identical multiple focal spots with three-dimensional arbitrary shifting," *Opt. Exp.* **25**, 17737-17745 (2017).

29. C. Wan, J. Chen, and **Q. Zhan**, "Tailoring optical orbital angular momentum spectrum with spiral complex field modulation," *Opt. Exp.* **25**, 15108-15117 (2017).

30. F. Karim, T. B. Smith, and **C. Zhao**, "Review of optical detection of single molecules beyond the diffraction and diffusion limit using plasmonic nanostructures," *J. Nanophotonics* **12**, 012504 (2017).

31. Y. Xie and **C. Zhao**, "An optothermally generated surface bubble and its applications," *Nanoscale* **9**, 6622-6631 (2017).

SIX HUST STUDENTS JOIN EOP IN FALL 2017

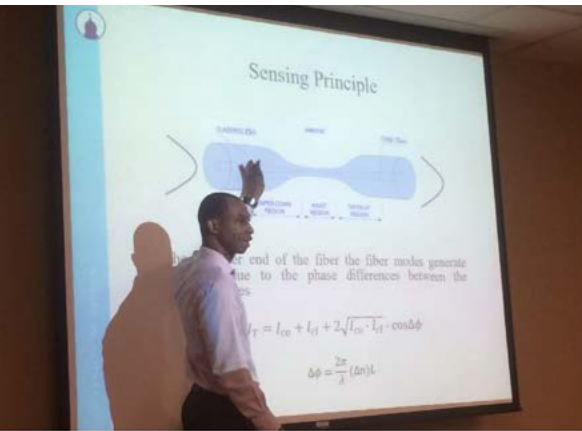


At U.S. Air Force Museum in Dayton, HUST students with Dr. Deng (right) in front of Flying Tiger Monument, which recognizes America's help to defend China against Japanese forces during WWII.

Huazhong University of Science and Technology (HUST) is a premier optics institution in China. HUST, along with the Wuhan National Laboratory for Optoelectronics (WNLO), the School of Optical and Electronic Information (SOEI), and the School of Engineering Science (SES), is located in Wuhan, which is also known in China as the Optics Valley. Since 2015, thanks to the groundwork of Dr. Cong Deng, alumnus of HUST and current research faculty in EOP, along with Drs. Partha Banerjee and Joseph Haus, cooperation between UD and HUST was established. Now, the two universities are officially cooperating under programs of faculty and student exchange. As part of the faculty exchange, Drs. Banerjee, Haus and Deng have been appointed as part-time visiting professors, teaching and conducting research. As part of student exchange, six HUST students came to our department in the fall of 2017. Except for one who only does her undergraduate project here, five students have joined our 3+2 Bachelor's Plus Master's Program. In their senior year, students study in our department while obtaining their bachelor of engineering degree at HUST. Following their first year at UD, they remain at UD to finish their M.S. studies. In the future, we hope that some of these outstanding students will join our Ph.D. program.

Two students, Yunyan Li and Xiaowei Ge, have obtained full scholarship from the Chinese government related to this 3+2 program. Furthermore, UD EOP has offered all of them 25 percent tuition waiver scholarship because of their outstanding background. Additional rewards from HUST will be given to those who perform well in our department. We warmly welcome these students and wish them every success.

Additionally, Dr. Deng taught in SES and interviewed some potential students in SOEI and SES in October 2017. During the summer of 2017, Dr. Banerjee taught at HUST. During the summer of 2018, Drs. Banerjee and Haus will teach and conduct research for a month at HUST.



EOP IN PICTURES



Clockwise from top left: Diego Garcia presenting at SPORTS organized by Josh Burrow; Elaheh Ghanati (center) and Diane Beamer (right) at the student poster section at SPIE Annual Meeting; Mikhail Vorontsov (center) with his ASC award; Jeff Kraczek with his family after his successful PhD defense.



EOP GRADUATES



MAY 2017

Mallik Hussain, M.S.

Mohamad Almanee, Ph.D.

Ryan Feaver, Ph.D.

Diego Garcia, Ph.D.

Chuan Ni, Ph.D.

AUGUST 2017

Joshua Burrow, M.S.

Alexander Downham, M.S.

Thomas Iverson, M.S.

Jeffrey Kraczek, Ph.D.

Zhijun Yang, Ph.D.

DECEMBER 2017

Michael Amonson, M.S.

Mitchell Bauer, M.S.

Hamza Salem, M.S.

Thomas Welsh, M.S.

Sean McDaniel, Ph.D.

Bryce Schumm, Ph.D.

Andrew Stokes, Ph.D.

Congratulations!

DID YOU KNOW?

Two of our former EOP graduates, Jian Gao (Ph.D., UD) and Yu Wang (M.S., UD; Ph.D., Boston University), are now employed at Apple in the Bay area. Prior to Apple, Jian was at GenTex, and Yu was at KLA-Tencor. Recent M.S. graduates, Alex Downham is with Naval Surface Warfare Center in Crane, Indiana; Michael Amonson is with Boeing in St. Louis; and Thomas Iverson is with Ford Motor Company in Detroit.

UNIVERSITY OF DAYTON DEPARTMENT OF ELECTRO-OPTICS & PHOTONICS

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