



# 2021 USAF/ TAIWAN MOST



NANOSTRUCTURED MATERIALS FOR SENSING AND SUSTAINMENT  
FINAL PROGRAM REVIEW

VIRTUAL 15-16 JULY, 2021

**2021 USAF/Taiwan MOST**  
**Nanostructured Materials for Sensing and Sustainment**  
 2021 臺美奈米材料基礎科學研發共同合作研究計畫  
**Final Program Review**

Virtual  
 15-16 July, 2021

\* Times listed are Eastern Daylight Time (EDT)  
 0730 EDT = 1930 TST = 2030 JST

**Thursday, 15 July**

0715-0730	Connect to virtual meeting
0730-0735	Administration/announcements
0735-0745	Opening Remarks (AFOSR)
0745-0800	Historical Overview of Program (M.K. Wu, MOST)
	Session 1: Novel and/or Flexible Functional Materials Chair: Dr. Todd Rushing, AOARD
0800-0830 Last 5 minutes for questions	Joint Project 1: <b>Materials Development of Periodical Nitride Structures – Growth, Doping, and Applications</b> 電子與光電應用的高導電率與高遷移率摻雜氮化鋁鎵 Taiwan PI: 楊志忠 (Chih-Chung Yang), National Taiwan University US PI: Shin Mou/Kent Averett, AFRL/Materials & Manufacturing Directorate
0830-0900	Joint Project 2: <b>Higher-Performance Flexible Organic Photovoltaics Based on Polymer Donor/Non-Fullerene Acceptor/2D Nanosheets</b> 基於聚合物給體/非富勒烯受體/二維奈米材料的高性能柔性有機太陽能電池 Taiwan PI: 韋光華 (Kung-Hwa Wei), National Chiao Tung University US PI: Yang Yang, University of California – Los Angeles
	Session 2: Bio-inspired Materials for Sensing Chair: Dr. Tien-Ming Chuang, Institute of Physics, Academia Sinica
0900-0930	Joint Project 3: <b>Development of Biocompatible X-ray Scintillating Nanoparticles for Biomedical Applications</b> 發展高生物相容性 X 光奈米閃爍晶體及其生醫應用 Taiwan PI: 胡宇光 (Yeu-Kuang Hwu), Academia Sinica US PI: John Boeckl, AFRL/Materials & Manufacturing Directorate
0930-0945	Break
0945-1015	Joint Project 4: <b>Nano-Confined Screening of Bio-Recognition Elements for Enhanced Detection of Biomarkers</b> 奈米流體平台用於篩選生物識別分子和多工檢測 Taiwan PI: 周家復 (Chia-Fu Chou), Academia Sinica US PI: Nathan Swami, University of Virginia
	Session 3: Novel and/or Flexible Functional Materials Chair: Prof. Yu-Ming Chang, National Taiwan University
1015-1045	Joint Project 5: <b>Adhesion Mechanics of Van der Waals Interfaces: Fundamental Nanoscale Experiments and Simulations to Enable Flexible Functional Systems</b> 凡德瓦爾材料之界面吸附力學機制:由奈米力學實驗與計算模擬建立可撓性功能系統之關鍵技術 Taiwan PI: 鄭友仁 (Yeau-Ren Jeng), National Chung Cheng University US PI: Robert Carpick, University of Pennsylvania
1045-1100	Day 1 Wrap-up

Friday, 16 July

0715-0730	Connect to virtual meeting
0730-0735	Administration/announcements
	Session 3 (continued): Novel and/or Flexible Functional Materials Chair: Prof. Yu-Ming Chang, National Taiwan University
0735-0805	Joint Project 6: <b>Gate-Tunable &amp; Multifunctional Metal Nitride Zero-Index &amp; Plasmonic Heterostructures for Advanced Optical Sensing &amp; Energy Harvesting</b> 可供光學感測和能源元件應用之可調控多功能金屬氮化物電漿 Taiwan PI: 果尚志 (Shangjr Gwo), National Tsing Hua University US PI: Howard Lee, University of California – Irvine/Zhenrong Zhang, Baylor University
0805-0835	Joint Project 7: <b>Mesochiral Assembly with Controlled Chirality in Chiral Block Copolymers</b> 由掌性分子建構掌性層級結構及其掌性光學之應用 Taiwan PI: 何榮銘 (Rong-Ming Ho), National Tsing Hua University US PI: Gregory Grason, University of Massachusetts - Amherst
0835-0845	Break
	Session 4: Predictive Functional Materials and Materials for Quantum Phenomenon Chair: Dr. Adam Neal, AFRL/RX
0845-0915	Joint Project 8: <b>Nanophotonic Architectures for Quantum Control of Light Emission</b> 基於奈米光子技術之量子輻射操控 Taiwan PI: 吳品韻 (Pin-Chieh Wu), National Cheng Kung University US PI: Harry Atwater, California Institute of Technology
0915-0945	Joint Project 9: <b>Scalable Single Photon Source Using CVD-Grown 2D TMDs on Nano-rod Lattices</b> 結合奈米柱陣列與化學氣相沉積法生長之二維過渡金屬硫族屬化物製備大面積單光子源 Taiwan PI: 李奕賢 (Yi-Hsien Lee), National Tsing Hua University US PI: Hui Deng, University of Michigan
0945-1015	Joint Project 10: <b>Artificially Engineered Exction Quantum Dot Arrays for Quantum Information Science Applications</b> 供量子資訊應用之人造激子量子點陣列研究 Taiwan PI: 安惠榮 (Hyeyoung Ahn)/張文豪 (Wen-Hao Chang), National Chiao Tung University US PI: Chih-Kang Shih, University of Texas - Austin
1015-1030	Concluding remarks

