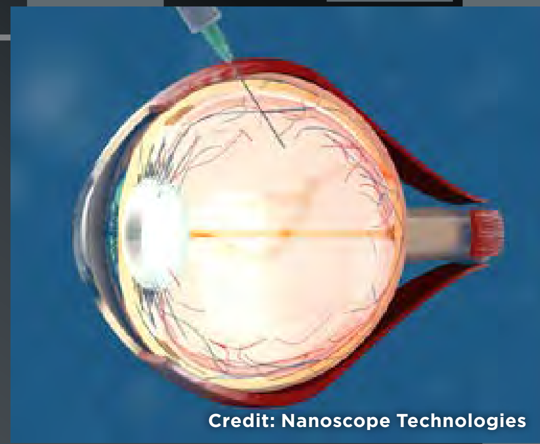
WEEKEND EDITION

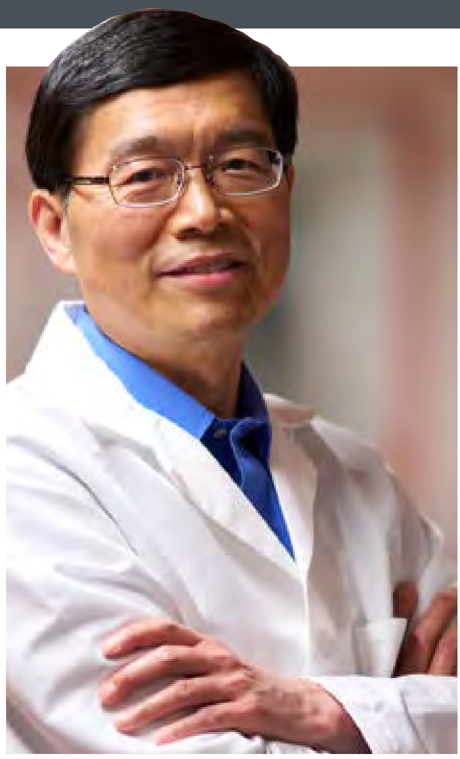
SPIE. | optics.org | JANUARY 22-23, 2022

PHOTONICS WEST BIOS SHOW DAILY

Nanoscope has vision set on optogenetics
p. 04



Credit: Nanoscope Technologies



Professor Lihong Wang, the Bren Professor of Medical Engineering and Electrical Engineering at Caltech. Credit: Caltech.

BiOS Hot Topics: imaging techniques break new ground

Advances in photoacoustic tomography, deep learning, and super-multiplex spectroscopy offer new views of cells and blood vessels.

Despite a period of severe disruption to clinical practice and supply chains, as well as to researchers' lives, biophotonics and bioimaging innovations have continued to make dramatic advances. Those breakthroughs are reflected now in the vitality of the BiOS Hot Topics session at SPIE Photonics West (Saturday, 22 January, 7:00 pm — 9:00 pm).

"The continuing pandemic has definitely slowed things right down," said Lihong Wang, the Bren Professor of Medical Engineering and Electrical Engineering at Caltech and a pioneer in photoacoustic (PA) imaging techniques. "Everything from arranging for human subjects to take part in clinical trials to the ordering of components and devices from suppliers has been disrupted. Meetings have been virtual most

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Connecting with 2022 SPIE President Anita Mahadevan-Jansen

For her 30th Photonics West meeting, Vanderbilt University biophotonics pioneer can't wait to say hello.

It's all about connecting, says 2022 SPIE President Anita Mahadevan-Jansen, Professor and Director of the Vanderbilt Biophotonics Center at Vanderbilt University. For her, attending this year's Photonics West completes something of a circle in her professional life. Or maybe it's another lap.

First off, she is happy to share with you about the interesting and rewarding road she travelled to become President of an international technical society like SPIE. It began at Photonics West:

"When I was a graduate student, Photonics West and SPIE were synonymous. I attended my first Photonics West in 1992 as a second year PhD student to present my most recent work," Mahadevan-Jansen says. "As it happened, attending my first Photonics West was one of the best decisions of my professional career. I walked into the meeting knowing just a handful of people and little else. In fact, I had walked into a new world."

This week, she'll be juggling the

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Anita Mahadevan-Jansen, SPIE President. Credit: Vanderbilt University.

DON'T MISS THESE EVENTS.

SATURDAY

BIOS EXPO
12 – 6 PM, Moscone Halls D & E

BIOS HOT TOPICS
7 – 9 PM, Rm 207/215, South Hall, (Level 2)

HEALTHCARE STARTUPS PANEL
3 – 4:30 PM, Expo Stage, Hall D/E (Exhibit Level)

SUNDAY

BIOS EXPO
10 AM - 4 PM, Moscone Halls D & E

FIRST TIMERS MEETUP
10:30 – 11 AM
2 – 2:30 PM
Membership Info Booth, (Level 1 Moscone West)

NETWORKING RECEPTION IN THE EXHIBITION
2:30 – 3:30 PM, Moscone Halls D & E

NEUROTECHNOLOGIES PLENARY
3:30 – 5:30 PM, Rm 207/215, Moscone South, Level 2

BIOS POSTER SESSION
5:30 – 7 PM, Lobby (Level 3 Moscone West)

For the full schedule, see the technical program and exhibition guide or download the SPIE Conferences app. Some events require registration.

IN THIS ISSUE.


NEW
Introducing VALO.
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At BiOS there is so much to see and so many to catch up with

After a year away, we are excited to host the community in San Francisco again. We look forward to a safe and productive week.

On behalf of the entire SPIE staff and the BiOS organizing committee, thank you for coming to San Francisco and helping us kick off 2022 and begin the return to in-person events. I am thrilled to be back doing what SPIE does best, hosting world-class conferences where engineers, scientists, students, and business professionals come together to better their careers, further their research, and grow their networks.

Of course, this year is a little different than years past. We are requiring vaccinations and masks, and we've made some changes in order to spread out activities and enhance safety. We've worked with our vendors and the City of San Francisco to make our event as safe as possible for the 10,000-plus people who have registered to attend throughout the week.

Since we last got together, much has happened and it seems the world has changed. Yet at the same time, we have been constantly reminded of the importance of connection. While photonics has enabled ways for us to connect virtually, it's been clear that we need in-person connection as well. SPIE believes strongly in the value of the in-person interactions that happen at our events and the benefits of getting smart people together to solve problems and make improvements to existing solutions. I truly hope that you are able to enjoy the company of colleagues and friends you have not seen in a while, and, despite not seeing them, are able to feel the smiles and connection behind the masks.

For us here in San Francisco this week, we have science and years of biomedical research to thank. For without it we would not have vaccines available or even the ability to test and diagnose. Many in our community have been working hard to fight the pandemic, and some of that research is being presented this week. I appreciate their work and also applaud all of our presenters this week for working hard on their research, despite the difficulties the pandemic has presented over the past two years.

This year BiOS will be a little smaller than previous years, due to many of our international community being unable to travel or attend. Despite this, we still have a full program of 45 conferences, over more than 1,300 oral and poster presentations, numerous networking events, and the BiOS Expo with 130 companies. I am sure you will all will find enough events and people to fill your schedules and then some.

Saturday night kicks off the plenary program with the always popular BiOS Hot Topics presentations featuring some of the most cutting-edge research in biophotonics. We will also honor one of the brightest minds in the field when we award the Britton Chance Biomedical Optics Award to Bruce Tromberg. On Sunday, in addition to the Neurotechnologies Plenary session highlighting brain research, there is a panel discussion on OCT featuring successful entrepreneurs and showcasing the technology's maturity 30 years in. Don't miss the other Photonics West plenaries on Monday and Tuesday, which feature talks on varied topics such as next-generation computing, laser fusion, nanomedicine, applications of ultrafast and terahertz science, and the future of quantum photonics.

