UCF CONTINUES ITS ODYSSEY WITH OPTICS

As part of a new series that follows student researchers making exciting contributions to the display world, we explore why the University of Central Florida's College of Optics and Photonics is lauded by industry and academia.

by **Nicole Saunders**

SINCE 2004, MANY WINNERS OF SID'S STUDENT PAPER AWARDS AND A HOST OF other coveted industry prizes have shared a common trait: They hail from CREOL, The College of Optics and Photonics at the University of Central Florida. CREOL routinely is ranked as a top American college for optics and photonics, alongside elite schools such as the University of Rochester's Institute of Optics and the University of Arizona's James C. Wyant College of Optical Sciences. Still, it holds a special place in tech history as the first full college in the US devoted solely to this area.

Moreover, it has a few unique factors working in its favor. That includes strong ties to industry, which are baked into the college's mission statement, and a secret weapon in the form of Shin-Tson Wu, the Pegasus Professor of Optics and Photonics who has trained his Ph.D. and master's students to be particularly prolific. On average, each student in his LCD research group publishes 20 papers in scholarly journals and industry publications throughout their time at UCF. That includes *Information Display*; see our Frontline Technology section for the article "Spotlighting Recent Advances in Liquid-Crystal Devices for Beam-Steering Applications" (**p. 9**) by a team of UCF students, led by Wu.

Wu's group co-owns 38 US patents with Innolux and nine with AU Optronics. In addition, the New Mexico startup Holochip has licensed three adaptive lens patents from them for making zoom lenses. Once his students graduate, they go on to become leaders in the field, Wu says, noting that 13 students from his group hold positions at Apple, and four are working on augmented and virtual reality (AR/VR) displays at Facebook.

Charting the Program's Rise

CREOL's origins date back to a push in the early 1980s by Florida's then-governor Bob Graham to realign the local economy. Determined to steer the state beyond its dependence on tourism and agriculture, he created the Florida High Technology and Industry Council (FHTIC) to draw more lucrative tech jobs to the region. The council seized on the idea of housing an optics research center at UCF that would give tech industries access to high-quality studies, students, and faculty.[1]

At the time, UCF was a commuter school just over two decades old, with scant resources in this area. The university was established in 1963 with a mandate to cultivate talent for Florida's "Space Coast"—the part of the state near the National Aeronautics and Space Administration's (NASA's) Kennedy Space Center and Cape Canaveral Air Force Station. Indeed, UCF's original proposed name was "Space University."[2] According to a retrospective published by the school, the university had "very little technical research activity, limited graduate programs, including no Ph.D. in physics, and only a handful of faculty who associated themselves with the optics field."[1]

Then in 1986, the Florida legislature earmarked $1.5 million in the UCF budget for permanent, recurring funds to support CREOL. The funds helped attract a group of optical scientists from the University of North Texas, who were disappointed by the lack of progress in creating a world-class research center at their own school. The fact that UCF was a young university was also a draw because, as founding director M.J. Soileau put it, it provided "the opportunity to develop something new, without the hindrance of 'tradition,' the short version of what some call the seven last words of an organization: 'We've never done it that way before.'" [1]

Initially CREOL was housed in a double-wide trailer, but it quickly grew, with the School of Optics' establishment in 1998. It was promoted to a full college in 2004 but kept the CREOL acronym. (However, officials changed the name to the Center for Research and Education in Optics and Lasers to reflect the school's ambitions.) Today, the college has its central facilities in a state-of-the-art building spanning more than 100,000 square feet.

Retaining Aspirations and Pursuing New Directions

Today the college houses four research centers: CREOL, the Florida Photonics Center of Excellence (FPCE), the Townes Laser Institute (TLI), and the Institute for the Frontier of Attosecond Science and Technology (iFAST). Its 55 faculty members, more than 60 research scientists, 150 graduate students, and 90 undergrads lead research that runs the gamut from nonlinear and quantum optics to imaging, sensing, and display.

Echoing the FHTIC's original aspirations, the school's mission statement includes a goal of "aiding in the development of Florida and the nation's knowledge-based and technology-based industries"[3] and fostering research collaborations and partnerships with industry. Four startups are incubated within CREOL and faculty members regularly seek corporate partners for research projects. All told, faculty members have produced more than 260 patents and spun off 26 companies throughout CREOL's history.