## Profiles

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<p>[USA]</p>  <p><b>Contact Details</b>  <b>Organization Name:</b>          U.S. Air Force Research Laboratory, Materials and Manufacturing Directorate  <b>Address:</b>          2179 12th Street          WPAFB, OH 45433 USA  <b>Phone:</b> (937) 255-9779  <b>Email:</b> shin.mou.1@us.af.mil</p>	<p><b>Dr. Shin Mou</b>  <b>Senior Research Electrical Engineer</b>  <b>Air Force Research Laboratory</b></p> <p>Shin Mou is a senior research engineer, the Transistor Materials research area lead at Materials &amp; Manufacturing Directorate, Air Force Research Laboratory. He received his BS and MS in Electrical Engineering from the National Taiwan University, Taiwan and his PhD in Electrical &amp; Computer Engineering from University of Illinois at Urbana-Champaign. He was a recipient of the National Research Council Postdoctoral Fellowship (2009-2011.) He previously worked at IBM as a CMOS device engineer/scientist. His doctoral research was on infrared photodetectors based on InAs/GaSb type-II superlattices. His current research interests include ultra-wide bandgap materials such as Ga<sub>2</sub>O<sub>3</sub> and AlN for transistor applications and quantum information science.</p>

# **MATERIALS DEVELOPMENT OF PERIODICAL NITRIDE STRUCTURES – GROWTH, DOPING, AND APPLICATIONS**

[Taiwan]

**Chih-Chung (C.C.) Yang**  
**National Taiwan University**

[USA]

**Shin Mou, Kent Averett, and Adam Neal**  
**Air Force Research Laboratory**

## **ABSTRACT**

The nitride based material system is the cornerstone of recent technological advancements in LEDs and RF/power electronics. It has been commercialized into various products especially in visible light LEDs and power switches in the past decade or two. With the success, researchers around the world continuously move the frontier of nitride based materials into novel material combinations, better performance, and new applications. In this presentation, we focus the material development on periodical nitride structures grown by molecular beam epitaxy (MBE) for improved electrical conductivity and wider bandgap energy aiming at ultra-violet (UV) LEDs.

We started the project with periodical n-type and p-type doping in binary GaN to improve the electrical conductivity, which is much needed especially in p-type GaN due to the high acceptor energy of Mg. By combining the high mobility of an nm-scale u-GaN (undoped GaN) layer with a neighboring high hole (electron) concentration p-GaN (n-GaN) layer, we obtained improved effective conductivity in this type of periodical structures. Furthermore, we applied the same technique to p-type AlGa<sub>N</sub> of 25-30 % in Al content and achieved an almost 5 times improvement in electrical conductivity. This result is especially important since UV LEDs using AlGa<sub>N</sub> suffer from low efficiency and part of that is due to the low electrical conductivity in p-AlGa<sub>N</sub>.

Last, we developed a novel periodical structure in AlN/GaN short-period superlattices (SPSLs) in order to achieve wider bandgap and UV emission without ternary AlGa<sub>N</sub>. Due to the very thin GaN quantum well (a few monolayer) in the SPSLs, we are able to widen the bandgap from bulk GaN energy (3.4 eV) in blue light to energy in UV light wavelength (4.4 eV) due to the quantum confinement effect. We will continuously pursue this new direction in our collaboration in which the Taiwan team will conduct UV emission/transmission measurements for the structures grown at AFRL in order to characterize their bandgap energy. In addition, we will attempt to optimize the doping, mobility, and conductivity in the AlN/GaN SPSLs for targeted applications.



