Spectroscopy: Introduction to the Techniques and Recent Advances

The SciX 2020 Preview and Companion Guide



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An e-book from



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Introduction Laura Bush











SERS and TERS Zachary D. Schultz

Inductively Coupled Plasma–Based Techniques (ICP-OES and ICP-MS)

Derrick Quarles Jr. and Benjamin T. Manard

Charles Mann Award Biomedical Applications of Raman Spectroscopy Over Several Decades An Interview with

Yukihiro Ozaki

Craver Award: Micro-Spatially Offset Raman Spectroscopy (Micro-SORS) for Research in the Conservation of Cultural Heritage An Interview with Claudia Conti

SAS Meggers Award Analyzing Soil and Meat with Shifted Excitation Raman Difference Spectroscopy An Interview with Kay Sowoidnich













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Raman Spectroscopy Xiaoyun (Shawn) Chen

Infrared Spectroscopy André J. Sommer

Laser-Induced Breakdown Spectroscopy Matthieu Baudelet

RSC Award: the Sir George Stokes Prize Spectroscopy for Medicine: From SERS, Laser-Induced Fluorescence, and Biosensors to Analytical Nanotools

An Interview with Tuan Vo-Dinh

SAS Strock Award Advancing Trace Elemental and Speciation Analysis with a Focus on Metrology An Interview with Heidi Goenaga-Infante

The 2020 Emerging Leader in Molecular Spectroscopy: Advancing Spectroscopy, Biotechnology, and Nanotechnology An Interview with Markita Landry

ADVANCES IN SPECTROSCOPY THE SCIX 2020 PREVIEW AND COMPANION GUIDE

The 2020 SciX conference—October 12–15, with pre-event activities already under way—will be held virtually this year. Not only is the virtual format safer for everyone during the current pandemic, but it also presents a particular opportunity for those who don't normally get to travel to the event. Right from your desk, you can listen to scientific talks from top speakers, both live and on-demand; check out posters and hear the presenters' mini-orals; and participate in meaningful networking conversations.

This e-book, prepared in collaboration with the SciX conference organization, is meant to serve both as a preview of the conference and as a companion guide during and after the event. It offers two sets of articles, for readers with different interests and needs.

The first section offers introductions to five core spectroscopy techniques:

- Raman spectroscopy
- surface enhanced Raman scattering (SERS) and tip-enhanced Raman scattering (TERS)
- Infrared spectroscopy
- Inductively coupled plasma-based techniques (ICP-OES and ICP-MS), and
- laser-induced breakdown spectroscopy (LIBS).

The second section presents the work of six spectroscopists who have won prestigious awards and will give talks at the virtual event. These articles are part of an annual series of interviews with the winners of these awards, and include:

- Prof. Yuki Ozaki of Kwansei Gakuin University in Japan, the winner of the Charles Mann Award for Applied Raman Spectroscopy, who discusses biomedical applications of Raman spectroscopy
- Prof. Tuan Vo-Dinh of Duke University, the winner of the Royal Society of Chemistry (RSC) Sir George Stokes Award, who is using a range of analytical techniques in medicine, from SERS, laser-induced fluorescence, and biosensors, to analytical nanotools
- Claudia Conti, of the Institute of Heritage Science of the Italian National Research Council (CNR), the winner of the Coblentz Society's Clara Craver Award, who is conducting research in cultural heritage conservation using micro-spatially offset Raman spectroscopy (micro-SORS)
- Heidi Goenaga-Infante of LGC, the winner of the Lester W. Strock Award from the Society for Applied Spectroscopy (SAS) and the SAS New England Regional Section, who is advancing the analysis of trace metals in biological samples, with an emphasis on metrology and validated reference methodologies
- Kay Sowoidnich of the Ferdinand Braun Institute of the Leibniz Institute for High Frequency Technology, one of the winners of the SAS William F. Meggers Award, who is developing the use of shifted-excitation Raman difference spectroscopy (SERDS) as an efficient tool for the analysis of soil nutrients and for rapid screening of meat samples along the supply chain, and
- Markita Landry of the University of California, Berkeley, the 2020 Emerging Leader in Molecular Spectroscopy, presented by *Spectroscopy*, who is combining single-molecule biophysics and nanomaterial-polymer science to develop new tools for understanding biological systems.

These interviews provide an excellent sampling of the fascinating information that will be presented this October during the SciX conference. The technique introductions, in turn, will provide a handy reference—for you, your colleagues, your students, or anyone who wants a brief tutorial.

We hope to "see" you online at the conference!

