

Proceedings of 2019 SPIE FOCUS: Light and Matter

OFFICIAL PROGRAM AND PROCEEDINGS

The SPIE Chapters at Northwestern University, University of Illinois at Urbana-Champaign,
University of Wisconsin-Madison, Purdue University, and Illinois Wesleyan University
October 12th–13th, 2019 | Evanston, Illinois

Light and Matter, Students and Researchers, We Are Connected



About SPIE FOCUS

The Federation of Optics College and University Students (FOCUS) Conference Grant provides SPIE student chapter leaders with financial support to organize a regional student conference that features a significant, non-technical professional development opportunity.

The 2019 SPIE FOCUS: Light and Matter was initiated under the same spirit. This is a student-organized regional conference which highlights not only the cutting-edge advancement in optics, optoelectronics, and materials science happening in the Midwest area, but also provides a stage for undergraduates and early-career graduate students to communicate on their research and career development.

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The Student Seminar Series has grown to become one of the most popular student-organized academic activities on the campus, which has allowed to bring together students from various departments to learn about the great research done by other students at Northwestern in a friendly environment. For the student speakers, this is a unique opportunity to train for presenting their research to a broad technical audience and to get excellent feedback from their peer graduate students. Research collaborations have also been established in the past through these student seminars.



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Conference Cochairs: **Simone Bianconi**, Northwestern University;
Wei Cui, University of Illinois at Urbana-Champaign;
Xiaohui Xu, Purdue University

Meeting Manager: **Sina A. Dereshgi**, Northwestern University

Program Chairs

Plenary Session P1: **Simone Bianconi**, Northwestern University

Symposium T1 – Materials for Optoelectronics:

Lin Sun, Northwestern University; **Jingshan S. Du**, Northwestern University

Symposium T2 – Materials Processing and Chemistry:

Wenjie Zhou, Northwestern University

Symposium T3 – Optical Device and Phenomenon:

Chenfei Hu, University of Illinois at Urbana-Champaign;

Harshil Dave, University of Illinois at Urbana-Champaign;

Wei Cui, University of Illinois at Urbana-Champaign

Program Manager, Career Development Programs: **Jinghan Zhu**, Northwestern University

Media, Logistics, and Outreach:

Sruthi Venkataramanababu, Northwestern University

Abhishek K. Amrithanath, Northwestern University

Ziyin Huang, Northwestern University

Yuyao Kuang, Northwestern University

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This meeting is made possible with the generous financial support from the SPIE through the Federation of Optics College and University Students (FOCUS) Conference Grant.

Schedule at a Glance

Saturday, October 12th, 2019

11:00 AM – 3:00 PM	Registration and Badge Pickup	(Tech Entrance/LR2)
11:30 AM – 1:00 PM	Social Time with Complimentary Lunchboxes	(Tech LR2)
1:00 PM – 2:00 PM	Plenary Session	(Tech LR2)
	P1.1 Opening Remarks	
	P1.2 Keynote presentation by Prof. Manijeh Razeghi: “The Power of Semiconductor Materials Innovation: Breaking Spectral and Performance Barriers for Quantum Devices”	
2:00 PM – 5:00 PM	Technical Sessions	
	T1 - Materials for Optoelectronics: T1.1 – T1.6	(Tech LR4)
	T2 - Materials Processing and Chemistry: T2.1 – T2.5	(Tech M177)
	T3 - Optical Devices and Phenomena: T3.1 – T3.6	(Tech M128)
	Coffee break available around 3:30 PM	
4:00 PM – 6:00 PM	Career Development Workshops	(Tech LR2)
	N1.1 “Patents and Patent Applications: What Every Scientist and Engineer Should Know”	
	N1.2 “Making Sense of How Media Cover Science”	
6:00 PM – 7:30 PM	Reception	(Willens Atrium, Tech B Wing 2 nd Floor)
	Announcing the Best Presentation Awards	

Sunday, October 13th, 2019

9:00 AM – 12:00 PM	Seminars and Discussions	(Tech LR4)
	N2.1 “Applying for Engineering Graduate School”	
	N2.2 “How to Thrive in Graduate School”	
	N2.3 “Working in Optics and Materials Engineering Industry”	
	Breakfast available at 8:30 AM	

LOOKING FOR MAPS? THEY ARE AVAILABLE
IN THE LAST PAGES OF THIS BOOK.

Programs

PLENARY SESSION P1

Program Chair: **Simone Bianconi**, Northwestern University

Event Time: October 12th, 1:00 PM – 2:00 PM

Location: Technological Institute LR2

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|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1:00 PM – 1:10 PM | P1.1 Opening Remarks |
| 1:10 PM – 2:00 PM | P1.2 Keynote Presentation: “The Power of Semiconductor Materials Innovation: Breaking Spectral and Performance Barriers for Quantum Devices” Manijeh Razeghi |

SYMPOSIUM T1 – MATERIALS FOR OPTOELECTRONICS

Program Chairs: **Lin Sun**, Northwestern University; **Jingshan S. Du**, Northwestern University

Event Time: October 12th, 2:00 PM – 5:00 PM

Location: Technological Institute LR4

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|-------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| 2:00 PM – 2:35 PM | T1.1 High-speed Room-temperature Control of Quantum Emitters with Plasmonic Nanostructures Simeon I. Bogdanov |
| 2:35 PM – 3:10 PM | T1.2 Light-spin Interaction in Optomagnonic Whispering Gallery Resonators Xufeng Zhang |
| 3:10 PM – 3:30 PM | T1.3 MOCVD Growth of All III-phosphide (AlInP-InGaP) Distributed Bragg Reflectors for Use in Multijunction Solar Cells David Rowell |
| 3:30 PM – 3:45 PM | <i>Coffee Break</i> |
| 3:45 PM – 4:20 PM | T1.4 Ultrathin Metasurfaces for the Visible Light Based on Dielectric Resonators Haogang Cai |
| 4:20 PM – 4:40 PM | T1.5 Uniaxial Expansion of the 2D Ruddlesden-Popper Perovskite Family for Improved Environmental Stability Ioannis Spanopoulos |
| 4:40 PM – 5:00 PM | T1.6 2D Dion-Jacobson Hybrid Lead Iodide Perovskites with Aromatic Diammonium Cation Xiaotong Li |