## Profiles

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<p>[Taiwan]</p>  <p><b>Contact Details</b>  <b>Organization Name:</b> National Yang Ming Chiao Tung University  <b>Address:</b> Dept. of Materials Sci. &amp; Eng. 1001 University Road, Hsinchu, Taiwan 300, ROC  <b>Phone:</b> +886-3-573-1871  <b>Email:</b> khwei@mail.nctu.edu.tw</p>	<p><b>Dr. Kung-Hwa Wei</b>  <b>Professor</b>  <b>National Yang Ming Chiao Tung University (NYCU)</b></p> <p>Professor Kung-Hwa Wei received his Ph.D. in Chemical Engineering from the University of Massachusetts, Amherst, and has published more than 210 SCI peer-reviewed journal papers. His main research fields include conjugated polymers, quantum dots, and two-dimensional materials, including graphene and MoS<sub>2</sub>. Professor Wei has been awarded Fellow of International Advanced Materials (2019), Lu CH award (2019) by MRS-T, YZ Hsu Chair-green energy (2017), Asia Pacific Academy of Materials Fellow (2017), the Ministry of Science and Technology Outstanding Research Award (three times: 2003, 2010 and 2014), the Materials and Science Award, the Ho Chin Tui Award (2014), and the Outstanding Research Award of the Polymer Society (2010). He is a Fellow of the Asia Pacific Academy of Materials. His Google Scholar citations exceed 16,700, and he has published papers in Science (2015) and Nature Nanotechnology (2017) relating to 2D materials.</p>

# HIGHER-PERFORMANCE FLEXIBLE ORGANIC PHOTOVOLTAICS BASED ON POLYMER DONOR/NON-FULLERENE ACCEPTOR/TWO-DIMENSIONAL NANOSHEETS

[USA]

**Yang Yang**

**University of California, Los Angeles**

[Taiwan]



**Kung-Hwa Wei**

**National Chiao Tung University**

## ABSTRACT

Thanks to the funding from the AF-Office of Scientific Research, huge progress on high-performance OPV has been achieved in these three years. Starting from narrow bandgap acceptors, we designed and synthesized new small molecular acceptors and broke the world record of the highest efficiency of OPV (12.6%, certified at the photovoltaic Lab of Newport Corporation) and brought up novel concepts to enhance the photovoltaic performance and the stability of OPV devices via versatile third components and alternative electron transporting layers. We also improved the vertical phase separation in nonfullerene system to provide a much better charge transportation efficiency of OPV devices. High-performance transparent OPV and tandem OPV devices were achieved by the support of this project. Through a careful selection of a third component, the power conversion efficiency (PCE) of the device was 16.8%. For semi-transparent OPV devices, we designed transparent hole-transporting frameworks and reached a power conversion efficiency of 12%. A sequential deposition strategy that involves individually depositing a polymer donor layer and a small-molecule acceptor layer as the active layer devices provide the champion PCE of 12.91%. For tandem OPV devices, we efficiently balanced the light distribution of the front and rear sub cells and achieved power conversion efficiency of 15.1%. Novel material system and device structure of the OPV devices were also realized during this project. We successfully developed nanoscale two-dimensional transition-metal dichalcogenide materials as third components and electron transporting materials. We realized a robust noncovalent  $\pi \cdots \pi$  interaction-stacked organic framework (OF) and developed a few-nanometer-thick third-component layer on a bulk-heterojunction binary blend layer. Our works have made a significant impact on the OPV community. To date, the total citation count of the published papers is over 500, which is remarkable given that it has only been three years. The fruits of these projects will leave a lasting impact in the field and for the broader research community.

## Profiles

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<p>[USA]</p>  <p><b>Contact Details</b>  <b>Organization Name:</b> Air Force Research Laboratory Materials and Manufacturing Directorate  <b>Address:</b>  Bldg 651 Room 257  3005 Hobson Way  Wright Patterson AFB, OH 45433-7707  <b>Office:</b> (937) 255-9906  <b>FAX:</b> (937) 255-4913  <b>Email:</b> John.Boeckl@us.af.mil</p>	<p><b>Dr. John Boeckl</b>  <b>Senior Research Scientist</b>  <b>US Air Force Research Laboratory</b></p> <p>Dr. John Boeckl is a Research Scientist in the Materials and Manufacturing Directorate at the Air Force Research Laboratory, Wright-Patterson Air Force Base, Ohio. He works in the Functional Materials Division, splitting time between the NanoElectronic Materials Branch; accelerating the maturation of two-dimensional material heterostructures as a solution to developing high frequency RF electronics, and the Photonic Materials Branch; analyzing cathode and anode materials to advance high power vacuum electronics. Recent research focuses on low dimensional carbon materials providing significant contributions in several areas focused on the decomposition of SiC into carbon nanotubes and epitaxial graphene. Dr. Boeckl has vast experience in electron optics characterization of materials and is well versed in scanning and transmission electron microscopy techniques to solve materials problems in nanostructured growth. Dr. Boeckl received his BS degree (1989) in Electrical Engineering from Cleveland State University and his M.S. (1998) and Ph.D (2005) degrees in Electrical and Electronic Engineering from The Ohio State University. Awards and honors include the Affiliate Societies Council Outstanding Scientists &amp; Engineers Award (2013), the Materials and Manufacturing Directorate International Award (2016,2010), the Exemplary Civilian Service Award (2000).</p>