Professor Shin-Tson Wu came to the school in 2001, after spending 18 years as a scientist at Hughes Research Laboratories in Malibu, California. There, among other things, he developed a physical model for understanding the origins of liquid crystal (LC) refractive indices that has since been embedded into commercial simulation software programs for designing full-color LCDs with optimized electro-optical properties.

Well known for his novel contributions to the industry, Wu is a SID Fellow who won the society's Jan Rajchman and Slottow–Owaki Prizes in 2008 and 2011, respectively.

When Hughes decided to sell its projection display technology to JVC for commercialization and shut down its LC research, Wu looked for his next move. "Many of my colleagues [at Hughes] either retired or had to change jobs," he recalls.

It just so happened that his thesis advisor from the University of Southern California where Wu had earned his Ph.D., was a vice president for research at UCF. He invited Wu to visit the campus and asked him to consider pivoting from industry to academia. After Wu convinced his family to relocate, he traded the eagle-eyed focus of industry, where he was accustomed to concentrating on one area, for a more diversified world of academic research.

With Hughes' blessing, Wu carried over some of his work and key relationships from his former lab to UCF. "They very generously allowed me to bring my Defense Advanced Research Projects Agency (DARPA) and Air Force Office of Scientific Research (AFOSR) programs with me. So that was a good startup for me," he says. Indeed, under DARPA and AFOSR, Wu's group developed new LC materials and devices that have been used in beam-steering systems produced by Raytheon.

Wu currently works with 10 Ph.D. students and two visiting scholars, but over the years, he has mentored 45 Ph.D. students, eight master's students, and 21 postdocs, and hosted more than 20 visiting scholars. Wu is often cited as a contributing factor for students who choose CREOL over other schools, both because of his reputation in the field and his eagerness to serve as a UCF ambassador overseas. Doctoral candidate Tao Zhan recalls that as an undergrad studying at Nanjing University in Jiangsu, China, Wu was in close contact with the school's professors, raising awareness about CREOL, and met with him several times before graduation. "He's like a guru in this area, and that's why I decided to join his group," Zhan says.

The secret to his program's success, Wu says, is a family-type environment that promotes collaboration—a boon especially to international students far from home—and efforts that start early on to help students grow more comfortable talking about their work. This includes Friday-night fellowships that Wu hosts in his living room nearly every week. Over home-cooked meals prepared by his wife, students chat about their lives and discuss research ideas and difficulties they've encountered, as their peers chime in with suggestions. That way, "we don't have just one student solving his own problems," Wu says.

By creating an environment where students learn to express their thoughts, the Friday-night fellowships have become an important training ground. "Every time I receive a request to write a recommendation letter, they ask two questions in particular. How is this [individual] as a student and how strong are their communication skills?" Wu says.

The Friday-night fellowships fortify students in other ways, too. Wu sympathizes with graduate students who, he says, are at one of the loneliest points of their careers, spending long days and nights in the lab or at the office. With that in mind, Wu says he chooses not to manage his group by aggressively exercising his authority but rather by treating the students as his own children.

Another important component, Wu says, is his program's focus on hot topics in the display world. Indeed, in his group, the research line-up features many of the same topics covered at Display Week. "This is especially important because if you spend five years educating students and they work on a cold topic like CRT [cathode-ray tubes] or plasma displays, nobody will hire them," Wu says. "We stand on the frontier of important technologies, and our research has to evolve accordingly.