SYMPOSIUM T2 – MATERIALS PROCESSING AND CHEMISTRY

Program Chair: **Wenjie Zhou**, Northwestern University

Event Time: October 12th, 2:00 PM – 4:45 PM

Location: Technological Institute M177

2:00 PM – 2:35 PM	T2.1 Colloidal Crystal Engineered from Anisotropic Nanoparticles and DNA Haixin Lin
2:35 PM – 3:10 PM	T2.2 Direct Optical Lithography of Functional Inorganic Nanomaterials Yuanyuan Wang
3:10 PM – 3:30 PM	T2.3 Bright and Stable SERS Nanoparticle Tags with Locked Hydrophobic Inner Domains Ruiyang Xue
3:30 PM – 3:50 PM	<i>Coffee Break</i>
3:50 PM – 4:25 PM	T2.4 High Carrier Mobility in HgTe Quantum Dot Solids Improves Mid-IR Photodetectors Menglu Chen
4:25 PM – 4:45 PM	T2.5 Effects of Nanoparticle Dimensionality on the Optoelectronic Properties of CdSe Nanoplatelets Alexandra Brumberg

SYMPOSIUM T3 – OPTICAL DEVICE AND PHENOMENON

Program Chairs: **Chenfei Hu**, University of Illinois at Urbana-Champaign; **Harshil Dave**, University of Illinois at Urbana-Champaign; **Wei Cui**, University of Illinois at Urbana-Champaign

Event Time: October 12th, 2:00 PM – 4:55 PM

Location: Technological Institute M128

2:00 PM – 2:30 PM	T3.1 Ultrafast Compressed Imaging Microscopy: Redefining the Speed limit of Microscopy Imaging Liang Gao
2:30 PM – 3:00 PM	T3.2 Clear Optically Matched Panoramic Access Channel Technique (COMPACT) for Large Volume Deep Brain Imaging Meng Cui
3:00 PM – 3:30 PM	T3.3 Towards Laser Cooling in Rare Earth Doped Silicate Glass Fibers Peter D. Dragic
3:30 PM – 3:45 PM	<i>Coffee Break</i>
3:45 PM – 4:15 PM	T3.4 Spectroscopic Single-molecule Localization Microscopy (sSMLM) Hao F. Zhang

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|-------------------|-----------------------------------------------------------------------------------------------------------|
| 4:15 PM – 4:35 PM | T3.5 Reconfigurable Lattice-Resonance Metalenses on Coupled Nanoparticle Jingtian Hu |
| 4:35 PM – 4:55 PM | T3.6 Transient Lattice Response upon Photoexcitation in CuInSe ₂ Nanocrystal Samantha Harvey |

SYMPOSIUM N1 – WORKSHOPS

Program Manager: **Jinghan Zhu**, Northwestern University

Event Time: October 12th, 4:00 PM – 6:00 PM

Location: Technological Institute LR2

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|-------------------|---------------------------------------------------------------------------------------------------------------------|
| 4:00 PM – 5:00 PM | N1.1 Workshop 1: “Patents and Patent Applications: What Every Scientist and Engineer Should Know” James L. Lovsin |
| 5:00 PM – 6:00 PM | N1.2 Workshop 2: “Making Sense of How Media Cover Science” Patti Wolter |

SYMPOSIUM N2 – SEMINARS AND DISCUSSIONS

Program Manager: **Jinghan Zhu**, Northwestern University

Event Time: October 13th, 9:00 AM – 12:00 PM

Location: Technological Institute LR4

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|---------------------|------------------------------------------------------------------------------------------------------------------------------|
| 8:30 AM – 9:00 AM | <i>Complimentary Breakfast</i> |
| 9:00 AM – 10:00 AM | N2.1 Seminar: “Applying for Engineering Graduate School” Bruce A. Lindvall |
| 10:00 AM – 11:00 AM | N2.2 Panel Discussion 1: “How to Thrive in Graduate School” Jingshan Du, Chenfei Hu, Simone Bianconi |
| 11:00 AM – 12:00 PM | N2.3 Panel Discussion 2: “Working in Optics and Materials Engineering Industry” Spencer Wells, Zhiyuan Sun, Andrey Ivankin |

P1.2 Keynote Presentation: “The Power of Semiconductor Materials Innovation: Breaking Spectral and Performance Barriers for Quantum Devices”

Manijeh Razeghi (*Northwestern University*)

My talk will be for all of the students and scientists, independent of race, religion, sex, or nationality. Showing them how having inspiration from Nature, we can overcome many problems and be happy, healthy, successful, mentor, leader, and role model.

Manijeh Razeghi

Walter P. Murphy Professor and Director

Center for Quantum Devices, Northwestern University

Dr. Razeghi is a pioneer in the area of III-V compound semiconductors and optoelectronic devices from the deep ultraviolet to the far infrared spectral bands, including in particular InP and GaAs based semiconductors and devices, which were at the heart of the optical fiber telecommunication revolution of the late 20th Century and the rise of the information age.

She is a fellow of SPIE, IEEE, OSA, APS, IOP, MRS, and throughout her career she has authored 19 books, 33 book chapters and more than 1000 papers. She also holds 55 patents. She has received many awards, the most recent of which is the Benjamin Franklin Medal in 2018.

Featuring Keynote Presentation by

Manijeh Razeghi

Walter P. Murphy Professor and Director

Center for Quantum Devices

Northwestern University



T1.1 High-speed Room-temperature Control of Quantum Emitters with Plasmonic Nanostructures

Simeon I. Bogdanov (*Purdue University*)

Quantum technologies simultaneously require accurate control over elementary quantum systems and robust protection from interactions with their environment. Single photons are arguably the best candidates for realizing quantum networks thanks to their fast propagation speed and low decoherence rates. However, the fast production of single photons and deterministic interactions between them are difficult to achieve because of photons' relatively weak coupling with matter. As a result, most of today's long-range photonic quantum networks still operate at kHz bitrates, while photonic quantum information processing is limited to systems consisting of about ten photons. Enhancing light-matter interaction is possible using dielectric resonators but the speed of the resulting devices will be eventually limited by the high-quality factors. Plasmonic metal-based nanostructures used along with the conventional dielectric photonic circuitry allow a targeted and strong enhancement of light-matter interaction in a broad wavelength range. This approach promises bitrates up to the THz range and room-temperature operation of quantum optical components. I will outline present and future directions in the development of a platform for room-temperature high-speed integrated quantum photonics, including the application of machine learning techniques for quantum optical measurements.