# **DEVELOPMENT OF BIOCOMPATIBLE X-RAY SCINTILLATING NANOPARTICLES FOR BIOMEDICAL APPLICATIONS**

[Taiwan]

**Yeu-Kuang Hwu**

**Institute of Physics, Academia Sinica**

[USA]

**John Boeckl**

**Air Force Research Laboratory**

## **ABSTRACT**

This project aims to develop an x-ray excited optogenetic technology using x-ray scintillating nanoparticles (ScNPs) to mediate high penetration x-rays to trigger light-sensitive proteins to modulate cell activities. Such manipulation at the cellular level was demonstrated using visible light illumination and is now considered one of the biotechnology breakthroughs which has already impacted neuroscience and other domains of life science. The objective of this project is to take this technology further by taking advantage of the high penetration depth of x-rays to achieve the same control and monitoring capability on large specimens and animals.

Optogenetics uses light-sensitive proteins to achieve cell level control by visible light. When genetically engineered cells, such as neurons, expressing a light-sensitive protein bombarded with light a conformational change of the cell channels or specific signaling pathways are opened for neural activation or silencing. Different light-sensitive protein variants have been discovered, or engineered, to stimulate intracellular signaling pathways with different wavelengths of light and achieved clean, complex and specific manipulation at the cellular level.

The current optogenetic technology faces one severe drawback: the low penetration depth using visible light in tissues. The objective of this project is to take the optogenetics further by replacing visible light with the high penetration depth of x-rays and achieving the same control capability on large specimens and animals. We propose an alternative approach: by implementing an internal conversion mechanism to convert x-rays to visible light photons. Placing high conversion efficiency scintillating materials in the vicinity of the light-sensitive proteins, x-rays could produce sufficient visible light photons to activate the optogenetic switch deep in the tissue. This objective can be achieved using scintillating nanoparticles (ScNPs) with high biocompatibility to mediate high penetration x-rays to trigger light-sensitive proteins to modulate cell activities.

## Profiles

<p>[USA]</p>  <p><b>Contact Details</b>  <b>Organization Name:</b> University of Virginia  <b>Address:</b> 351 McCormick Rd, PO Box 400743, Charlottesville, VA 22904, USA  <b>Phone:</b> (434) 924 1390  <b>Fax:</b> (434) 924 8818  <b>Email:</b> nswami@virginia.edu</p>	<p><b>Dr. Nathan S. Swami</b>  <b>Professor</b>  <b>Electrical &amp; Computer Engineering</b>  <b>University of Virginia, Charlottesville</b></p> <p>Nathan Swami serves as Professor of Electrical Engineering at the University of Virginia, with joint appointments in the Chemistry department and the Cancer Center. His research group specializes in microfluidic platforms for biofabrication, biophysical single-cell isolation and cytometry and for nanoconfined signal amplification in biomolecular sensing. His recent honors include the 2021 Mid-Career Award from the AES Electrophoresis Society within the Federation of Analytical Chemistry &amp; Spectroscopy Societies (FACSS) and the Charles L. Brown Outstanding Faculty Research Award of the Department of Electrical &amp; Computer Engineering at University of Virginia in 2020. Prior to University of Virginia, he served on the scientific staff at Motorola Labs and at Clinical Microsensors, Inc., a Caltech start-up company. He seeks to impact diagnostic systems within point-of-care and resource-poor settings for enabling precision medicine. More information on his research is at: <a href="https://scholar.google.com/citations?user=iS12HRMAAAJ&amp;hl=en">https://scholar.google.com/citations?user=iS12HRMAAAJ&amp;hl=en</a></p>
<p>[Taiwan]</p>  <p><b>Contact Details</b>  <b>Organization Name:</b> Academia Sinica  <b>Address:</b> 128, Sec. 2, Academia Rd., Nankang District, Taipei 11529, Taiwan  <b>Phone:</b> 886-2-2789-6761  <b>Fax:</b> 886-2-2651-0704  <b>Email:</b> cfchou@phys.sinica.edu.tw</p>	<p><b>Dr. Chia-Fu Chou</b>  <b>Professor &amp; Fellow</b>  <b>Institute of Physics</b>  <b>Academia Sinica, Taipei, Taiwan</b></p> <p>Dr. Chou received his Ph.D. in 1996 from the State University of New York at Buffalo, and served as an NIH Postdoctoral Fellow at Princeton University. Following appointment as a Principal Staff Scientist at Motorola Labs from 2000-2003 and an Associate Professor at Applied Nanobioscience Center at Biodesign Institute, Arizona State University, he joined Institute of Physics, Academia Sinica, as a Research Fellow in 2006. His group conducts multidisciplinary research at the boundaries between the physical and life sciences, in the emerging fields of bioMEMS, biosensors, micro/nanofluidics, molecular and cellular biophysics. He has over 100 scientific papers and 13 issued patents. He is best known in the BioMEMS community as an inventor of electrodeless dielectrophoresis for molecular trapping and the nanoscale molecular dam for ultrafast molecular enrichment and sensing. His work has led to an Outstanding Research Award in 2014 from the Ministry of Science &amp; Technology, ROC, and Academia Sinica Investigator Award (2020-2024).</p>