Kent Rochford, SPIE CEO. Credit: SPIE

Starting on Sunday in Moscone West is our SPIE AR|VR|MR event. This co-located symposium has grown dramatically from the popular events held at Photonics West in 2018 and 2019. Your Photonics West technical badge gives you access to this exciting event, so don't miss the opportunity to hear the latest from industry leaders and sample some of the latest hardware. Early applications of this technology in medicine are quite impressive and, when leveraged by innovative biomedical engineers, the possibilities are truly endless.

Speaking of endless possibilities, another impressive emerging technology will be on display during Quantum West, a new event organized in partnership with the Quantum Economic Development Consortium (QED-C). Taking place on Wednesday, this one-day event has a particular focus on photonics in quantum and the path for building a commercial ecosystem, and promises to offer a glimpse into the future of quantum technologies.

The week offers many networking events, panels, workshops, and technical forums — there truly is something for everyone. In addition, there are many after-hours events held in conjunction with Photonics West and BiOS. Make the most of all the week has to offer, and be sure to make some new connections and learn from those around you. Have fun, but please remember to follow all health guidance around mask wearing, hand-washing, and social distancing. SPIE staff are here to help you make the most of your week, so if you have any questions or concerns, please let us know. We are easy to spot; we're the ones with name badges and smiles (behind a mask).

KENT ROCHFORD

Hot Topics

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of the time, and opportunities to travel have remained limited — for me, this SPIE Photonics West conference will effectively be my only travel."

Despite these obstacles, the volume of groundbreaking PA research being discussed at Photonics West remains impressive. Wang commented that his field has been the largest sector in its conference at the show for some years, a reflection of the substantial number of papers relating to it appearing in the primary literature, which Wang put at over 1000 annually.

The field of PA imaging for human clinical use reached a substantial milestone in 2021, with FDA approval for a platform using PA and ultrasound technologies in tandem to differentiate between benign and malignant breast lesions. The ability of PA techniques to image hemoglobin molecules, and hence map the exact location and extent of blood vessel networks, should be a major help to clinical diagnoses of breast cancer and to ensuring that those diagnoses are correct. False-positive diagnostic assessments in the US are believed to cost the healthcare system more than $2 billion each year, so the impact of PA technologies could be substantial.

"The first FDA approval for human breast imaging is a big step forward," confirmed Wang. "We now expect it to lead to a lot of commercialized applications down the road."

Seeing into the brain

With PA breast imaging translating into clinical use, researchers have turned to the next major challenge for photoacoustic technologies, the imaging of the human brain. The underlying principle behind PA techniques, whereby the transient heating effect of short laser pulses on hemoglobin molecules creates a brief ultrasonic acoustic signal that can be used to image the blood vessels, are common to both applications. But the practical concerns are quite distinct, since the intention is not simply to map blood vessels in the brain but to detect small functional hemodynamic changes taking place under different conditions — more than an order of magnitude harder to measure.

Wang's group tackled this problem by developing a platform for massively parallel functional photoacoustic computed tomography, or fPACT. In a paper published by Nature Biomedical Engineering, the Caltech team has showed that massively parallel ultrasonic transducers arranged hemispherically around the human head can produce tomographic PA images of the brain with a 10-centimeter diameter field of view, and spatial and temporal resolutions of 350 microns and 2 seconds respectively.

"We have finally been able to achieve brain imaging using functional photoacoustics that is on a par with results from BOLD — for Blood Oxygenation Level Dependent — MRI scans, which was always considered either impossible

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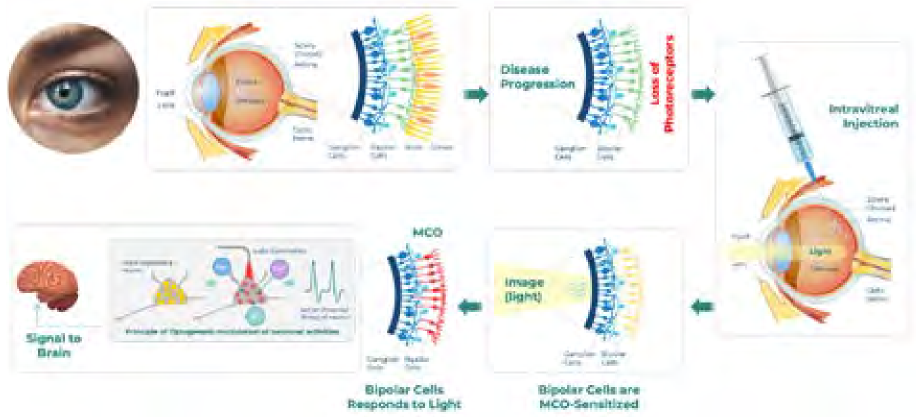
Optogenetics a promising route to vision restoration

Continuing breakthroughs in synthesis and light delivery are helping to tackle sight loss.

Loss of eyesight can be the result of many different conditions, with inherited retinal disease thought to be the most common cause of blindness in developed countries. Management has tended to involve supportive measures rather than cures, although significant surgical procedures using retinal implants of several different kinds have also been developed.

Optogenetics, in which the activity of neurons or other cells is influenced by incident light, could offer a more attractive solution. It may be possible to use an optogenetics approach to render secondary and tertiary neurons of the retina light sensitive, allowing them to effectively take the place of the degenerate or dysfunctional receptors responsible for the loss of vision.



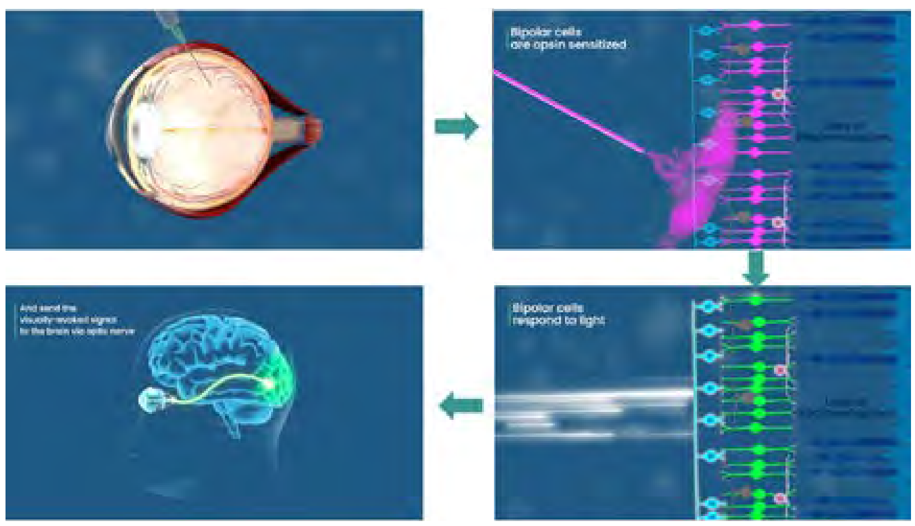
Nanoscope's MCO optogenetics therapy for vision restoration. Credit: Nanoscope Technologies.

This topic will be the subject of a session in the Optogenetics and Optical Manipulation conference at SPIE Photonics West, where Samarendra Mohanty and a team from Nanoscope will update attendees on the latest breakthroughs in the field for treatment of different retinal disorders.

"Optogenetics can make surviving neurons photosensitive, so as to replace the light-sensing function of the non-functioning photoreceptors," commented Mohanty. "To make them suitably light-sensitive, for example sensitive to a broadband ambient environment, depends on appropriate molecular engineering plus the sensitivity of the optogenetic probe.

"The opsin protein that we use, delivered using an adeno-associated virus (AAV) as a vector, has to be sensitive enough that neurons can be activated at low light levels without causing phototoxicity. Optogenetics involving molecules designed from microbes generally works as a single component system, whereas natural vision transduction in humans involves the interplay of several molecules, so the opsin kinetics has to be fast enough to allow visual processing of moving scenes," Mohanty added.