T1.2 Light-spin Interaction in Optomagnonic Whispering Gallery Resonators

Xufeng Zhang (*Argonne National Laboratory*)

Photonics provides high-precision methods for detecting and manipulating electronic signals. On the other hand, magneto-optical interactions make it possible to control magnetism using optical photons. In particular, collective magnetic excitation, which are also known as spin waves or magnons, can be coherently controlled by a laser. Because of the unique properties of magnonics such as its widely tunable frequency, they have recently emerged as a promising candidate for coherent information processing. Here we demonstrate that magnonic devices can be integrated with photonic resonators on magnetic insulator yttrium iron garnet. The excellent material property allows high optical quality factors approaching one million in the telecom C band, which significantly enhances the interaction between magnon and optical photons. The Brillouin scattering process between the optical photons and magnons generates asymmetric optical sidebands with orthogonal polarization. The magnon-photon interaction is further enhanced through the triple resonance of magnon, pump, and signal photon modes. Our results pave the way towards the development of optomagnonics and its application in signal processing.

T1.3 MOCVD Growth of All III-phosphide (AlInP-InGaP) Distributed Bragg Reflectors for Use in Multijunction Solar Cells*

David Rowell (*MicroLink Devices*), Kamran Forghani (*MicroLink Devices*),
Rao Tatavarti (*MicroLink Devices*)

We report on the MOCVD growth of all III-phosphide (AlInP-InGaP) Distributed Bragg Reflectors and their applications for multijunction (MJ) solar cell devices. DBR's with peak reflectance of 0.89 μ m GaAs bandgap energy were grown on top of inverted GaAs single junctions and are compatible with epitaxial lift off processing of solar cells. The DBR's were grown on 150 mm (6") substrates and exhibited smooth surfaces. Dual junction InGaP/GaAs solar cells with AlInP-GaInP DBR exhibited an increase of 3% in J_{sc} , and 44% increase in the EL integrated intensity of both GaAs and InGaP peaks.

At MicroLink Devices, we have been developing inverted metamorphic (IMM) based devices using epitaxial lift off (ELO) process for the past decade. In this work, we present the first ever growth and application of InAlP-InGaP DBR structure as a reflective stack for a GaAs subcell. This all-phosphide DBR has unique qualities suitable for IMM devices. These DBRs can be used as a wavelength-selective reflector with three major implications: (i) Photon recycling increases internal quantum efficiency (IQE). (ii) The back mirror also results in an increase of effective optical path thickness. Thus, the sub-cell can be thinned down while maintaining the photogenerated current. (iii) The reduced diffusion length for minority carriers reaching the tunnel junctions or contact layers results in the devices being more radiation hard, i.e. they have a higher EOL, as well as an overall improvement to the BOL performance.

The DBR did not reduced the V_{oc} or FF , which can sometimes happen due to the introduction of defects or excess series resistance. Moreover, the DBR structure seems to be reducing the leakage current in the DIV tests. This work proves the feasibility of using phosphide-based DBRs for various MJ solar cells for various applications, including terrestrial (1-sun or concentrated: CPV) and space applications.

* Poster presentation available at the coffee break.

T1.4 Ultrathin Metasurfaces for the Visible Light Based on Dielectric Resonators

Haogang Cai (*Argonne National Laboratory*)

Metasurface-based optical elements enable abrupt wavefront engineering by locally controlling the properties (amplitude, phase, etc.) of the incident illumination. They hold great potential to promote a new generation of wearable devices and thin optical systems for imaging and sensing. To date, most of the existing metasurface designs rely on high-aspect-ratio nanostructures, with a thickness close to or even higher than the wavelength. There has been an increasing demand to reduce the metasurface thickness and nanostructure aspect-ratio, in order to facilitate the fabrication compatibility and integration with electronics and dynamic tunable platforms.

In this talk, I will present ultrathin ($\sim 1/5$ of the wavelength) transmissive metalenses for the visible light, using two different approaches of either amplitude or phase modulation. For amplitude modulation, we developed a digital transmission coding scheme that allows manipulation of multiple wavelengths without increasing the thickness or complexity of the structural elements. Phase modulation is necessary in order to improve the optical efficiency. But the design is more challenging, because ultrathin nanoresonators are electromagnetically coupled with each other, compared with high-aspect-ratio nanostructures with wave-guiding confinement. To solve this problem, we developed an inverse design strategy using evolutionary optimization. We employed genetic algorithms interfaced with Finite-Difference Time-Domain solvers, which mimic natural selection in order to determine the optimal arrangement of nanoresonators to achieve the desired target optical functions. The inverse designs significantly improved the focusing efficiency, approximately double of the conventional designs by library search, which was demonstrated experimentally.

T1.5 Uniaxial Expansion of the 2D Ruddlesden-Popper Perovskite Family for Improved Environmental Stability

Ioannis Spanopoulos (*Northwestern University*), Mercouri Kanatzidis (*Northwestern University*), Ido Hadar (*Northwestern University*), Weijun Ke (*Northwestern University*), Qing Tu (*Northwestern University*), Vinayak Dravid (*Northwestern University*)

The unique hybrid nature of 2D Ruddlesden-Popper (R-P) perovskites has bestowed upon them not only tunability of their electronic properties but also high-performance electronic devices with improved environmental stability as compared to their 3D analogs. However, there is limited information about their inherent heat, light and air stability, and how different parameters such the inorganic layer number and length of organic spacer molecule affect stability. To gain deeper understanding on the matter we have expanded the family of 2D R-P perovskites, by utilizing pentylamine (PA)₂(MA)_{n-1}PbI_{3n+1} (n = 1-6, PA = CH₃(CH₂)₄NH₃⁺, C5) and hexylamine (HA)₂(MA)_{n-1}PbI_{3n+1} (n = 1-4, HA = CH₃(CH₂)₅NH₃⁺, C6) as the organic spacer molecules between the inorganic slabs, creating two new series of layered materials in single crystal form, for up to n = 6 and 4 layers, respectively. The increase in the length of the organic spacer molecules does not affect their optical properties, however it has a pronounced effect on the air, heat and light stability of the fabricated thin films. We fabricated films on various substrates, and performed extensive environmental stability tests, evaluating their air, heat and light stability, both with and without encapsulation. Multiparameter, invaluable information was extracted from these studies, which showed that for the same number of layers the PA based materials, exhibited improved heat, light and air stability (e.g. stable for 450 days in air), as compared to BA, HA and 3D analogues. Furthermore, we verified for the first time that hybrid halide perovskites are inherently heat and light stable in the absence of moisture, a most critical finding for their potential commercialization. Lastly, evaluation of the out of plane mechanical properties of the corresponding materials showed that their soft and flexible nature can be compared to the current commercially available polymer substrates (e.g. PMMA), rendering them suitable for fabricating flexible and wearable electronic devices, expanding their utilization beyond photovoltaic applications.