# NANO-CONFINED SCREENING OF BIO-RECOGNITION ELEMENTS FOR ENHANCED DETECTION OF BIOMARKERS

[USA]  
**Nathan Swami**  
University of Virginia

[Taiwan]  
**Chia-Fu Chou**  
Academia Sinica

## ABSTRACT

Tools for biomolecular assessment and enhancement of human performance among field personnel of the Department of Defense is a central vision of AFOSR, but this requires platforms capable of identifying receptors that can recognize key neurochemical human performance biomarkers and platforms to monitor biomarker expression profiles under perturbations. Using nanoscale fluidic confinement strategies to alleviate diffusional transport limitations, this project seeks to develop biofunctionalized material and device platforms for selecting receptors based purely on chemical binding affinity characteristics to biomarkers and on signal amplification schemes to enhance detection sensitivity.

In the current year of the collaboration, the Chou group at Academia Sinica led on the development of a nanoconfined optofluidics platform to study binding kinetics of aptamer candidates for binding to model biomarkers (*Nanoscale*, submitted), using thrombin aptamer-sensing as the model, as well as the screening platform for coliform bacteria (*ACS Sensors*, in revision) and the spike protein of SARS-COV2. Specifically, a unique surface plasmon resonance imaging (SPRI) system was developed to aid in high-throughput aptamer screening (manuscript in preparation). The Swami group at University of Virginia has focused on confinement for redox amplification using nanoporous gold electrodes in microfluidic channels to screen for candidate peptide receptors for binding to the S-layer protein of SARS-COV2 (*ACS Central Science*, submitted in collaboration with AFRL), for detection of bacterial secretions and intracellular factors that are activated by neurological analytes *in vivo* (*Sens. Act. B: Chem.* (2020) 312, 127936) and for impedance cytometry to detect single vesicles (*Adv. Biol.* (2021) 2100438). Upcoming work includes the application of the optofluidic platform to screen for aptamer interactions with biomarkers and detection schemes to improve sensitivity.

The researchers supported as part of this work have been advised by both PIs: Chia-Fu Chou and Nathan Swami, as apparent from the joint publications. Various aspects of this work were conducted in collaboration with the groups of Jorge Chavez (AFRL's 711<sup>th</sup> Human Performance Wing) and Nancy Kelley Loughnane (AFRL's Synthetic Biology initiative). Future experiments on biomarker targets, aptamers and plasmids involve samples from AFRL, nanofluidic devices from Academia Sinica and detection schemes from University of Virginia to further this vision for human performance assessment.