The challenge with an opsin approach is to have all the ideal characteristics, such as high sensitivity, broad spectral response and fast on-off response, present and distinguishable in one practical system. Nanoscope Technologies has developed an opsin named Multi-Characteristic Opsin, in which the unique structure — a transmembrane ion channel coupled to a ligand and enhancer — is said to lead to a distinct mechanism of action. The intention is to allow the dynamic range of the optogenetic vision restoration to approach that of the several complementary mechanisms used in a natural eye.



Optogenetic approach does not require the use of any intensifying goggles. Credit: Nanoscope Technologies.

"Another issue relates to the delivery of opsin so as to achieve high transduction in target cells without causing inflammation," said Mohanty. "Our high dose AAV vector has shown limited and well controlled inflammation over a long period, while other viral vectors at high dose may lead to long-term adverse effects. Therefore it needs to be rigorously studied and controlled," Mohanty said.

Challenges being tackled

Other approaches to vision restoration can employ a combination of an opsin and an external device. While the optogenetic approach being taken by Nanoscope Technologies does not require the use of any intensifying goggles, instead exploiting the bespoke properties of the opsin, alternative methods can employ eyewear as part of combined optical platforms intended to capture an external scene with a camera and relay it to the retina as a scanning light beam. In these combination therapy approaches, control of the delivered light's pulse and intensity is essential, often exploiting current photonics technologies such as MEMS devices, sensors and image processing algorithms to enhance the overall performance.

"Some versions of these therapies use light intensifying goggles, and others use smart goggles that transform the light pattern, conditioning it as would normally have happened in the upstream retinal circuit," commented Ehud Isacoff from the University of California, Berkeley, who will discuss the use of rod and cone opsin for optogenetic vision restoration during the conference.

"We need a system that is sensitive enough to work in room light and on standard computer displays, one that provides high acuity, and is fast enough to prevent blurring when subject or surround are in motion. And gene delivery must be across as much of the retina as possible while also selective for a cell type that is densely represented, in order to provide acuity," said Isacoff.

In addition, if photochemicals are used then they must demonstrate long-lasting slow release to minimize frequency of injection. The overall vision restoration system must be capable of being switched off if it proves to have an undesired effect, and ideally should be upgradable. "The list of challenges is daunting," commented Isacoff. "But we are getting there. Many boxes have already been checked, and we have cleared a path to the rest."

Clinically meaningful vision improvements

The hurdle for combination therapy using optical devices alongside opsin, according to Samarendra Mohanty, is to make sure that the phototoxicity over prolonged use is limited. A further challenge is to match the projected simulation beam with the opsin-transduced cells in the retina, which can be patchy or arranged in a ring format. The system may even need to track eye movement and simultaneously reposition the scanning beam with respect to the transduced areas of the retina.

In 2021, Nanoscope released results from a clinical trial in which the company's optogenetic gene therapy restored clinically meaningful vision to 11 patients blinded by retinitis pigmentosa. These results represented the first clinically meaningful functional improvement achieved by optogenetic therapy, according to the company, with further positive results expected to follow.

"We are in a late-stage clinical development program, a multi-center double-masked randomized trial in US, with very exciting data that should expedite bringing the therapy to patients," noted the company at the time. "With our Multi-Characteristic Opsin and viral/non-viral delivery platforms, we hope to address a wide patient population with severely degenerated or partially-degenerated retina."

Alongside this progress in restoring vision to those who have lost it, optogenetics could also address patients with a partially degenerated retina, tackling geographic atrophy in dry AMD and thus addressing another widely encountered disease. This will require localization of the opsin delivery to the atrophic areas only.

"We have developed an OCT-guided optical non-viral delivery approach to deliver opsin-encoding genes to target areas of the retina," commented Mohanty. "This eliminates the inflammation that can arise from using viral capsids, and also allows us to re-dose the subject in the same and newly evolved atrophic areas in these progressive retinal degenerative diseases, or deliver an improved opsin."

TIM HAYES

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Anita Mahadevan-Jansen

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responsibilities of SPIE President with being PI, author and mentor to her co-authors and research team. They have no doubt practiced presentations and come up with a plan about how to tackle the many demands of the week.

"Over the last few years, my ability to attend the technical sessions and exhibit hall has been limited by the committee meetings that I need to attend. Add to that meetings with collaborators and old friends and the week flies by. So we have a system — we look through the program to identify talks of interest and companies to talk to and then divvy these up amongst my group. We then have a post-meeting pow-wow back at Vanderbilt to catch up.

"Now I usually attend every one of my team's presentations — but I have had to warn my students that this year, I may just not be able to attend. So they have already practiced and are ready. And my Vanderbilt faculty colleagues will be there to support them in my stead if needed. Besides, the BiOS community is so supportive that I am not worried about them. I know they will have a productive time."

Despite the busy schedule, she still insists that people come up and introduce themselves and engage with her on how SPIE can can help their career.

Openness to others is an approach that has served her — and SPIE — well. She says it harks back to her first Photonics West meeting and the great feedback she received on her presentation. "But it was everything else that captivated me. As a shy young woman from India, I was not comfortable talking to strangers. And yet there I was talking to people from all over the world."

Growing up in India, she says, "I had always wanted to go into medicine but missed the required grades by one point. I didn't know what to do next, but I was good at physics, so pursued an undergraduate degree in physics and mathematics at the University of Bombay-Mumbai with an attitude of not wanting to be there. Then I met Professor S. B. Patel, my Nuclear and Laser Physics Professor and lifelong mentor, who suggested that I should consider bringing physics and medicine together. He introduced me to biomedical engineering and optics and turned my professional life around."

Next, she moved to the University of Texas-Austin to do a PhD in Biomedical Engineering with Professor Rebecca Richards-Kortum.

"She introduced me to optical spectroscopy and its application for the diagnosis of cervical pre-cancer," Mahadevan-Jansen says. "While I started with fluorescence spectroscopy, I quickly became convinced this might not be the answer to solve this problem and switched to Raman spectroscopy. I soon discovered that signals from the optical fibers interfered with tissue measurements, so designed a novel probe that could filter these spurious signals and detect tissue. Each measurement took 90 seconds instead of today's two seconds but building a system that could collect Raman signals *in vivo* was the highlight of my PhD and convinced me to continue this area of research."

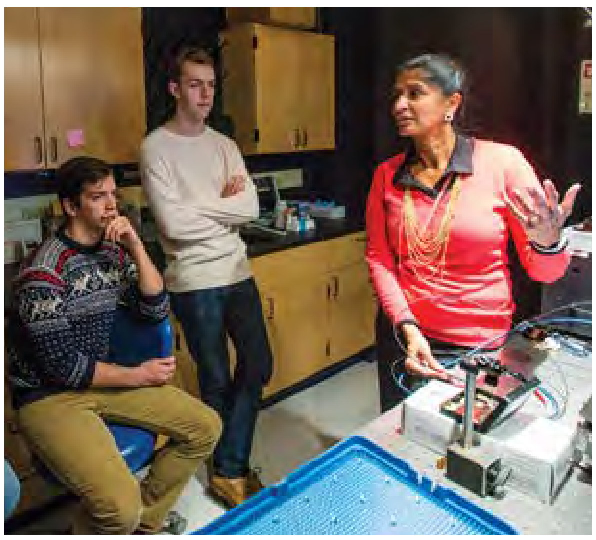
Today, Mahadevan-Jansen's interdisciplinary research at Vanderbilt seeks to use optical technologies to solve a wide array of medical problems. In fact, she says, hers is an entirely problem-based approach in which she first seeks to understand the problem and then find the best light-based technique to solve it.