T1.6 2D Dion-Jacobson Hybrid Lead Iodide Perovskites with Aromatic Diammonium Cations

Xiaotong Li (*Northwestern University*), Weijun Ke (*Northwestern University*),
Mercouri Kanatzidis (*Northwestern University*)

Two-dimensional (2D) halide perovskites have extraordinary optoelectronic properties and structural turnabilities. Among them, the Dion-Jacobson (DJ) phases incorporating diammonium cations with the inorganic layers stacking exactly on top of each other are less explored. When linear diammonium cations are incorporated, even though the carbon-chain is as short as four, the structure is still offset. Using cyclic diammonium cations instead, the DJ phases can be templated by the x-(aminomethyl)piperidinium (AMP) cations ($x = 3$ or 4). Furthermore, when the aromatic analogues ((x-(aminomethyl)pyridinium (AMPY) cations ($x = 3$ or 4)) are used instead of the aliphatic ones, the more symmetric 4AMPY cation can maintain the DJ structure. By modifying the position of the $-\text{CH}_2\text{NH}_3^+$ group from 4AMPY to 3AMPY, the stacking of the inorganic layers changes from exactly eclipsed to slightly offset. The perovskite octahedra tilts are also different between the two series, with the less titled 3AMPY series exhibiting smaller bandgaps than the 4AMPY series. Compared to the aliphatic AMP cations, the xAMPY C-C bonds are shorter because of the aromaticity of the pyridine ring, and they bring the inorganic layers even closer to one another ($< 4 \text{ \AA}$). Another feature caused by the aromatic cations is a decrease in the exciton binding energy which is attributed to the increased dielectric constant. Taking all these factors into consideration, we also fabricated preliminary solar cell devices using the $n=4$ members as solar absorbers. The device based on $(3\text{AMPY})(\text{MA})_3\text{Pb}_4\text{I}_{13}$ showed a champion power conversion efficiency (PCE) of 9.20 %, which is higher than the $(4\text{AMPY})(\text{MA})_3\text{Pb}_4\text{I}_{13}$ and the corresponding aliphatic analogue $(3\text{AMP})(\text{MA})_3\text{Pb}_4\text{I}_{13}$ based ones.

T2.1 Colloidal Crystals Engineered from Anisotropic Nanoparticles and DNA

Haixin Lin (*Northwestern University*)

DNA-mediated programmable assembly is a promising route for synthesizing novel materials. This strategy has been successfully used to synthesize crystalline structures with more than 35 different symmetries and over 500 structures. However, most of the properties of these colloidal crystals are dictated by the identity of the building blocks, instead of their structural arrangements. In contrast, crystal structure plays a crucial role in determining the properties of several traditional molecular/atomic crystals such as porous (e.g. MOFs, clathrates, zeolites) and anisotropic crystals (e.g. uniaxial crystals, biaxial crystals). Analogous porous or anisotropic colloidal crystals are difficult to fabricate given that the most commonly used building blocks are highly symmetric spherical particles. Unlike spherical particles, anisotropic particles can directionally guide the formation of DNA bonds with specific angles, which affects the lattice symmetry and crystal habit of the resulting colloidal crystals. In this work, we show two examples of how low symmetry nanoparticles assemble into either porous or anisotropic crystals.

Natural clathrates are mainly hydrate frameworks with a variety of host molecules such as methane. The cages in natural clathrates are formed when molecular or atomic nodes adopt discrete bond angles between 100 and 125°. To assemble the nanoparticle analog, oblate trigonal bipyramids were identified as ideal building blocks as they can promote the formation of DNA bonds with ~110° bond angle. DNA-mediated assembly of triangular bipyramids generated three different clathrate architectures, which, to date, are the most sophisticated architectures made by programmable assembly. The cavities in the clathrates may have potential for host-guest recognition applications (such as proteins or virus) as well as catalysis.

Natural anisotropic crystals have different refractive indices along different crystallographic axes which allows them to modulate the phase or path of light. Using low symmetry nanoparticles such as nanoscale pentabipyramids and nanorods, anisotropic colloidal crystals such as rhombohedra, hexagonal prisms, and rhombic prisms were assembled. In particular, colloidal rhombic prisms which have face-centered-orthorhombic symmetry, the lowest symmetry achieved by programmable assembly to date, were prepared. Importantly, these represent the first examples of biaxial colloidal crystals. Anisotropic colloidal crystals such as these have potential as important optical components in micro-optical systems.

T2.2 Direct Optical Lithography of Functional Inorganic Nanomaterials

Yuanyuan Wang (*University of Chicago*), Jia-Ahn Pan (*University of Chicago*),
Dmitri V. Talapin (*University of Chicago*)

Photolithograph is an important manufacturing process that relies on using organic or polymer photoresists. Here, we demonstrate a general technique named DOLFIN to prepare photosensitive inks and direct pattern inorganic nanocrystals (NCs) and sol-gel nanomaterials without diluting or contaminating them with photoresists and other byproducts. By purposely designing surface ligands outside NCs with photochemically active X^- or Cat^+ groups, we design a series of novel NC inks that can be directly patterned not only with DUV, but also with near UV light (i-line, 365 nm), blue light (h-line, 405 nm) and even visible light (450 nm) using environmentally benign and industrially accepted solvents. The generality of DOLFIN approach is demonstrated for a wide range of colloidal NCs including metals, semiconductors, oxides, magnetic or rare earth compounds. Since DOLFIN is a photoresist-free method, no organic impurities are present in the patterned layers, which will help achieve good electronic and optical properties. The ability to directly pattern all-inorganic layers with the resolution and the exposure dosage comparable to that of organic photoresists provides a powerful and versatile nanomanufacturing platform for solution processed thin film device fabrication.