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Laura Bush Editorial Director, Spectroscopy





The 2020 Emerging Leader in Molecular Spectroscopy: Advancing Spectroscopy, Biotechnology, and Nanotechnology

An Interview with Markita Landry

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y combining singlemolecule biophysics and nanomaterial-polymer science, Markita Landry of the University of California, Berkeley has developed new tools for understanding biological systems. Using a combination of nanoparticles, imaging, and spectroscopy, her work has led to the discovery of aspects of neuromodulation in the brain and for the delivery of genetic materials into plants for crop biotechnology. She is the 2020 winner of the Emerging Leader in Molecular Spectroscopy Award, presented by Spectroscopy magazine.

Landry received her PhD from the University of Illinois at Urbana-Champaign in 2012. She then completed a postdoctoral fellowship at MIT before taking her current position at the University of California, Berkeley. She is also currently a faculty scientist with Lawrence Berkeley National Laboratory, an investigator at the Chan-Zuckerberg Biohub in San Francisco, and an investigator with the Innovative Genomics Institute in Berkeley. Landry's research focuses on the intersection of single-molecule biophysics and nanomaterial-polymer science to develop new tools to probe and characterize biological systems. Her research has generated



Markita Landry, PhD

Faculty scientist, investigator University of California, Lawrence Berkeley National Laboratory, Chan-Zuckerberg Biohub, Innovative Genomics Institute in Berkeley



nanoparticle-polymer conjugates for imaging and spectroscopic detection of neuromodulation in the brain, and for the delivery of genetic materials into plants for crop biotechnology applications.

In recognition of her work, Landry was scheduled to be presented the 2020 Emerging Leader in Molecular Spectroscopy Award at the SciX 2020 conference in October, where she was to give a plenary lecture and be honored in an award symposium, but the inperson conference has been cancelled because of the COVID-19 pandemic. This interview with Landry describes her early and most recent research.

Please tell us about some of your earliest research interests. How did you become interested in science? What has kept you motivated? What are the most exciting aspects of your work each day?

I am a physicist by training, having developed several instruments capable of measuring piconewtonscale forces and imaging at the nanometer-scale (1) for my doctoral work. My goal as a postdoc was to leverage my expertise in singlemolecule biophysics to design molecular recognition tools, during which time I developed a generic platform to create synthetic nearinfrared nanosensors (2,3), enabling the detection of any molecule with purely synthetic molecular recognition elements. When I started my lab at UC Berkeley in 2016, I grew increasingly interested in developing tools to study biological systems: As a scientist, I find the complexity of thought and intricacy of the brain fascinating. As a friend of several individuals suffering from mental health illnesses, I find it astounding that the status quo for diagnosing and treating psychiatric disorders remains qualitative. Understanding how our brain cells communicate (and miscommunicate) needs to be addressed by a collective and interdisciplinary approach to overcome the many limitations currently rendering this information inaccessible. Motivated by this, one of my lab's research directions is in developing optical probes to image brain chemistry-the neurotransmitters in the brain that support healthy brain function but can also lead to psychiatric or



neurodegenerative disease when their signaling is disrupted.

What have been the most difficult aspects of your research to date? How have you worked to overcome these challenges?

Research is inherently challenging because we initiate projects with big goals and don't usually have a clear path to achieve those goals. For every successful dopamine imaging experiment my lab performs today, there are dozens of failed experiments that have led up to it. The students and postdocs in my lab are the reason for the success of our lab's research: Their tenacity, intelligence, and clever approaches to their research projects are what enable our science to progress.

In your postdoctoral work, you and your colleagues created single-walled carbon nanotubes (SWNTs) that were inserted into the lipid envelope of extracted plant chloroplasts to promote higher photosynthetic activity and maximum electron transport rates (4). SWNTs have allowed

near-infrared (NIR) fluorescence monitoring of nitric oxide both ex vivo and in vivo,demonstrating that a plant can be altered to function as a photonic chemical sensor. How did you conceive this idea and what has been learned from this work?

In this work, we hypothesized that the broad absorption spectrum of nanomaterials such as single walled carbon nanotubes, which extends well into the near infrared and past the absorption spectrum of chlorophyll pigments, could capture a broader range of photons from broad-spectrum sunlight. This work demonstrated that these nanotubes could internalize into chloroplasts and could increase their photosynthetic activity as assessed by in vitro assays. This paper opens the opportunity for the incorporation of nanomaterials into plants for energyharvesting purposes and for detection of chemicals in the environment to which plants may be exposed.

Also as a postdoctoral researcher, you used corona phase molecular recognition (CoPhMoRe) to identify adsorbed polymer phases on fluorescent



single-walled carbon nanotubes (SWCNTs) for the selective detection of neurotransmitters, such as dopamine (5). This research suggested that polymer– SWCNT constructs may be useful as fluorescent neurotransmitter sensors, potentially within living tissue. Is this work continuing to show promise? And what has been unique about this approach?