Recent work in her laboratory only begins to show how her method of inquiry has yielded astonishing results: using a very strong near-IR autofluorescence signal to locate the parathyroid glands in complex neck surgery; Raman spectroscopy to find breast cancer margins, detect inflammatory bowel disease, and early throat cancers. And, she has been exploring, with neurosurgeon colleagues, the use of pulsed infrared lasers for infrared nerve stimulation. The approach might have applications for treating cerebral palsy and/or guiding surgery in which nerves must be selectively cut to minimize loss of function.

"Interdisciplinarity is directly responsible for my success, but so is making connections with people and accepting help," Mahadevan-Jansen says. "If it wasn't for my mentors, many of whom I met at my first few SPIE meetings, it would have been difficult to achieve everything that I have done. I encourage everyone, first-timers and more experienced attendees to seek the mentors and role models — SPIE is a huge resource here.

"The conference showed me the breadth and depth of what light can do, and the networking was invaluable," the SPIE President says.

"'Connecting Minds. Advancing Light.' is SPIE's tag line. And the former is exactly what I experienced at my first Photonics West. Photonics West 2022 will be my 30th! Along the way, I have built my career in biophotonics and taken every opportunity for professional development that SPIE offers," Mahadevan-Jansen says. "I have presented papers, received an SPIE Travel Grant, attended Photonics Europe, organized a conference session, become a Lifetime Member of SPIE (it makes sense!), served on the SPIE BiOS conference program committee, started a new biomedical conference, became part of the group today known as Women in Optics, become an SPIE Fellow, and I made numerous friends who I meet each year at Photonics West."



Anita Mahadevan-Jansen, SPIE President with students.
Credit: Vanderbilt University.

In time, she says, she got to know the SPIE staff and started to understand that there was more to SPIE than conferences. To learn more, she served on a few SPIE committees to help guide the Society.

"Next thing I knew, I was elected to the Board of Directors, and with the help of all those friends and Members' votes, I was elected SPIE President. What a journey!"

She acknowledges the ongoing impact of COVID-19, but quickly adds: "We are engineers, and scientists, and creative thinkers. But ultimately, we are people who like to and need to connect with people. And as I step into the

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CAREER HUB

Moscone West, Career Hub (Level 1)

Gain insights and tips to help advance your career and workplace satisfaction. Hone valuable job skills and focus on career development at these informative and engaging events. Build your schedule and don't miss opportunities to make valuable connections.

Professional development events on the Career Hub Stage

How to Network When You Hate Networking

23 January 2022 • 1:30 PM–4:30 PM | Moscone West, Career Hub Stage (Level 1)

Open to SPIE Members only. Speaker David Giltner leads us through this workshop on understanding the critical importance of networking and how to make the most of your networking opportunities.

Designing Your Own Career Path in the Private Sector

24 January 2022 • 9:00 AM–12:00 PM | Moscone West, Career Hub Stage (Level 1)

Not all career trajectories follow a traditional path. Speaker David Giltner's workshop on designing private sector career paths will help you create a future you can be excited about. Open to SPIE Members.

Essential Skills for a Career in Industry

24 January 2022 • 1:30 PM–4:30 PM | Moscone West, Career Hub Stage (Level 1)

Open to SPIE Members only. In this workshop, speaker David Giltner walks us through the vital components of a successful career in industry, and how it differs from that of academia.

Equity, Diversity and Inclusion Presentation

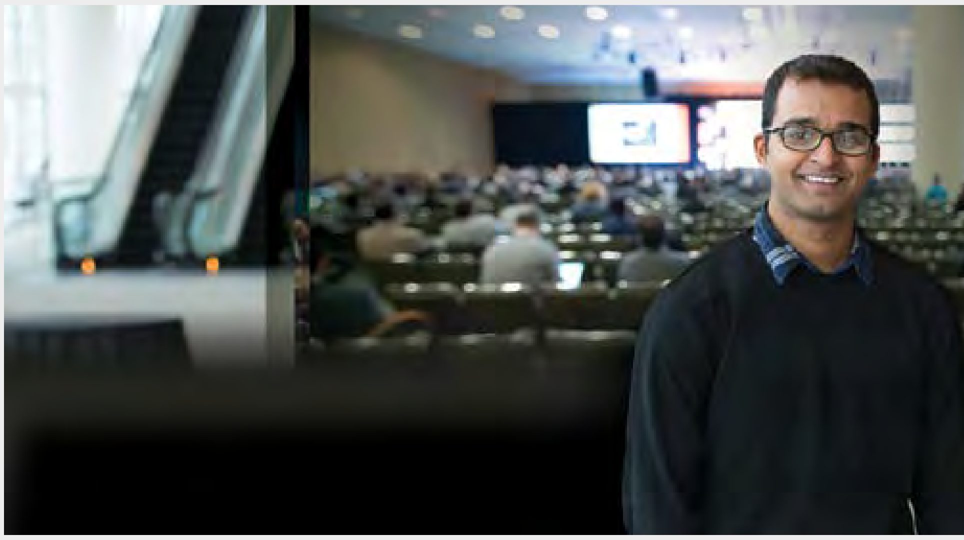
24 January 2022 • 5:00 PM–6:30 PM | Moscone West, Career Hub Stage (Level 1)

Join us for a thought-provoking presentation from Dr. Kayla Lee and stay after to discuss topics with your colleagues during the reception.

Resumes to Interviews: Strategies for a Successful Job Search

25 January 2022 • 1:00 PM–3:00 PM | Moscone West, Career Hub Stage (Level 1)

Open to SPIE Members. Whether you are about to graduate or a professional looking for a new role, join us for this vital workshop on resume and interview must-dos and don'ts!



Career Networking Mixer

25 January 2022 • 4:00 PM–5:00 PM | Moscone West, Lobby, adjacent to Job Fair

A casual mixer to chat with recruiters from the Job Fair and other industry and academia professionals about careers in the optics industry.

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Navigating Career Growth in a Changing Optics Industry: Challenges and Opportunities for Diverse Voices

25 January 2022 • 4:30 PM–5:15 PM | Moscone West, Career Hub Stage (Level 1)

Join us for a panel discussion on the future of equity, diversity and inclusion in the workforce as well as hiring practices in the optics and photonics sectors.

Grant Writing from the Ground Up

26 January 2022 • 9:00 AM–12:00 PM | Moscone West, Career Hub Stage (Level 1)

Open to all. Author and speaker, Damon Diehl, leads us through this critical workshop on successful grant writing.

Charting a Course in the Photonics Industry

26 January 2022 • 2:00 PM–3:00 PM | Moscone West, Career Hub Stage (Level 1)

Open to all. Come hear expert panelists discuss the wide array of career paths in the optics and photonics industry, so you can make informed decisions for your future.

Services from SPIE to get your job search on track

Free Professional Headshots

24 January 2022 • 10:00 AM–5:00 PM | Moscone West, Lobby (Level 1)

25 January 2022 • 10:00 AM–5:00 PM | Moscone North/South, Hall F (Exhibit Level) and Moscone West, Lobby (Level 1)

26 January 2022 • 10:00 AM–5:00 PM | Moscone North/South, Hall F (Exhibit Level) • 10:00 AM–3:00 PM | Moscone West, Lobby (Level 1)

Get your free professional portrait taken during SPIE Photonics West.

Resume Review

24 January 2022 • 10:00 AM–4:00 PM

25 January 2022 • 10:00 AM–4:00 PM

26 January 2022 • 10:00 AM–2:00 PM

Moscone West, Career Hub (Level 1)

Bring your resume to receive tactical tips and tricks from a professional resume reviewer.