T2.3 Bright and Stable SERS Nanoparticle Tags with Locked Hydrophobic Inner Domains

Ruiyang Xue (*University of Illinois at Urbana-Champaign*),
Li Lin (*University of Illinois at Urbana-Champaign*), Lucas Lane (*Nanjing University*),
Subhendu Pandit (*University of Illinois at Urbana-Champaign*),
Shuming Nie (*University of Illinois at Urbana-Champaign*)

Surface enhance Raman scattering (SERS) is an ultra-sensitive spectroscopic technique induced by surface plasmon resonance effect on metal surface. It greatly boosts the intensity of standard Raman signal of molecules and thus exhibits great potential in the fields such as nanomaterials science, optical devices for single-molecule sensing and trace analysis. Specially, SERS nanoparticles (NPs), which are plasmonic metallic colloids modified with Raman reporter molecules and surface coatings, has been a promising optical tag in biomedical applications. High brightness and stability are of great significance for SERS NPs to achieve satisfactory detection sensitivity.

In this work, a wet-chemistry method is reported to synthesize SERS NPs with enhanced intensities and better signal stability by introducing a hydrophobic aliphatic domain into polyethylene glycol (PEG) coating. The aliphatic domain is composed of an 11-carbon alkyl chain, which forms a hydrocarbon environment near Au surface, leading to a change in the refractive index and dielectric constant of the ambient medium to increase NP polarizability. An additional 2 to 5 times SERS enhancement is introduced by this hydrophobic enhancement effect, which turns out to be universal for a variety of Raman reporter molecules. We also demonstrate that larger packing density and longer aliphatic chain length tends to bring in higher Raman enhancement. Moreover, the hydrophobic shell around NPs protects Raman molecules from diffusing out via favorable hydrophobic and van der Waals interactions, resulting in a better long-term signal stability in different solvents. Given that a hypothetical competitive adsorption between reporters and hydrophobic domain modified PEGs, a tradeoff strategy has been put forward to adjust their relative concentrations, achieving an optimal SERS intensity for specialized applications. Our investigation into hydrophobic domain enhanced gold SERS nanoparticles provides a new strategy for Raman signal amplification and open up new opportunities for SERS-based optical devices and biomedical applications.

T2.4 High Carrier Mobility in HgTe Quantum Dot Solids Improves Mid-IR Photodetectors

Menglu Chen (*University of Chicago*)

Improving charge mobility in quantum dot (QD) films is important for device performance, where high mobility helps to improve efficiency of photodetectors, solar cells, and LEDs. However, these applications also require preserving well-defined quantum dot electronic states and optical transitions. We present HgTe QD films which show the highest mobility yet achieved for transport through discrete QD states. A novel hybrid surface passivation process efficiently eliminates surface states, provides tunable air-stable n and p-doping, and enables hysteresis-free filling of QD states evidenced by strong conductance modulation. QD films dried at room temperature without any post treatments exhibit mobility up to $\mu \sim 8 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ at low carrier density of less than one electron per QD, bandlike ($\partial\mu/\partial T < 0$) behavior down to 70 K, similar drift and Hall mobilities at all temperatures. We compare the photoconductive properties with the prior “solid-state ligand exchange” using ethanedithiol, and we find that the new process affords a ~ 100 -fold increase of the electron and hole mobility, a ~ 100 -fold increase in responsivity, and a ~ 10 -fold increase in detectivity. These photodetector improvements are primarily attributed to the increase in mobility because the optical properties are mostly unchanged. We show that the specific detectivity (D^*) of a photoconductive device is expected to scale as $\mu^{1/2}$. The application potential is further verified by long-term device stability.

T2.5 Effects of Nanoparticle Dimensionality on the Optoelectronic Properties of CdSe Nanoplatelets

Alexandra Brumberg (*Northwestern University*), Richard Schaller (*Northwestern University*)

Recent advances in nanoparticle synthesis have presented scientists with the opportunity to control not only nanoparticle size and composition, but also morphology and dimensionality. Among these advances, colloidal, two-dimensional nanocrystals known as nanoplatelets have emerged, which display exceptionally narrow photoluminescence linewidth and large absorption cross-sections that arise specifically as a result of their dimensionality. However, while extensive studies have led to an understanding of how electron transfer rates scale with nanoparticle size, analogous studies relating rates of electron transfer to nanoparticle dimensionality are lacking. Here, we study electronic interactions in films containing mixtures of zero- or two-dimensional nanostructures (quantum dots or nanoplatelets, respectively) with constant driving force and nanoparticle separation, achieved via the use of isoenergetic nanoparticles and identical capping ligands. Electron transfer is observed in all of the examined mixtures, regardless of the particle dimensionality, and characterized via static and time-resolved photoluminescence, as well as transient absorption spectroscopy. Rates of electron transfer for different combinations of dimensionalities in dilute and concentrated films reveal that dimensionality does, in fact, impact rates of electron transfer, with films containing nanoplatelets exhibiting faster charge separation rates. This novel insight into how dimensionality affects exciton dynamics has implications in the design of photocatalysts and optoelectronic devices such as photovoltaics, as the appropriate selection of nanoparticle dimension can potentially boost device efficiencies.

T3.1 Ultrafast Compressed Imaging Microscopy: Redefining the Speed Limit of Microscopy Imaging

Liang Gao (*University of Illinois at Urbana-Champaign*)

In this talk, I will present our recent development of an ultrafast compressed imaging microscope which can image transient biological dynamics at an unprecedented speed up to 100 billion fps. Its application in high-speed fluorescence lifetime imaging microscopy will be discussed.