This is an exciting body of work, showing that molecular recognition can be conferred synthetically. Normally, to detect biomolecules, natural molecular recognition elements such as antibodies are used to detect the target molecule over all other molecules that can be found in a biological system—for example, detecting dopamine over other neurotransmitters. With this approach, we show that synthetic polymers can be adsorbed to the surface of carbon nanotubes, and while most polymers will take on random conformations, every once in a while a polymer will take on a conformation that can selectively bind the target molecule, such as dopamine. In this manner, we can screen for polymernanotube conjugates that can in turn serve as synthetic probes to image biomolecules.

The work you have done on carbon nanomaterials has been highly cited and has been shown to be useful in biomedicine for imaging, sensing, targeting, delivery, therapeutics, catalysis, and energy harvesting (6). Are these materials and techniques restricted to research and discovery use or do you think this technology will lead to a clinically viable tool for measurements on patients? Are there any plans for creating a diagnostic method for physicians using carbon nanomaterials?

For the foreseeable future, the tools developed with nanomaterials in my lab are intended for research purposes. Until the nascent field of nanotechnology achieves consensus on the toxicity and environmental impacts of nanomaterials, their restricted use in a research setting is best. However, one advantage of abiotic (nonbiologically based) tools in neuroscience is that they can be deployed in nonmodel organisms. This feature of our neurotransmitter imaging technologies could be incorporated into form factors enabling their use in humans, for instance, using our dopamine probes



to measure changes in brain dopamine in organisms other than those traditionally used for neuroscience research, such as mice.

Of all your research papers so far, what are the most meaningful papers you would like to highlight for our readers that describe your current research interests?

Our most meaningful work at this point involves both genetic engineering and spectroscopy as separate, but related, pursuits.

In our genetic engineering related work, my lab demonstrates the use of various nanomaterials and their associated surface chemistries to controllably graft and quickly deliver functional biomolecular cargoes such as whole DNA plasmids to various agriculturally relevant plants (7, 8). We accomplish nanoparticle-mediated heterologous and transient expression of a protein in plants, and show that there is no transgenic DNA integration into the host plant genome. We demonstrate gene expression in both model and non-model plant species of agricultural relevance: Nicotiana benthamiana (tobacco, model dicot plant), Eruca sativa (arugula, non-

model dicot plant); Triticum aestivum (wheat, non-model monocot plant), and Gossypium hirsutum (cotton, nonmodel dicot plant). Wheat and cotton are cash crops; cotton, in particular, is challenging to genetically transform with current technologies. We further demonstrate with single-molecule imaging that the process of grafting DNA on nanoparticles prevents DNA degradation by nucleases, providing a complete picture of how this nanotechnology both promotes delivery of functional biomolecules to plants, and also protects cargo from enzymatic degradation en route to its intracellular function.

In our spectroscopy-related work, my lab has developed a tool that newly enables imaging of the chemical communication between neurons in the brain at the spatial (micrometer) and temporal (millisecond) scales the brain uses to communicate (9). In particular, chemicals known as neuromodulators tune neuronal networks that control a wide variety of brain function, including motor control, learning, and attention. Aberrations in the chemistry of neuromodulators lies at the core of many psychiatric and neurological disorders such as schizophrenia, Parkinson's disease, addiction, depression, and anxiety. Yet,



the inability to measure the dynamics of neuromodulation at high spatial and temporal resolution has hindered fundamental neuroscience research and the validation of neuropsychiatric drugs. Thus, a technology that enables neuromodulator visualization could be influential for our understanding of basic neurobiology and for the treatment of our psychiatric and neurodegenerative disorders.

We have developed a near-infrared nanoscale catecholamine probe (nIRCat) that can be used to image the neuromodulator dopamine in the brain, and is validated against "gold standard" techniques in neuroscience, including electrophysiology and optogenetics. This work elucidates the core of what neuroscientists can use to implement this technology to image the dynamics of dopamine neuromodulation at the spatial and temporal scales that have eluded existing methods of inquiry. To our knowledge, this is the only optical probe for dopamine that enables dopamine imaging in the presence of dopamine receptor agonists and antagonists, and thus the only probe that can be implemented to study how dopamine dynamics gets modulated by full-panel

antidepressants and antipsychotics that are used to treat psychiatric and neurodegenerative disease. Owing to its synthetic nature, our probe is remarkably flexible in implementation, requiring no reliance on genetic engineering techniques that protein-based optical probes typically demand. This latter point is important because nIRCats are based on a purely synthetic molecular recognition element for dopamine. This last feature has enabled us, for example, to optically record previously undetected heterogeneity in D2 dopamine autoreceptor modulation of presynaptic dopamine release upon exposure to various drugs with micrometer spatial resolution. This result is important because most psychiatric drugs target dopamine receptors, thus it is imperative to know where receptors are expressed within neurons-prevs. post-synaptically-and whether they respond to drugs similarly or heterogeneously. The non-genetically encoded nature of the probe has also enabled us to newly measure dopamine modulation in bats, a largely genetically intractable species. This method should therefore uniquely support similar explorations of the effects of other



dopaminergic drugs at the level of individual synapses, experiments that are currently unachievable.