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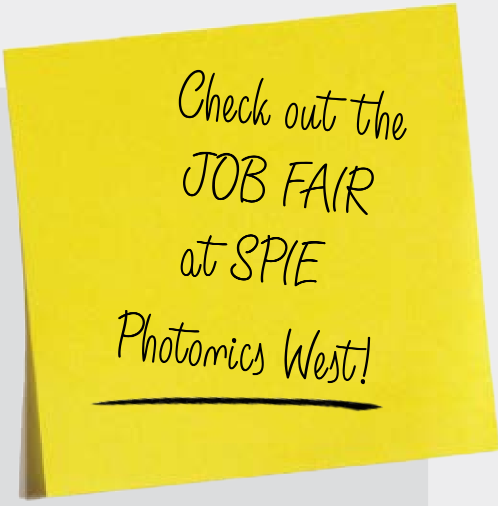

SPIE Job Fair

Tuesday 25 January • 10:00 AM–5:00 PM

Wednesday 26 January • 10:00 AM–5:00 PM

Moscone West, Lobby Level

Speak with hiring companies

Connect with company representatives looking for qualified candidates. Hone your interviewing skills, prepare your resume, and explore job opportunities in the photonics industry.

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Visit the SPIE Mobile event app or the website for current list of Job Fair exhibitors

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spiecareercenter.org

Ivan Kosik wins SPIE-Franz Hillenkamp Postdoc Fellowship

The $75,000 annual award will support Kosik's research into developing an innovative treatment for prostate cancer.

Ivan Kosik using a diffuse optical tomography system to map out the laser fluence intensity in a 3D imaging volume. Credit: University of Toronto.

Since 2018, SPIE Senior Member Gabriela Apiou — a translational scientist, assistant professor at Harvard Medical School, director of the Wellman Center for Photomedicine's Translational Research Core, and director of Strategic Alliances at the Mass General Research Institute — has led a successful pilot program known as the SPIE-Franz Hillenkamp Postdoctoral Fellowship in Problem-Driven Biomedical Optics and Analytics.

The $75,000 fellowship supports interdisciplinary problem-driven research and provides opportunities for translating new technologies into clinical practice in order to improve human health and stems from distinguished roots. The recognition honors German scientist Franz Hillenkamp's career as a researcher, teacher, and mentor who had an enormous international impact: he introduced the first medical laser applications laboratory and marked the genesis of translational research in biomedical optics in Europe in the 1970s.

Today's SPIE-Franz Hillenkamp Fellowships reflect not just the translational aspects of Hillenkamp's research but his far-reaching global impact as well, an achievement highlighted by the multiple countries represented among the recipients thus far.

Within the structure of the fellowship itself, the focus is 80 percent on research and 20 percent on addressing how to bring those research outcomes to patients — translating scientific and technological research into real-life clinical applications, into industry, and creating accessibility for patients. Ideally, as well, the fellowship program is a way of building a new generation of collaborative faculty who will continue to bring translational research-generated solutions to bear on real-world challenges. "Hillenkamp Fellows are potential future faculty," Apiou told SPIE last year. "At this early stage they are in academia, but they also learn how to reach out to their industry peers so that they can solve problems together."

One of the earliest SPIE-Franz Hillenkamp winners, Haley Marks, has already incorporated that teaching element into her career arc. Marks, who worked on SMART (Sensing, Monitoring, And Release of Therapeutics), a luminescent oxygen-sensing, drug-releasing bandage offering quantitative feedback for clinical guidance, pursued her Hillenkamp research under the supervision of Apiou and of Conor Evans at the Wellman Center for Photomedicine. Since the conclusion of her fellowship, Marks has been promoted to Instructor in the Department of Dermatology at Harvard Medical School and Staff Research Scientist at Massachusetts General Hospital, where a clinical trial using the oxygen-sensing hydrogel developed for her Hillenkamp fellowship is currently underway. Most recently she has been exploring FLIM and Raman imaging methodologies for visualizing the efficacy of laser-assisted drug delivery.

Jan Philip Kolb, a second SPIE-Hillenkamp winner alongside Marks in 2018, pursued his work at Lübeck's Medical Laser Center on fiber-based nanosecond two-photon microscopy (nsTPM) which is translatable into clinical applications such as pathology and endoscopy. Since the completion of his fellowship, Kolb has continued working at the Medical Laser Center and University of Lübeck on his original project which has led to a successful EXIST Forschungstransfer, a research transfer program offered by the German Federal Ministry for Economic Affairs and Energy and the European Social Fund that facilitates outstanding research-based startup projects and spinoffs associated with complex development work. Kolb's EXIST project — of which he is project manager — is in place to continue until September 2023.

A 2019 Hillenkamp winner, Andreas Wartak, worked with Guillermo J. Tearney and Apiou to target an earlier, cheaper, less invasive diagnosis of eosinophilic esophagitis, a poorly understood allergic inflammatory condition of the esophagus. After a total of almost three years as a postdoc in Tearney's lab at the Wellman Center for Photomedicine at Mass General Hospital, Wartak returned to his home to Austria where he now holds a senior postdoctoral position in the field of super-resolution microscopy at the Institute of Science and Technology. His focus in the new lab is on developing the highest resolution optical imaging technologies for biology and neuroscience.

Also a 2019 winner, Jie Hui conducted his research under the supervision of Ji-Xin Cheng at the Boston University Photonics Center and Tianhong Dai at the Wellman Center for Photomedicine. His work focused on a light-based approach to treat MRSA-caused diseases. He is currently a Research Fellow at Wellman Center for Photomedicine at Massachusetts General Hospital and Harvard Medical School where he continues his work on developing novel waveguides/devices for drug-free phototherapy of bacterial wound infections.

The 2020 Hillenkamp Fellow, Fernando Zvietcovich, whose fellowship research with Kirill Larin and Michael Twa at the University of Houston's Biomedical Optics Lab, was on translating a novel biophotonics-based optical coherence elastography method into *in vivo* clinical use, is currently a postdoctoral fellow at the VioBio Laboratory with the Institute of Optics at The Spanish National Research Council. There since June of 2021, Zvietcovich is working under the direction of Professor Susana Marcos within the framework of the European Horizon project IMCUSTOMEYE. His focus is on developing a clinical biomarker capable of detecting pre-clinical stages of keratoconus in human patients using wave-based optical coherence elastography.

Nitesh Katta, who is utilizing the 2021 SPIE-Hillenkamp Fellowship as we speak, is pursuing research on his project, "a cold laser wire (CLW) for true-lumen crossing of tortuous coronary arteries with calcified chronic total occlusions (CTOs)." Katta's research, conducted in conjunction with Thomas Milner and Marc Feldman at the Beckman Laser Institute and Medical Clinic, is building on a challenge Katta discovered during his doctoral work: in recognizing an unmet need for piercing calcified material in performing true-lumen percutaneous coronary intervention (PCI) of chronic total occlusions (CTOs), Katta, together with his then-doctoral mentors Milner and Feldman, invented intravascular cooling and guidance methodologies for achieving true-lumen crossing in CTOs using the cold laser wire. Katta's aim is to bring this research into the clinical setting, addressing an urgent clinical need of a tool for safe PCI in patients suffering with CTOs.

This year's winner, announced in December, is Ivan Kosik. His research, conducted with Professor Brian Wilson at the University of Toronto, will develop a new form of transrectal photoacoustic tomography (TR-PAT) in combination with thermal enhancement using multifunctional porphyrin-lipid nanoparticles. The goal is to create a safe, effective photothermal therapy (PPT) treatment platform that eliminates the necessity for intraoperative MRI.

"Being awarded the 2022 SPIE Hillenkamp Fellowship represents a high point in my career to date," Kosik told SPIE on learning that he was the recipient of this year's fellowship. "The award will give me the opportunity to expand my work on applying photonics to guide cancer treatment. I have lost loved ones to cancer, so this has personal as well as professional impact for me."

From the personal to the professional, certain things remain integral to all SPIE Hillenkamp Fellows: a shared commitment to addressing the core aspects of translational research from bench to bedside and a determined dedication to applying their endeavors in labs, hospitals, and institutes across the world.

DANEET STEFFENS

Meet the SPIE Gold Medal winner Michael Berns

Known as "the father of laser microbeams," he has followed a path guided by mentors.