T3.2 Clear Optically Matched Panoramic Access Channel Technique (COMPACT) for Large Volume Deep Brain Imaging

Meng Cui (*Purdue University*)

With the advance of function molecular indicators and actuators, neurophotronics has become a powerful paradigm for discovering the principle of brain function. However, a major limitation of employing light to study mammalian brain is the limited access depth. Even with the advance of multiphoton imaging, the majority of implementation in mammalian brain is limited to ~ 1 mm depth, about the thickness of mouse neocortex. The majority of mouse brain remains inaccessible, not to mention the brain of larger mammals. To investigate deeper brain regions, invasive miniature optical probes are often employed. A key difficulty with the available optical probes is the tiny tissue access volume, which is only a small fraction of the inserted probe volume. The design of miniature optical probes has largely remained the same over the past two decades. Can we fundamentally change the design of miniature optical probes and greatly increase the tissue access volume? Here we report our latest technology development, Clear Optically Matched Panoramic Access Channel Technique (COMPACT), which can effectively increase the tissue access volume by ~ **three orders of magnitude**. The development of COMPACT will provide tremendous capacity, flexibility and adaptability to the neuroscience research. We will discuss our experiment on employing COMPACT for two-photon calcium imaging of deep mammalian brain.

T3.3 Towards Laser Cooling in Rare Earth Doped Silicate Glass Fibers

Peter D. Dragic (*University of Illinois at Urbana-Champaign*)

Laser cooling in solids can be achieved by pumping a rare earth (RE) element at an energy less than its average spontaneous emission energy. Phonons then can be extracted from the host material; under proper conditions giving rise to temperatures reaching even the cryogenic range. Since laser cooling efficiency usually is only on the order of a few percent, the material system must be free of parasitic heating processes, such as non-radiative decay, impurity absorption, etc. This places particularly strict requirements on the quality of the optical host material and the local environment of the RE. Owing in part to its simple two-level $f-f$ transition diagram, possessing only one excited state (and therefore lacking upconversion or excited state absorption processes), and a relatively high concentration quenching limit, Yb^{3+} is a preferred RE ion for the cooling application. While laser cooling has been demonstrated in several Yb-doped crystalline materials, laser cooling of Yb-doped glass has been most successful in fluorides, namely ZBLAN, whereas the observation of cooling in silicate hosts has remained elusive. Due to its being physically robust, and having a relatively high optical damage threshold, doped silica is the material of choice for high power, multi-kW fiber lasers in the near infrared. Demonstration of fluorescence cooling in these materials could therefore enable, for example, lasers that generate no internal heat. The correlated efforts to tailor the host to achieve cooling in silicate glass fibers will be presented. Both conventional (including nanoparticle doped) and unconventional optical fiber fabrication methods, as well as procedures to measure and quantify glass properties and cooling, will be discussed.

T3.4 Spectroscopic Single-molecule Localization Microscopy (sSMLM)

Hao F. Zhang (*Northwestern University*)

Traditional single molecule localization microscopy analyses the spatial distributions of photons emitted by individual molecules to reconstruct super-resolution optical images. To further push the envelope of this imaging technology, we developed spectroscopic single molecule localization microscopy (sSMLM) that is capable of capturing the inherent spectroscopic signatures of photons from individual stochastic radiation events. sSMLM further improved the spatial resolution of single molecule localization microscopy through spectral discrimination to identify the photons emitted from individual molecules. As a result, we demonstrated a resolution of sub-10 nm without significantly increase the total number of image frames through a novel regression method. Using sSMLM, we demonstrated simultaneous multi-color super-resolution imaging, where the number of fluorescence labels can have largely overlapping emission spectra with only minute differences. In addition, we further investigated intrinsic stochastic fluorescence emission from unstained nucleotides using sSMLM, seeking potential label-free super-resolution imaging.

T3.5 Reconfigurable Lattice-Resonance Metalenses on Coupled Nanoparticles

Jingtian Hu (*Northwestern University*)

Compact lensing components are crucial for miniaturized imaging systems that can be integrated into portable electronic and optical devices. Metalenses—rationally designed surfaces with nanoscale building blocks—have accomplished subwavelength imaging and can correct for spherical/chromatic aberrations. However, existing metalenses have fixed structures once fabricated and cannot adjust their focal spots based on the position of an object. Here we describe a reconfigurable metalens system that can image at visible wavelengths based on arrays of coupled plasmonic nanoparticles. These lenses manipulated the wavefront and focused light by exciting surface lattice resonances that were tuned by patterned polymer blocks on single-particle sites. Predictive design of the dielectric nano-blocks was performed using an evolutionary algorithm to create a range of 3D focusing responses. For scalability, we demonstrated a simple technique for erasing and writing the polymer nanostructures on the metal nanoparticle arrays in a single step using solvent assisted nanoscale embossing. This reconfigurable materials platform enables tunable focusing with diffraction-limited resolution and offers prospects for highly adaptive, compact-imaging.

T3.6 Transient Lattice Response Upon Photoexcitation in CuInSe₂ Nanocrystals

Samantha Harvey (*Northwestern University*)

CuInSe₂ nanocrystals (CISE NCs) offer promise for optoelectronics such as thin film photovoltaics and printed circuits owing to near-infrared bandgap, low toxicity, and scalable synthesis. Additive manufacturing methods such as photonic curing to produce sintering of NCs offers routes to improved performance, yet little is known regarding the physical behavior of NCs under elevated excitation conditions. Here, we directly investigate the impact of photoexcitation on NC lattice response via time-resolved X-ray diffraction measurements for three sizes of CISE NCs and two different capping ligands (oleylamine and inorganic Na₂S) to characterize resultant crystal lattice temperature, phase stability, and thermal dissipation rates. Fluence-dependent measurements show a clear increase in loss of crystallinity with NC size. Kinetics convey a size-dependent recrystallization and cooling lifetime ranging from 80 – 1200 ps and an additional slower cooling lifetime between 2 – 25 ns. The Na₂S-capped NCs show reduced melting and recrystallization lifetimes compared to the oleylamine capped NCs and cool completely within ~200 ps. Static XRD with temperature elevation permits evaluation of effective lattice temperature with fluence and also show higher thermal expansion and lower melting temperature than the bulk composition.

Career Development Programs – Speaker Biography

N1.1 Workshop 1: “Patents and Patent Applications: What Every Scientist and Engineer Should Know”

James Lovsin is a partner with McDonnell Boehnen Hulbert & Berghoff LLP in Chicago. Mr. Lovsin concentrates his practice on intellectual property matters, including patent litigation and appeals, and patent and trademark procurement and counseling. He has experience in all phases of litigation and has litigated patents, trademarks, trade dress, copyrights, and trade secrets. He also has substantial experience preparing and prosecuting patent applications.