What is the most difficult or challenging aspect of your current research? How do you manage a research group, while at the same time mentoring and directing students?

Research is inherently hard. By far the best part of my job is mentoring and directing students and postdocs—working with talented lab members to come up with ideas and research directions together. Of my tasks as a professor, meetings with students and postdocs to discuss research are the highlights of my day. And of the "outputs" of my work, more so than papers, awards, or grants, what I am most proud of are the scientists that emerge from the lab, and the careers they subsequently build for themselves.

How were you able to direct your research toward discovery of important biomedical and agricultural challenges? What made you choose the path of your research versus industrial,

chemical, or environmental problems?

The goal of our lab is to develop tools that can be as broadly useful as possible. The tools we develop for neuroscience and for plant biomolecule delivery are meant to fill voids in the toolkits available to study the brain and to genetically modify plants, respectively. Therefore, the directions that my lab takes seek to avoid redundancy in the tools we develop with preexisting tools, and developing technologies that uniquely enable studies that would not be possible without our developments.

What areas would you like to see this research expand into when looking toward the future? Do you plan to stay your current work with carbon nanomaterials or are there another analytical techniques or areas of research that look promising?

In the future, I am excited to take the tools my lab has developed and to use them to learn more about biological systems. This will require parallel developments in nanotechnology, and also in



near-infrared spectroscopy and microscopy that are necessary to complete our studies. While carbon nanotubes in particular, and their unique spectroscopic properties, have been very useful as the basis of our research thus far, we are also exploring other nanomaterials such as graphene quantum dots and gold nanoparticles.

What would you tell young people interested in science about how to prepare for a career in research?

It is never too late to get involved in science and in research. Before starting as a professor at UC Berkeley, I had never been involved in research with living systems. This transition from physics to the research areas my lab works on today was not an easy change, and required a lot of time spent with introductory level textbooks to get up to speed on this new field of research. Just to say, if I can learn new areas of science and research this late in my career, aspiring young scientists should feel empowered to get involved by volunteering in research labs, taking science classes, and participating in extracurricular activities in STEM.

References

- M.P. Landry, X. Zou, L. Wang, W.M. Huang, K. Schulten, and Y.R. Chemla, *Nucleic acids research.* 41(4), 2416–2427 (2013).
- J. Zhang, M.P. Landry, P.W. Barone, J.H. Kim, S. Lin, Z.W. Ulissi, D. Lin, B. Mu, A.A. Boghossian, A.J. Hilmer, and A. Rwei, Nature nanotechnology. 8(12), 959–968 (2013).
- M.P. Landry, H. Ando, A.Y. Chen, J. Cao, V.I. Kottadiel, L. Chio, D. Yang, J. Dong, T.K. Lu, and M.S. Strano, *Nature nanotechnology*. 12(4), 368–377 (2013).
- J.P. Giraldo, M.P. Landry, S.M. Faltermeier, T.P. McNicholas, N.M. Iverson, A.A Boghossian, N.F. Reuel, A.J. Hilmer, F. Sen, J.A. Brew, and M.S. Strano, *Nat. Mater.* 13(4), 400-408 (2014).
- S. Kruss, M.P. Landry, E. Vander Ende, B.M. Lima, N.F. Reuel, J. Zhang, J. Nelson, B. Mu, A. Hilmer, and M. Strano, *J. Am. Chem. Soc.* **136**(2), 713–724 (2014).
- S.F. Oliveira, G. Bisker, N.A. Bakh, S.L. Gibbs, M.P. Landry, M.S. Strano, *Carbon* 95. 767– 779 (2015).
- G.S. Demirer, H. Zhang, J. Matos, N. Goh, F.J. Cunningham, Y. Sung, R. Chang, A.J. Aditham, L. Chio, M.-J. Cho, B. Staskawicz, M.P. Landry, *NaturevNanotechnology.* 14, 456–464 (2019).
- H. Zhang, G.S. Demirer, H. Zhang, T. Ye, N.S. Goh, A.J Aditham, F.J. Cunningham, C. Fan, M.P. Landry, Proc. Natl. Acad. Sci. U.S.A. 116(15), 7543–7548 (2019). DOI: 10.1073/ pnas.1818290116.
- A.G. Beyene, K. Delevich, J.T.D.B. ODonnell, D.J. Piekarski, W.C. Lin, A.W. Thomas, S.J. Yang, P. Kosillo, D. Yang, L. Wilbrecht, M.P. Landry, *Sci. Adv.* 5(7),1–11 (2019).