Throughout a lifetime of accomplishments that include achieving scientific firsts, philanthropy, painting, and authoring international spy thrillers, Michael Berns notes the mentors his had along his journey.

Perhaps the first in his life was his grandfather, an inventor who raised Berns on Long Island, New York. Described as a "very gentle, kind man," Bern's grandfather had come from "the old country" at age 14, and the family never knew more than that about his past.

"He became a clothing designer for Treo (a New York clothing company) and had a wall with all his patents," says Berns. "The one that always stuck with me was the "stretch girdle" that resembled an American Flag. He liked to tell the story of being sued by the DAR for desecration of the American flag. They were all pulled off the market and distributed as mementos to our extended family." Berns has one of the samples on a bright metal mannequin on display in his home, along with several of his grandfather's patents. "The design for that girdle ended up as part of an exhibit in the Museum of Modern Art in NYC as an example of 1960s 'pop' art."

"My grandpa was a real tinkerer with gadgets and that is where I first honed my technical skills," says Berns. "Whenever some new technology came out, he was interested. We went up on the roof of our apartment building with a pair of binoculars to see the Russian Sputnik fly over." The satellite itself was barely visible, but its R-7 core stage was visible as a bright light moving across the sky.

Today, Berns is widely known as the "the father of laser microbeams," thanks, in part, to his groundbreaking work in delineating how the laser can perform subcellular surgery on chromosomes. With a focus on light interactions with cells and tissues, his research works to address biomedical problems such as nervous-system repair at the single-cell level, a laser-leveraging technique that extends to degenerative diseases such as Parkinson's, Alzheimer's, and Huntington's.

A professor of biomedical engineering, surgery, and developmental and cell biology at the University of California, Irvine (UCI), and cofounder and founding director of the Beckman Laser Institute & Medical Clinic, Berns is receiving SPIE's top award in recognition of his work in bioengineering research and his distinguished career that has brought together engineers, physicists, biologists, and physicians to collaborate on ground-breaking discoveries and innovations.

Changing course

Berns "discovered" lasers as a graduate student at Cornell University in 1964. One of the first of his fellow students to experiment with lasers, he used a ruby laser as a micro-surgical device to study the development and evolution of the leg-building region of a millipede. "Actually, it was a complete failure," says Berns. "But the lesson for me was that just because something didn't work in one type of experiment, that didn't mean it wasn't useful for something else."

After finishing his PhD at Cornell, he headed out to Pasadena, California, to use lasers to manipulate single cells. "I was fortunate to have a post-doc mentor in Donald Rounds who basically said, 'there's the lab, have fun.' And I did."

Part of the fun included becoming the first to perform subcellular surgery of chromosomes (*Nature* 1969), followed by a 1970 *Scientific American* article, "Cell Surgery by Laser." He was first to perform laser nanosurgery in a cell with the goal of cell survival and subsequent cloning and he introduced the use of real-time digital image processing in biology, widely used in microscopy (*Science* 1981).

Berns credits the *Nature* and *Scientific American* articles with helping him land his first academic job as an assistant professor in the department of zoology at the University of Michigan, Ann Arbor. He had always loved animals, so his career goal since childhood was become a veterinarian. But as seems to be a theme in his life, he got sidetracked by another influential mentor.

"It was my high school biology teacher, Robert Abrams, who asked me if I would help him measure tumors on mice after school at a research lab on Long Island," says Berns. "He's really the one who first introduced me to laboratory research and the scientific method. I read my first *Scientific American* magazine as part of his advanced biology class and decided that my goal was to someday write an article for that magazine."

As a postdoc and professor, Berns wasn't really interested in the clinical/medical uses of lasers, but he took notice that at key conferences the utility of lasers was often being discussed. "At some point I realized that getting big grants was more likely if I was investigating laser use for a disease," says Berns. "This led me to cancer and the use of light-activated dyes for the diagnosis and treatment of human and animal cancers — like in pet dogs, cats, and snakes."

Lighting the LAMP

In 1979, Berns was awarded a prestigious NIH Biotechnology Resource grant to establish what he called the LAser Microbeam Program (LAMP) — a laboratory for laser microscopy using sophisticated continuous-wave (CW) and short-pulsed picosecond lasers.

After spending a year building the LAMP system — an instrument with a tunable wavelength laser microbeam and a wide range of energies and exposure durations — Berns sent out invitations to every CEO of medical and biotech companies in Orange County, California. To his surprise, Arnold Beckman (then 80 years old and still running Beckman Instruments in Fullerton, California), came through his door.

Michael Berns was first to perform laser nanosurgery in a cell with the goal of cell survival and subsequent cloning. Credit: UCI.

"He was fascinated with lasers and how I was focusing them inside of cells to perform sub-cellular surgery, says Berns. "This started a friendship that continued until he passed away at the age of 104. After a year or so, I proposed that he support the construction of the Beckman Laser Institute and Medical Clinic (BLIMC), a facility where basic scientists and clinicians would rub shoulders in the same building."

The institute and clinic became the first interdisciplinary program that combined engineers, physicists, biologists, and physicians under the same roof, leading to intense interactions that resulted in over 52 inventions, including biomedical devices now used worldwide.

Giving back

Currently, Berns is leading two research projects: one funded by the BLIMC non-profit corporation to develop an internet-based robotic laser scissors-tweezers microscope (RoboLase), and a second on nervous system repair following laser damage, funded by the Air Force Office of Scientific Research. But he's also involved in community and philanthropic activities — becoming an influential mentor as the mentors in his life did for him. While director of UC Irvine's BLIMC, Berns garnered more than $63 million in extramural grants and $40 million in philanthropic support.

Berns has served on the editorial board of the SPIE *Journal of Biomedical Optics* for more than ten years, where he promoted the journal to the wider scientific community encouraging them to publish their work in this journal, making it an essential "go to" journal for new, interesting results in biomedical optics. He has chaired a session at the SPIE Conference on Optical Trapping and Optical Micromanipulation at SPIE Optics + Photonics for the past 14 years, giving numerous keynote and invited talks.

"I have always been involved with community activities," says Berns. "While raising our kids in Orange County, I was on the Planning Commission of San Juan Capistrano, and now I'm trying to motivate our university community to get behind our ecological preserve by offering to match any gifts. I have been fortunate to have had personal relationships with such pillars of our society as Arnold Beckman and David Packard. I learned from them that giving back to the society that made our careers successful is uniquely rewarding."

He adds that "extending the use of optical technologies to high school students is very rewarding especially when their eyes light up in amazement. It reminds me of my own high school experience with my biology teacher, Mr. Abrams."

KAREN THOMAS

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or very hard to do," commented Lihong Wang. "Doing so required the signal-to-noise ratio to be carefully controlled, so that the small functional changes relative to baseline activity that we are looking for could be seen. The image quality has to be very high in order to see that kind of small change, and we finally pulled that off."

PA could ultimately prove to be better than traditional MRI imaging in certain brain imaging applications. It offers more contrast mechanisms, since fPACT can derive an imaging signal from both oxy- and deoxy-hemoglobin. PA is also faster in response, exhibits lower background signal levels, and should be drastically less expensive than current 7-Tesla MRI systems, which can carry a price tag of $6 million.

It should also lead to a more comfortable examination procedure for patients. Caltech's fPACT platform employed four hemispheric ultrasonic transducer arrays of 256 elements each, positioned around the patient's head to record the signals generated. Although this detector array presented some logistical challenges of its own, the environment for the patient is considerably more open and less claustrophobic than the experience of being inside a standard MRI examination.

Improvements to the sensing methodology are one topic of current research aimed at improving fPACT performance further, with researchers examining whether optical acoustic sensors might have advantages over conventional piezoelectric sensors. Such optical devices are likely to allow area-independent sensitivity, although they may also introduce new multiplexing considerations.