Mr. Lovsin received a B.S. in Mechanical Engineering from Northwestern University in 2005, and he received a J.D. from University of Illinois College of Law in 2010. Prior to law school, he worked for ExxonMobil as a reliability engineer and a mechanical engineer.

N1.2 Workshop 2: “Making Sense of How Media Cover Science”

Patti Wolter joined the Medill faculty in the spring of 2002 and was named the Helen Gurley Brown Magazine Professor in 2018. Prior to joining the faculty, she spent 12 years in senior staff magazine jobs in New York, San Francisco and Chicago. She served as managing editor as well as acting editor at Mother Jones magazine and oversaw the award-winning health investigations team at Self magazine. Her freelance writing on women’s health and nutrition has appeared in a range of publications, and she continues to work as an editorial consultant for various print and online outlets.



Wolter’s teaching focuses on the magazine industry, factchecking, science writing and narrative, especially in relationship to feature writing and multimedia storytelling. She teaches courses in magazine editing, feature writing, health and science reporting, and narrative structure for undergraduate and graduate students. In addition to her regular teaching, Wolter has designed and implemented fact-checking curricula across Medill classes and programs and regularly guest lectures on the topic. For Northwestern’s Graduate School, Wolter is part of the team that developed a writing-for-consumer-audiences class for STEM+ Ph.D. students and is the lead lecturer for the course, now in its fifth year. Wolter also gives lectures and runs workshops for scientists on how to communicate with media and to develop skills for sharing their findings

to lay audiences. She is a regular judge for the National Magazine Awards and is a member of the Knight Foundation's Science Journalism Project. She also leads Medill's prestigious John Bartlow Martin Award for Public Interest Magazine Journalism annual contest. She has received numerous teaching awards from Northwestern's Associated Student Government and was Medill's Undergraduate Professor of the Year in 2017.

N2.1 Seminar: "Applying for Engineering Graduate School"

Bruce A. Lindvall is Assistant Dean for Graduate Studies at the McCormick School of Engineering and Applied Science, Northwestern University. He is responsible for the management and growth of existing and future graduate degree programs at McCormick. He works closely with others to coordinate strategic planning, integrated brand marketing, and the student learning environment.



Bruce is also responsible for communication with prospective students and applicants, while overseeing the MS and PhD admissions processes in McCormick. He is also responsible for the student environment which includes 900 PhD and nearly 600 MS students. Bruce is the Northwestern GEM University representative and serves on the GEM Board of Directors.

Before joining Northwestern, he worked at the College Board, the University of Kansas, and Purdue University. He has a BS in Mathematics, an MS in Guidance and Counseling, and a PhD in Educational Administration, all from Purdue University.

N2.2 Panel Discussion 1: "How to Thrive in Graduate School"

Jingshan Du is a Ph.D. Candidate in the Department of Materials Science and Engineering at Northwestern University, co-advised by Prof. Chad A. Mirkin and Prof. Vinayak P. Dravid. He received his B.Sc. in Engineering from Chu Kochen Honors College, Zhejiang University in 2015. Under the advisory of Prof. Deren Yang and Prof. Hui Zhang, he investigated the synthesis and structural evolution of colloidal noble metal and oxide nanostructures for catalytic purposes. Before joining Northwestern, he spent his senior year with Prof. David A. Weitz at Harvard



University studying the interfacial dynamics of AgCl–Ag nanoparticle heterojunctions using in situ electron microscopy. His current research interests include complex nanoparticle systems, nanoscale thermodynamics, and nanoscale phase transformation. He was named a Ryan Fellow by the International Institute for Nanotechnology at Northwestern University, a Perkin Scholar by the Society of Chemical Industry America, and a recipient of the 2019 IPMI Sabin Metal Ron Bleggi

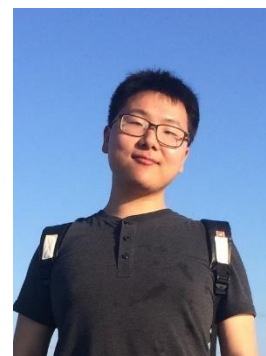
Student Award. He currently serves as the Vice President of the SPIE Northwestern University Chapter.

Chenfei Hu is currently a Ph.D. candidate at University of Illinois at Urbana-Champaign. He got his Bachelor's degree in Optoelectronics at Tianjin University, China in 2014, and Master's degree in ECE at Duke University (Durham, NC). His research is focused on optical engineering,



microscopy, and biophotonics. So far, he has authored 8 research articles and more than 15 conference presentations.

Simone Bianconi is a 4th year PhD candidate in the Electrical and Computer Engineering department, president of the Northwestern SPIE student chapter and Ryan Fellow since 2018, at Northwestern he organized and took part in several career development and outreach events.

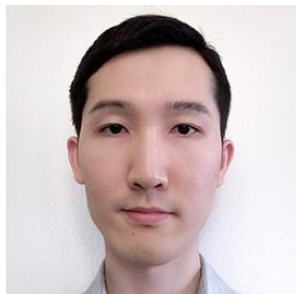


N2.3 Panel Discussion 2: “Working in Optics and Materials Engineering Industry”

Spencer Wells is a research scientist at Facebook Reality Labs where he works on developing materials to enable new optical and display systems and components for virtual and augmented reality. He received a B.S. in Materials Science and Engineering from the University of Illinois at Urbana Champaign with highest honors in 2013. Subsequently he received a Ph.D. in Materials Science and Engineering from Northwestern University in 2018 for research on “Processing and Devices for chemically Reactive Two-Dimensional Materials” under the supervision of Professor Mark Hersam. He has previously received awards including the National Defense Science and Engineering Graduate Fellowship and the Northwestern University Ryan Fellowship. He is the (co)author of 17 published papers, has over 2200 citations, an h-index of 11, and over 20 patent applications pending. Outside of work he enjoys reading, cycling, and running.



Zhiyuan Sun obtained his B.S. from the Materials Science Department at University of Science and Technology of China (USTC) where worked in Prof. Qianwang Chen's group from 2011 at the Hefei National Lab for Physical Sciences at the Microscale. After his graduation from USTC, Dr.