## Profiles

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<p>[Taiwan]</p>  <p><b>Contact Details</b>  <b>Organization Name:</b>  National Chung Cheng University  <b>Address:</b> Chia-Yi 62102,  Taiwan  <b>Phone:</b> +886-5-275-7575  ext. 31308  <b>Fax:</b> +886-5-272-0589  <b>Email:</b> imeyrj@gs.ncku.edu.tw</p>	<p><b>Dr. Yeau-Ren Jeng</b>  <b>Endowed Chair Professor</b>  <b>National Cheng Kung University</b></p> <p>Yeau-Ren Jeng is Endowed Chair Professor of National Cheng Kung University, Founding Director of Advanced Institute for Manufacturing with High-tech Innovations (AIM-HI). His research has provided significant benefits to multiple industries, including the automotive, electronic, manufacturing, and nano-related industries. His publications are widely cited including several textbooks and handbooks. He is the advisor of several dissertation awards from the Ministry of Science and Technology and the Chinese Society of Mechanical Engineers. He holds over 30 patents and his awards include Academic Achievement Award from Ministry of Education, Outstanding Technology Transfer Medal and Merit Research Fellow Award of Ministry of Science and Technology, Y.Z. Hsu Science Medal from Far Eastern Y. Z. Hsu Science and Technology Memorial Foundation, Life Time Achievement Medal from Chinese Society of Mechanical Engineers, Innovative Research Award from American Society of Mechanical Engineers, Captain Alfred E. Hunt Medal from Society of Tribologists and Lubrication Engineers, and McCuen Special Achievement Award from General Motors.</p>

## Profiles

[USA]



### Contact Details

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### Dr. J. David Schall

#### Associate Professor

North Carolina Agricultural and Technical State University

Dr. Schall is an associate professor in Mechanical Engineering at North Carolina Agricultural and Technical State University. Previously he was a faculty member at Oakland University (2009-2019). He received his Ph.D. in Materials Science and Engineering from North Carolina State University in 2004. He was a postdoc at the United States Naval Academy from 2004 to 2009. He investigates nanotribology and nanomechanics using molecular dynamics simulation and specializes in characterizing and understanding tribo-initiated chemistry, adhesion, and wear using simulation. He has authored 67 peer-reviewed journal publications.

# ADHESION MECHANICS OF VAN DER WAALS INTERFACES: FUNDAMENTAL NANOSCALE EXPERIMENTS AND SIMULATIONS TO ENABLE FLEXIBLE FUNCTIONAL SYSTEMS


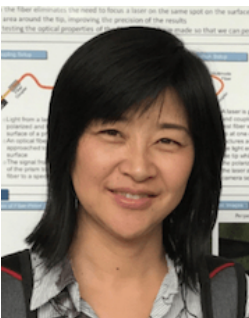
[USA]	[Taiwan]	
<b>Robert W. Carpick</b>	<b>J. David Schall</b>	<b>Yeau-Ren Jeng</b>
<b>U. Pennsylvania</b>	<b>North Carolina</b>	<b>National Chung-Cheng University</b>
	<b>A&amp;T</b>	

## ABSTRACT

Our goal is to investigate the atomic-scale mechanisms governing the contact and adhesion behavior of two-dimensional (2D) materials through innovatively combining experiments and simulations. 2D materials, including molybdenum disulfide ( $\text{MoS}_2$ ), boron nitride (BN), and graphene, are also known as van der Waals (vdW) materials. The unprecedented properties arising from their unique 2D architecture render them crucial for Air Force (AF) applications, especially in lightweight, low power, flexible, wearable devices for active components in sensing applications and wireless communication. Fundamental studies of their contact and adhesion mechanics are needed as the growth, processing, and functioning of devices at high strains hinge crucially on adhesive properties. Here we utilize conventional and *in situ* transmission electron microscopy (TEM)-based atomic force microscopy (AFM), *in situ* Raman-based nanoindentation, and molecular dynamics (MD) simulations to investigate contact and separation processes in self-mated and heterostructure vdW interfaces. We have developed a method in collaboration with AFRL to create nanoasperities coated with 2D-materials. We observe that the structure of the  $\text{MoS}_2$  films depends on the curvature of the tip. Below a critical tip radius, disorder in the layering becomes pronounced. We have conducted MD simulations to explore the physical origins of this effect. We then measured adhesion of self-mated  $\text{MoS}_2$  -  $\text{MoS}_2$  nanoasperity contacts inside the TEM. From this, we estimate the work of adhesion between the asperities. Work of adhesion values are far in excess of estimates for the van der Waals force between the asperities, indicating that high surface energy defects in the 2D material are likely present at their surface. We also observed a progressive increase in the work of adhesion upon repeated contact-separation cycles. Using the *in situ* visualization capabilities of our instrumentation, we attribute the increase to nanometer-scale transfer and/or exfoliation of  $\text{MoS}_2$ . MD simulations of the nanocontacts are conducted for comparison. The simulations account for the effect of unintended offsets of the tips' axes. The simulations reveal significant differences in adhesion when making contact at different points on the tip and with different tip orientations, which may have important ramifications in device design when utilizing vdW materials. *In situ* Raman microscopy measurements were also used to examine indentation and sliding of both monolayer graphene. The measurements reveal removal of graphene from the center of the wear track, and the formation of multilayer regions stacked at the edge, with higher applied load increasing the number of defects in these multilayer regions.