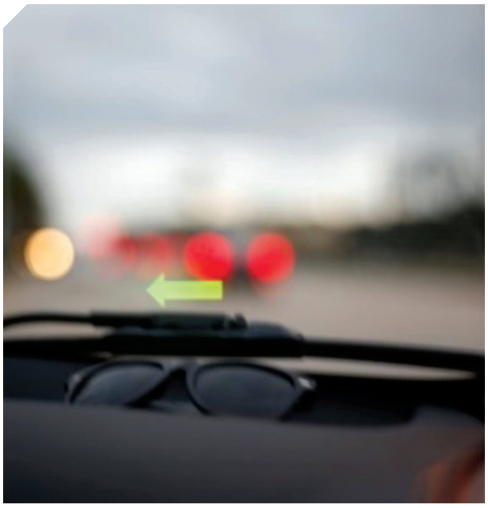
As the US struggles to regain its financial footing during the coronavirus pandemic, Wu says he's fortunate to still have some sources of industry and state funding, although the latter was cut by 10 to 20 percent. "How many students I take each year depends on how much funding I have." (Industry members, alumni, and others can donate to CREOL's research programs at *https://www.ucffoundation.org/givetoucfoptics*.) Nonetheless, he is looking forward to working with a new crop of young researchers.

An Industry Talent Pool

Shin-Tson Wu and former and current CREOL students.

RECOGNIZING OUTSTANDING WORK

CREOL's students landed top prizes and awards for their novel research over the last year.



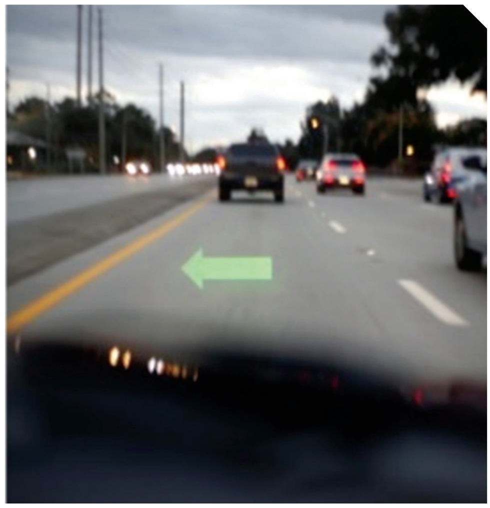


Fig 1.

A photo captured through a head-up display focusing at a short (left) and long (right) virtual image distance enabled by passive-driven Pancharatnam-Berry lenses (PBL).

FOR THE FOURTH CONSECUTIVE YEAR, THE *JOURNAL OF the Society for Information Display* (*JSID*) has awarded its Outstanding Student Paper prize to researchers from CREOL, The College of Optics and Photonics at the University of Central Florida. Tao Zhan, a Ph.D. candidate set to earn his degree next spring, and Yun-Han Lee, who recently graduated from the program and is a research scientist at Facebook Reality Labs, earned the honor for their work on "High-Efficiency Switchable Optical Elements for Advanced Head-Up Displays."[4] The paper was supported by CREOL students Jianghao Xiong, Guanjun Tan, and Kun Yin, and Goertek engineers Jilin Yang and Sheng Liu, as well as professor Shin-Tson Wu.

Furthermore, Fangwang Gou, a display hardware engineer at Apple who graduated from CREOL in August, received *JSID*'s Best Paper Award 2019 for leading work on "High Performance Color-Converted Micro-LED Displays,"[5] which was supported by CREOL students En-Lin Hsiang and Guanjun Tan, and AUO principal engineers Yi-Fen Lan and Cheng-Yeh Tsai, and professor Wu.

Boosting HUDs' Performance

Zhan and Lee's work explores how emerging Pancharatnam-Berry phase optical elements (PBOEs) can boost the performance of next-generation automotive head-up displays (HUDs) (**Fig. 1**). HUDs improve road safety and can create a better driving experience, but the technology is far from perfect, Zhan says. For example, although most commercialized HUDs project a virtual image at a fixed distance—typically around 2.5 m in front of the driver—the driver may not be able to focus on that fixed virtual image distance (VID) in certain circumstances, such as driving at high speeds on highways or slow speeds in local lanes. Display luminance and total power efficiency are other areas of concern, according to Zhan and Lee. For the driver to perceive an image, a tolerable ambient contrast ratio of >3:1, for example, must be maintained under a range of ambient conditions, which is challenging (especially when the sunlight is strong). That issue may become even more pressing in next-generation HUDs that have an enlarged field of view (FOV) and longer VID, they say.