Sun started pursuing his Ph.D. at Northwestern University under the supervision of Prof. Lincoln Lauhon and Prof. David Seidman, with research focuses on atom-probe tomography and semiconductor nanowire. Zhiyuan has published papers as first author and co-author in Nano Letters, ACS nano, Energy and Environmental Science et. al. He also served as reviewer for more than 20 journals, including ACS Nano, ACS Applied Science & Interfaces, and Nano-Miro Letters, and has peer-

reviewed more than 100 manuscripts. Currently, Zhiyuan works at Apple Inc. as a Hardware Engineer, working on emerging interactive module for future consumer electronics.

Andrey Ivankin is a Co-founder and the Chief Technology Officer at TERA-print, a nanotechnology startup spun out of Professor Chad Mirkin's lab at Northwestern University. He heads the engineering and technology development program at TERA-print and was behind the design of the Company's two highly innovative desktop nanoprinters, which are already being used by >20 research groups worldwide for applications in materials science, biology, chemistry, and physics. Prior to TERA-print, Dr. Ivankin worked on advancing micro- and nanofabrication techniques at Northwestern University and single-molecule detection strategies at Northeastern University. Dr. Ivankin holds Ph.D. in Chemical Engineering from the Illinois Institute of Technology.



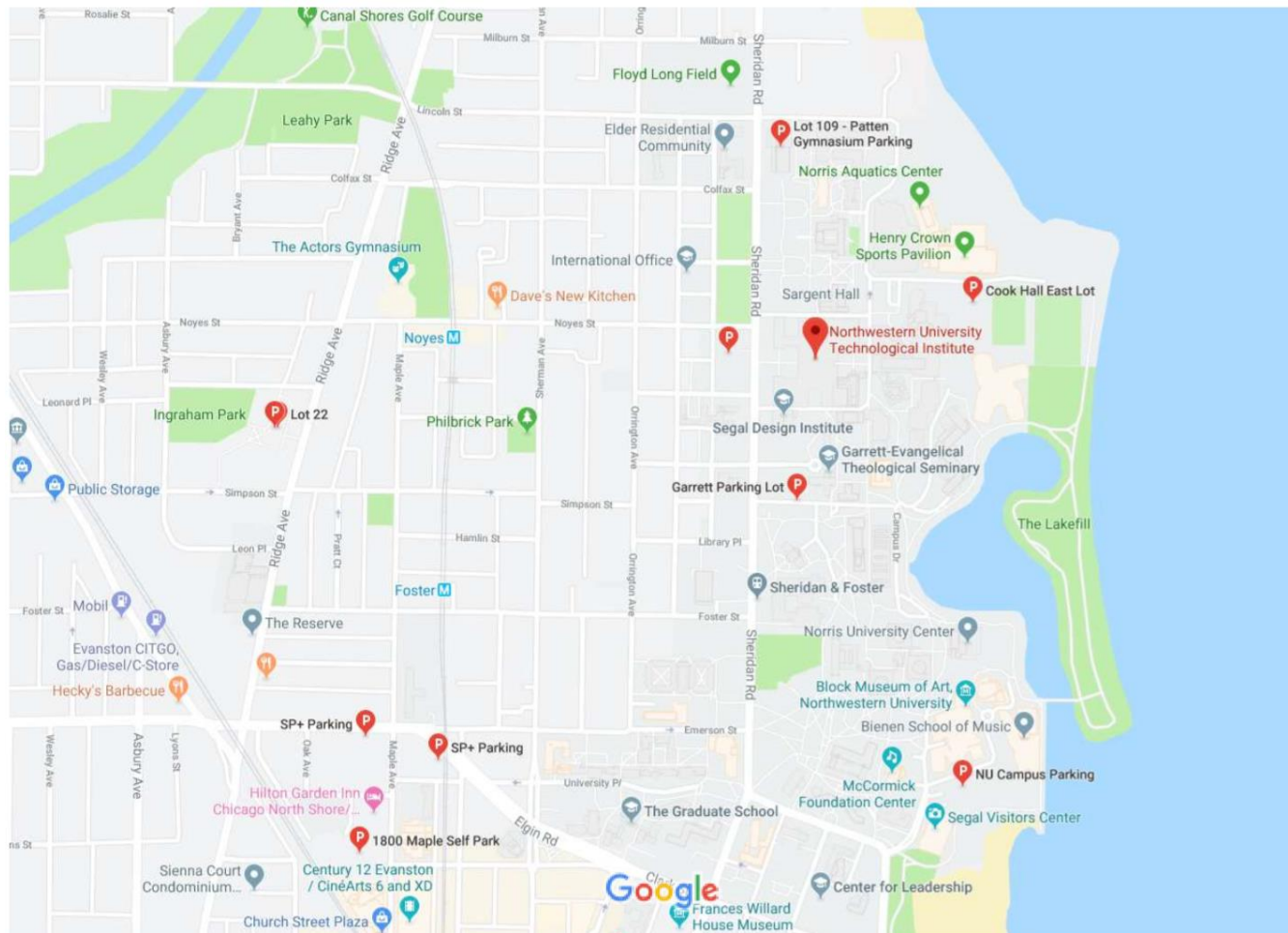
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Notes

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Maps and Directions

Conference Site: Northwestern University Technological Institute
2145 Sheridan Rd, Evanston, IL 60208



Map data ©2019 Google 500 ft

The image is a detailed floor plan of the Technological Institute, showing the first and second floors. The plan is color-coded: red for key areas, yellow for corridors, and purple for other rooms. The first floor includes a Main Entrance, Willens Atrium Reception, Registration Desk, Tech Express (Cafeteria), Ryan Auditorium LR1, and various lecture rooms (LR2, LR3, LR4, LR5). The second floor includes a Willens Atrium Reception, Undergraduate Engineering, and Graduate Engineering. The plan also shows a Courtyard, Library, Chemical and Biological Engineering, and Chemistry departments. Red boxes highlight specific areas of interest, and red arrows indicate the path from the Main Entrance to the Willens Atrium Reception and then to the Undergraduate Engineering department.

Technological Institute, First Floor

Technological Institute, Second Floor