## Profiles

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<p>[USA]</p>  <p><b>Contact Details</b>  <b>Organization Name:</b> Baylor University  <b>Address:</b> Department of Physics, Baylor University, One Bear Place #97316, Waco, TX 76798-7316  <b>Phone:</b> 2547102419  <b>Fax:</b> 2547103878  <b>Email:</b> Zhenrong_Zhang@baylor.edu</p>	<p><b>Dr. Zhenrong Zhang</b>  <b>Associate Professor</b>  <b>Baylor University</b></p> <p>Dr. Zhang joined the Baylor faculty in January 2010. Prior to coming to Baylor, she held a postdoctoral position in University of Innsbruck, Austria (2002-2004) with Prof. Erminald Bertel and a joint postdoctoral position in Pacific Northwest National Laboratory with Zdenek Dohnalek and University of Texas at Austin with J. Mike White (2004-2009).</p> <p>Dr. Zhang's research is interested in energy and environment related catalytic chemical physics, specifically, understanding the mechanisms and dynamics of catalytic reactions on metal oxides by using scanning probe microscopy (SPM) coupled with the Raman spectroscopy.</p>

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**Dr. Shangjr (Felix) Gwo**

**Professor; Director and Distinguished Research Fellow**

**National Tsing-Hua University; Research Center for Applied Sciences, Academia Sinica**

Dr. Gwo received his Ph.D. in Physics from the University of Texas at Austin.

Dr. Gwo's research interests include semiconductor material physics, nanophotonics, nanoplasmonics, and surface/interface science. Most recently, his research group has been working extensively on plasmonic metamaterials composed of colloidal metal nanoparticles, linear and nonlinear plasmonic metasurfaces, plasmonic nanolasers, surface-enhanced Raman spectroscopy, and III-nitride nanostructure-based light-emitting devices. He has published more than 225 peer-reviewed papers with over 9,500 citations (h-index: 52). PI Gwo is an elected Fellow of the American Physical Society (APS) and the Physical Society of the Republic of China (PSROC).

# **GATE-TUNABLE AND MULTIFUNCTIONAL METAL NITRIDE ZERO-INDEX AND PLASMONIC HETEROSTRUCTURES FOR ADVANCED OPTICAL SENSING AND ENERGY HARVESTING**

[USA]

**Howard Lee**  
(Original US PI)  
UC Irvine/Baylor University

**Zhenrong Zhang**  
(Substitute US PI)  
Baylor University

[Taiwan]

**Shangjr Gwo**  
National Tsing-Hua University and  
Academia Sinica

## **ABSTRACT**


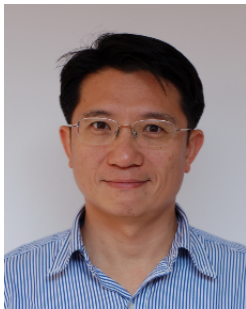
The optical response of epsilon-near-zero (ENZ) materials has generated significant interest recently as the electromagnetic field inside media with near-zero permittivity has been shown to exhibit unique optical properties. These ultrathin ENZ/plasmonic materials hold promise for enhancing optical emissions for optical sensing and enhanced absorption for energy harvesting. ENZ/plasmonics optics have been explored extensively, but prior studies show several limitations, including (1) lack of precise control of carrier distribution for efficient ENZ/plasmonic mode excitation, (2) high optical loss due to the film's amorphous or high surface roughness, and (3) narrow bandwidth of operating wavelength.

Here we report the progress of our collaborative research to establish an efficient titanium nitride (TiN) ENZ/plasmonic material and heterostructure with enhanced optical properties such as enhanced optical emission and broadband absorptivity/emissivity for nano-optoelectronic devices. We present our recent results on advanced fabrication of high-quality, single crystalline titanium nitride (TiN) and double ENZ TiN thin films via nitrogen-plasma-assisted molecular-beam epitaxy (MBE) and magnetron sputtering techniques for zero-index and plasmonic applications. In addition, we also present our results on single-TiN-layer metasurface broadband absorber made from the refractory and oxidation-resistant TiN(111) epitaxial film grown on c-plane sapphire by nitrogen-plasma-assisted MBE with optimized plasmonic characteristics and ~90% absorptivity over the visible spectrum.