However, Pancharatnam-Berry lenses (PBLs) offer a possible solution, as they can enable multiple or switchable virtual image distances for various driving circumstances. Indeed, with images in different locations and at different distances, "we can display different content at different depths," Zhan explains. Moreover, Pancharatnam-Berry deflectors (PBDs) provide a switchable looking-down angle, and the Bragg PBDs can function as a polarization-sensitive optical combiner for better ambient contrast ratio and grating couplers for waveguide-type HUDs, significantly reducing the component volume while increasing the FOV.

The work wasn't without challenges, including experimental issues in dealing with a new technology, particularly throughout the fabrication process, which was sensitive to temperature and humidity, Zhan says. "We are definitely looking at some new fabrication processes that simplify the production process. For example, we recently developed a method that can do the fabrication without a laser, which is much faster and also cheaper."

According to Zhan, they've already received industry interest and are in talks with one company about collaborating on the technology. In the meantime, he says, the *JSID* award was a great boost. "I've received awards from optical societies, but this is especially exciting because it's from the display industry," he says.

Improving MicroLEDs' Optical Efficiency

In her paper, Gou proposes introducing a funnel-tube array and reflective coating to the inner surface of a color-converted microLED system to eliminate crosstalk and more than double the optical efficiency. As one of just a few researchers who are exploring this topic, her work has helped pioneer research in this area.

The funnel tube array, she writes, is formed above the microLED-layer. In a nutshell, two-color phosphors are filled inside to obtain white light, and on top of the funnel-tube array, color filters with red, green, and blue (RGB) subpixels are aligned with each tube region. Phosphors for each subpixel region in the system are designed to be isolated, thereby eliminating crosstalk.

Developing a simulation model for the paper was an important first step, she says, but new efforts and industry partnerships will be needed to fabricate the actual device and configure AI to optimize its performance further. Gou expects younger students in the program who supported her paper to help drive this forward. With them in mind, she offers this advice to ambitious student researchers: “It may sound contradictory, but the most important thing is to collaborate with others, while at the same time working independently to solve problems.” It’s easy to feel frustrated as you hash out the kinks of a project, she explains, and having peers and professors you can use as reliable sounding boards can help you think more broadly. Ultimately, however, it’s up to you to determine the best direction for your research.

Zhan agrees that the collaborative spirit he’s found in CREOL was a key ingredient for success. “This paper and the *JSID* award are a result of teamwork,” he says. “We had great and helpful crewmates who gave me very strong support with this project, and I also really appreciate the help and advice from Dr. Wu.”

CREOL CONTRIBUTES MULTIPLE INNOVATIVE OFFERINGS

Student researchers from CREOL offer a sampling of what is emerging from their group, in terms of new, exciting research.

Practical chromatic aberration correction in virtual reality displays enabled by large-size ultra-broadband liquid crystal polymer lenses | Tao Zhan et.al.| **doi.org/10.1002/adom.201901360**
VR optics’ complexity is limited by the demanding form factor, which usually has strong chromatic aberrations (CAs). Although the current digital compensation method can reduce CAs by preprocessing image content, it does not address subchannel CAs, or CAs within each color channel. We designed and demonstrated an optical approach that can significantly reduce subchannel CAs while adding negligible volume to the headset to address this issue. The critical component in our approach is a thin-film PBL, which manifests opposite CAs to refractive optics. We spent most of our effort designing and fabricating this three-layer polymer-based PBL to manifest high efficiency over the entire display spectrum. In the end, the CAs in a VR system were reduced by more than 5 times and the imaging appeared much sharper. As a next step, we’ll further optimize PBL’s performance and investigate a simpler fabrication process to facilitate the potential mass-production of this technology. –*Tao Zhan*

Mini-LED, micro-LED, and OLED displays: present status and future perspectives | Yuge Huang et al. | **doi.org/10.1038/s41377-020-0341-9**
MiniLED, microLED, or OLED displays: What’s the winning technology? To answer this controversial and debatable question, we conducted a comprehensive analysis of the viewing performance of miniLED, micro-LED/OLED emissive displays, and miniLED backlit LCDs, in which we evaluated the power consumption, ambient contrast ratio, motion picture response time, dynamic range, and adaptability to flexible/transparent displays (**Fig. 2**). Furthermore, we suggest design strategies for various application scenarios such as TVs, gaming monitors, smartphones, and VR displays. –*Yuge Huang*