Field-of-view, imaging speed, and penetration depth are also recognized hurdles for fPACT developers to tackle. For its clinical trial, Caltech was able to apply fPACT to patients who had undergone a hemicraniectomy procedure, in which a large flap of the skull is removed as part of treatment for traumatic brain injury. Although this made access to the brain tissues more straightforward for the fPACT platform, real-world *in vivo* applications of the technique will need to overcome the barrier to imaging presented by the intact human skull.

"Safety limits regulate the energy per area that you can deliver to a human patient, so the instrumental platforms we develop must stay within those guidelines," noted Lihong

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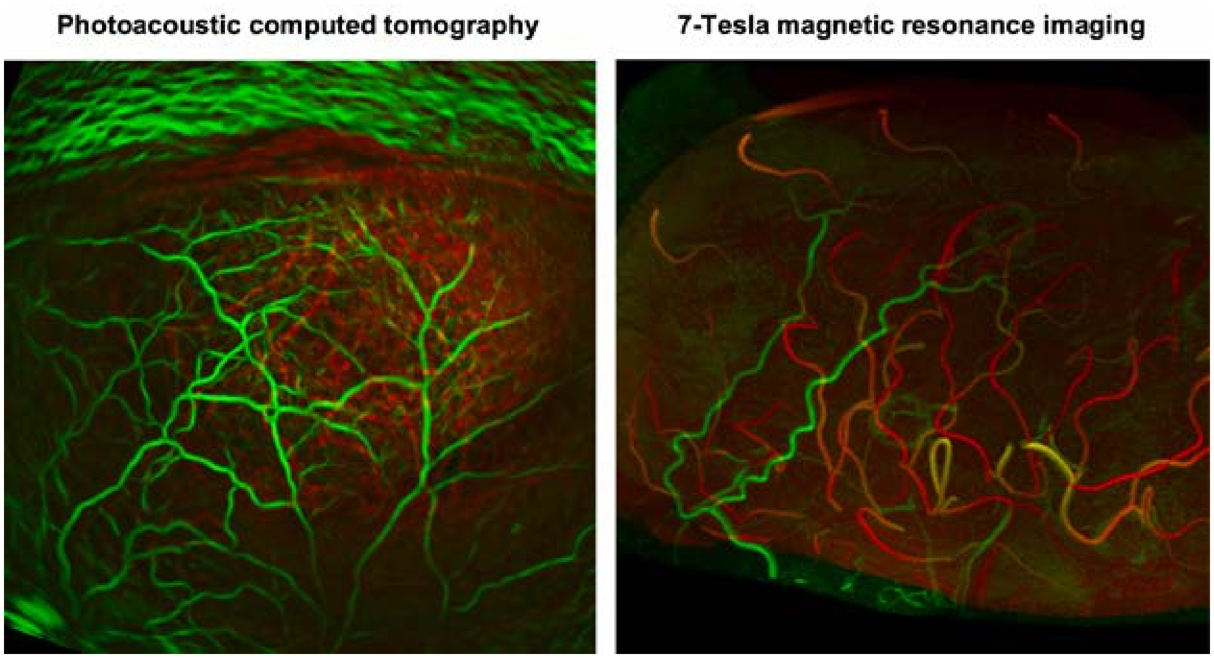


Massively parallel functional photoacoustic computed tomography of the human brain, from Nature Biomedical Engineering (2021) via Lihong Wang.

Quantum microscope enhances sensitivity — without causing photodamage

A promising option for new types of microscopy that can inspect live or delicate samples in greater detail is to use quantum light rather than the highly energetic particles in X-ray or electron microscopy that can damage sensitive cells.

European researchers from ICFO, Politecnico di Milano, Micro Photon Devices, Fraunhofer IOF — partners in the "Q-MIC project" — have developed a quantum-enhanced microscope. Since 2018, the European project Q-MIC (q-mic.eu) has been working to develop quantum imaging for microscopy of highly sensitive samples. The results of their work have now been gathered in a recent paper published in *Science Advances* (science.org/doi/10.1126/sciadv.abj2155).

Q-MIC researcher Robin Camphausen. Credit: Q-MIC / ICFO.

Alvaro Cuevas. Credit: Q-MIC / ICFO.

The team of researchers includes Barcelona, Spain-based research center ICFO scientists Robin Camphausen, Alvaro Cuevas, Luc Duempelmann, Roland Terborg, Ewelina Wajs, led by ICREA Prof. at ICFO Valerio Pruneri, in collaboration with the project partners Simone Tisa and Alessandro Ruggeri from Micro Photon Devices (MPD), Iris Cusini, from Politecnico di Milano and Fabian Steinlechner, from Fraunhofer IOF.

They have reported on the results obtained from the new quantum-enhanced microscope that the whole consortium has developed. The scope uses very low intensity levels of light to image large areas of samples, with a higher sensitivity and resolution, compared to classical microscopes.

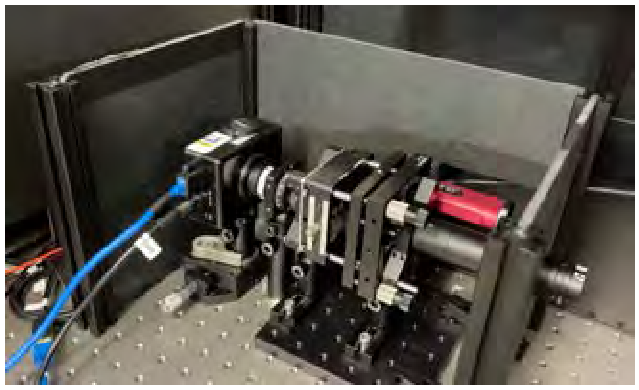
As Robin Camphausen explains, "the Q-MIC microscope is unique in the sense that it has been designed to actually illuminate the sample using quantum light. Instead of normal light, where many unordered photons reach the sample, our quantum source uses pairs of entangled photons and sends them in small numbers to hit the sample and retrieve information in a more detailed and specific way."

Generally, using low levels of light to avoid damage unfortunately increases the amount of background noise in the measurement and hampers all details and sharpness you can get in an image. "It's just like when the first mobile phone cameras were launched into market. If you tried taking a picture at night, the sharpness of the picture was really bad because not enough photons would be captured to form a clear image so the pixels would look undefined, and also the background lights disturbed the quality of the image," says Camphausen.

This issue is bypassed with this microscope, because it uses interference patterns of entangled photons to actually reconstruct the image of a sample. Specifically, it integrates a quantum source, which generates space-polarization hyper-entangled "NooN state" photons, a large field of view lens-free interference microscope and a single photon avalanche diode (SPAD) array camera.

"The device we built and the technique we have developed actually uses the entanglement of photons to enhance the interference patterns obtained in the imaging process, and because of this quantum effect, we are able to reduce the noise level and increase the sensitivity of the measurements by more than 25% when compared to classical measurements," comments fellow researcher Alvaro Cuevas, a co-author of the *Science Advances* paper.

In doing so, what the camera registers are not optical intensities nor single photon counts, but actually two-photon coincidences across the entire field of view. When the pairs of photons go through the device, a set of Savart plates divides them into two paths, and guides them to the sample. If the sample is flat, the path of the photons will be the same, but if the sample has different thicknesses, the individual paths of the photons change and an interference pattern is created on the detector. By repeating this process of sending in photons, the researchers obtain an interference pattern image without the need of a pixel-to-pixel scanning system. And with the help of mathematical algorithms, they can reconstruct the image to find more details in the sample itself.



The QMIC quantum-enhanced large FoV phase imager integrates: a source of space-polarization hyperentangled "NOON" states; a large FoV lens-free interferometric microscope; and a SPAD array camera, with computational methods for coincidence imaging and holographic phase retrieval. Credit: Q-MIC / ICFO.

Testing with Protein A

To confirm such improvement in the results, the researchers took a standard diagnostic solution made of a sample of Protein A, a reference material used as a calibration tool. The proteins were deposited onto a glass slide, equally spaced out, and then the sample was mounted on a sample holder inside the microscope. Firstly, the sample was initially illuminated with classical light and then with quantum light; secondly, the respective interference patterns were obtained, and, finally, the images reconstructed. What they saw is that the quantum technique retrieves a much smoother image when compared to the classical one.

Even though the quantum image was reconstructed using fewer photons than the classical one, the smoothness of the image was much cleaner. Cuevas summarizes this as follows: "when we refer to smoothness, it means that if you take an image of a flat surface with low intensity classical light, the level of noise seen in the image is due to the randomness in the level of the data, basically the noise that comes from all the discrete disordered photons that constitute this type of light. With quantum light, the noise level and thus the randomness is reduced, so you get better information about sharp edges, which, in the end, is essential for recognizing concentrations, depths, heights of the samples."

The team says the results are "very promising and enable a completely new way of implementing quantum imaging in everyday sensing and imaging technology." As Valerio Pruneri, coordinator of the project, concludes, "this innovative device has the potential to become an everyday tool used at large. It shows amazing capabilities that can definitely be exploited in several applications, ranging from material sciences, analyzing transparent surfaces for quality assurance in flexible electronics, to quantum cryptography for secure communications or ultra-sensitive imaging of micro-organisms, viruses, and molecules, just to mention a few. Quantum-enhanced microscopy could become a game-changer in the world of microscopy."

MATTHEW PEACH

Anita Mahadevan-Jansen

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role of SPIE President, I want to help you connect. I consider myself the 'Ambassador for SPIE,' and over the course of this year, I plan to be available to the members of the Society and to listen and learn. I would like to continue the work I helped start in equity, diversity, and inclusion."

But the question remains: How do you become the president of an international technical society—one that today touches some 250,00 people globally? "By becoming involved at every opportunity. You must also talk to people and listen, and truly care about others who are like you but also not. SPIE is about the people who have the vision of using optics and photonics to enhance our world. And it is up to you to take advantage of what the Society has to offer."

WILLIAM SCHULZ

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Wang. “Some applications might in theory suit the use of fiber bundles, which could allow some form of hand-held instrumentation; but the price you then pay is a significant cut in the deliverable energy, a lot of which is lost.”

The Caltech group expects that all these hurdles will eventually be tackled successfully, as the success of the initial human trials now allows momentum behind fPACT to build further. Many companies are now actively working on further human trials for different applications using various implementations of PA technology, according to Lihong Wang, although the timescale for commercial translation is hard to predict — and the Covid-19 pandemic has already affected any estimates of the translation schedule made in previous years.

“PA has in some respects made a slow move from original animal testing to FDA

Professor Wei Min. Credit: Columbia University.

approvals and to different human applications,” commented Wang. “So on one hand we might feel like complaining about the pace. But on the other hand, it means we know that the field of photoacoustics is not a bubble, or growing so fast that it risks a collapse. We can feel pretty safe working in this field, an extremely exciting area and one where I want to see more young people coming in and starting to participate. New graduates, new students, new postdocs — we need new blood.”

Commercializing deep learning

Aydogan Ozcan from UCLA will speak to the BiOS Hot Topics audience about progress in the application of deep learning techniques in histopathology, a topic set to transform the examination of tissue samples by eliminating the need for traditional chemical staining.

Virtual staining of unlabeled auto-fluorescence images is intended to leverage the increasing speed and computational power of current deep learning systems, which after training with suitable data can identify and delineate the cellular structures that would previously have been made visually distinct with added chemical indicators.

The UCLA group has created a “digital staining matrix”, which allows the generation and digital blending of multiple stains using a single deep neural network, by specifying which stain should be performed at the pixel level. Not only can this framework be used to create micro-structured stains, digitally staining different areas of label-free tissue with different types of stains, it can also enable these stains to be blended together in unique combinations, according to the project team.

A further breakthrough has seen the development of a deep-learning framework designed to operate on image data from reflectance confocal microscopy (RCM), which detects backscattered photons to generate greyscale images of tissue. UCLA used RCM images of excised skin tissue with and without nuclear contrast staining to train its deep convolutional neural network, until the framework was able to transform *in vivo* RCM data into virtually stained 3D microscopic images.

A commercial spin-out, Pictor Labs, has been created to bring the virtual staining technology to market, and build a cloud computing-based platform for clinicians to employ. “Our team is very excited to bring this cutting-edge academic research into the commercialization phase, and looks forward to impacting human health over the coming years,” said Aydogan Ozcan.

Beating the color barrier

Also in the BiOS Hot Topics session, Wei Min from Columbia University will describe developments in super-multiplexed optical microscopy, which exploit the nature of Raman microscopy to increase the number of colors resolvable in an individual image.

“The ‘color barrier’ in fluorescence microscopy arises from the physics,” commented Wei Min. “Fluorescence microscopy is often the method of choice for imaging biological samples because of its molecular specificity. However, fluorescence can only image two to five colors at once; the emission spectra of individual

Professor Aydogan Ozcan, of UCLA. Credit: innovate.ee.ucla.edu

colors are too broad to be distinguished in the presence of other colors.”

The Columbia team tackled this hurdle by developing novel Raman probes and coupling them with ultra-sensitive stimulated Raman scattering microscopy, an approach which has achieved “super-multiplex” vibrational imaging of a higher number of individual colors.

The original super-multiplexing breakthrough was made in 2017, when the technique exploited the narrow resonances of the spontaneous Raman microscopy probes used to detect vibrational transitions in living cells. This spectral response was thought to make detection of more individual colors possible, although the inherently weak Raman signals made many bioimaging applications impractical. The solution involved combining available fluorescent probes with a palette of bespoke triple-bond-conjugated near-infrared dyes that each displayed a single peak in the cell-silent Raman spectral window, an arrangement which allowed no fewer than 24 colors to be resolved in samples of DNA and proteins.

Although that record for the number of colors still stands for now — Wei Min believes that the ultimate usable limit will be higher, perhaps approaching 100 — recent developments from the Columbia team have focused on applying the existing technique in live cell imaging scenarios, and on the ability to make multi-parameter measurements from single cells, increasingly recognized as a key technology for understanding complex molecular and cellular functions in biological systems.

In 2021 the group devised a multiplexed Raman probe panel with sharp and mutually resolvable Raman peaks to simultaneously quantify cell surface proteins, endocytosis activities, and metabolic dynamics of an individual live cell. When coupled to whole-cell spontaneous Raman micro-spectroscopy, this technique achieved 14-plexed live-cell profiling and phenotyping under various drug perturbations, according to the project.

Further research has led to the development of methods to map the localization of multiple proteins in their native three-dimensional context, efforts that would be useful across many areas of biomedicine but which are currently hindered by both the limited multiplexing capability of fluorescence imaging and the fact that most methods for increasing multiplexity can only be applied to samples below 100 microns in thickness.

A 2021 paper from Wei Min’s group describes the development of RADIANT, a technique designed to further harness the narrow spectrum of Raman spectroscopy by combining suitable bioorthogonal Raman dyes with a solvent-based system of tissue clearing. RADIANT was used to image up to 11 targets in millimeter-thick brain slices, according to the project team, extending the imaging depth 10 to 100-fold compared to prior multiplexed protein imaging methods. By allowing the extraction of region-specific correlation networks and their topology in studies of the cerebellum, RADIANT should facilitate the exploration of the intricate 3D protein interactions in this complex area of the brain.

Such super-muliplexing breakthroughs are likely to assist in a number of other vital biological studies too, by allowing the extraction of data beyond the reach of fluorescence techniques.

“For example, accurate sub-typing of tumors will require imaging the spatial distribution of a large number of protein markers, which will also be important for precision medicine in general,” said Wei Min. “Mapping neural circuits for neuroscience will require imaging of a large number of protein markers in brain tissue.”

TIM HAYES