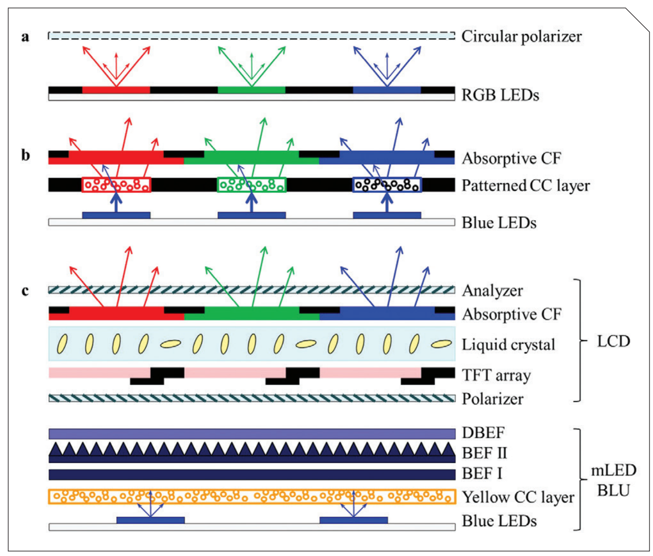


Fig. 2.

MiniLED, microLED, and OLED display system configurations. (a) Red, green, and blue (RGB)-chip mini-LED, micro-LED, and OLED emissive displays. (b) Color conversion mini-LED, micro-LED, and OLED emissive displays. (c) Mini-LED backlit LCDs. CF: color filter; CC: color conversion; TFT: thin-film transistor; DBEF: dual brightness enhancement film; BEF: brightness enhancement film; and BLU: backlight unit.

Reflective polarization volume lens with small f-number and large diffraction angle | Kun Yin, Ziqian He, and Shin-Tson Wu| **doi.org/10.1002/adom.202000170**
Planar optics based on patterned cholesteric liquid crystals (CLCs) increasingly attract attention because of their self-organized helical structure and the ability to create an arbitrary reflected wavefront through spatial orientation control. However, it's challenging for LC lens to achieve a low f-number (f/#) and large deflection angle simultaneously, because of the subwavelength-orientation requirement. Furthermore, with the increasing demand for compact size in novel optical systems, reflective lenses that can fold the optical path urgently are needed.

Recently, our group demonstrated a new off-axis reflective polarization volume lens (PVL) with f/#=0.825, a large aperture size, simple fabrication process, flat and thin profile, polarization selectivity, and a large diffraction angle. PVLs provide promising applications to novel foldable optical systems with these attractive and unique optical properties, including AR/VR displays as an optical combiner or polarized surface with a large angle and high optical power. *–Kun Yin*

Passive polymer-dispersed liquid crystal enabled multi-focal plane displays | Ziqian He, Kun Yin, and Shin-Tson Wu | **doi.org/10.1364/OE.392489**

We recently reported birefringent light-shaping films (BLSFs) for miniLED backlit LCDs.6 The film consists of both isotropic and anisotropic material, and we found that by aligning the anisotropic material properly and carefully designing its refractive indexes, we can tailor the angle-selective scattering properties.

The film is designed to have a strong scattering for normal incidence and weak scattering at certain large oblique incident angles. By directly adhering the BLSF onto an LED, we could tailor the angular distribution of light f-rom Lambertian-like to batwing-like. Such control of an angular distribution of LED emission can be leveraged for thinner backlight designs. Moreover, choosing different material compositions allows the angular properties to be manipulated further. We proved this idea in the experiment by fabricating passive polymer-dispersed liquid crystal (PDLC) films with a high-quality vertical alignment of LCs. The critical challenge during the films' realization was figuring out how to achieve that alignment, which we did by sweeping the material composition and applying a UV curing condition.

We further engineered the passive PDLC systems' material composition such that normal incidence showed high transmittance and scattering became strong at oblique incidence.3 This property can be utilized to achieve transparent displays. It's intriguing that by adjusting the material composition, we achieved opposite angular properties. This tuning knob can be a powerful tool for designing diffusers and functional films with different angular properties. *– Ziqian He*

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