We also present our recent results on room temperature photoluminescence (PL) enhancement of monolayer MoS<sub>2</sub> on epitaxial TiN ENZ thin film. We observed that photoluminescence enhancement increases as TiN becomes more metallic, and strong enhancement is obtained at excitation wavelengths equal to or longer than the ENZ wavelength of TiN films. The enhancement is attributed to the increased excitation field in MoS<sub>2</sub> at TiN's ENZ wavelength, and interference effects for thick spacers that separate the MoS<sub>2</sub> flakes from TiN films in the metallic regime. Finally, the active control of the emission of quantum dot of ultrathin ultra-thin ENZ heterostructure will be discussed. Our studies enrich the fundamental understanding of emission properties of ENZ substrates that could be important for developing advanced nanoscale lasers/light sources, optical/bio-sensors, and nano-optoelectronic devices.

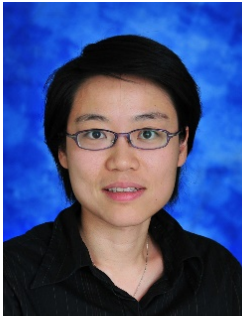
Our U.S. team and TW team have established a close collaboration in this project, including exchanging TiN samples, sharing optical measurement data, and discussing results. The PIs met three times in person and every quarter online during the project period. PI Lee visited PI Gwo's lab in Taiwan and discussed the results and project directions with him and his students during summer 2019. Sixteen journal papers were published/submitted including two joint papers, and more than 20 conference invited talks were presented during the grant period. PIs and their students also earned prestigious awards during the grant period. This project provided a solid foundation for research collaboration on ENZ/plasmonic optics based on high-quality TiN thin films and opened research opportunities with AFRL. The PIs will continue the successful collaborations beyond the grant period.

## Profiles

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<p>[Taiwan]</p>  <p><b>Contact Details</b>  <b>Organization Name:</b>          Department of Chemical Engineering, National Tsing Hua University  <b>Address:</b>          No. 101, Sec. 2, Kuang-Fu Road, Hsinchu, 30013, Taiwan  <b>Phone:</b> +886-3-5738349  <b>Fax:</b> +886-3-5715408  <b>Email:</b> <a href="mailto:rmho@mx.nthu.edu.tw">rmho@mx.nthu.edu.tw</a></p>	<p><b>Dr. Rong-Ming Ho</b>  <b>Tsing Hua Chair Professor</b>  <b>National Tsing Hua University</b></p> <p>Dr. Ho received his Ph.D. in the Institute of Polymer Science from the University of Akron in 1995. Dr. Ho has published more than 170 peer-reviewed scientific papers. Dr. Rong-Ming Ho is a pioneer in the research areas of chiral block copolymer self-assembly. He has also developed a platform technology using degradable block copolymers as templates for templated syntheses to fabricate well-ordered nanonetwork materials for metamaterial applications. His research also focuses on nanopatterning from integration of top-down and bottom-up methods collaborating with TSMC for soft lithography. Currently, he is a Tsing Hua Chair professor at Dept of Chemical Engineering, NTHU. Also, he is a Coordinator of the Polymer and Fiber division for the Ministry of Science and Technology (MOST), Taiwan. Dr. Ho received the Outstanding Research Award, the MOST of Taiwan. Outstanding Polymer Research Award, Society of Polymer, Taiwan. He was elected as a fellow of the American Physical Society in 2014. He is an editorial advisory board member of <i>GIANT</i>.</p>

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### Dr. Yu-Chueh Hung

**Professor**

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Dr. Hung received her Ph.D. in Electrical Engineering from the University of California, Los Angeles, in 2007. After graduation, she worked as a postdoc at Zentrum für Halbleitertechnik und Optoelektronik, Universität Duisburg-Essen in Germany from May to November 2007. In February 2008, she joined the faculty of the National Tsing-Hua University in Taiwan, where she is now a Professor of Electrical Engineering Department and Institute of Photonics Technologies. Dr. Hung's research activities lie in the fields of DNA biopolymer photonics, optoelectronic devices, and electromagnetic properties of 3D nanostructured materials. Dr. Hung is the recipient of Wu Ta-You Memorial Award (Young Investigator Award) from the Ministry of Science and Technology of Taiwan in 2017.

# MESOCHIRAL ASSEMBLY WITH CONTROLLED CHIRALITY IN CHIRAL BLOCK COPOLYMERS

[Taiwan]

**Rong-Ming Ho & Yu-Chueh Hung**  
National Tsing Hua University

[USA]



**Gregory M. Grason**  
University of Massachusetts

## ABSTRACT

The presentation will report our progress towards a new strategy for fabrication functional chiroptical nanonetwork materials via mesochiral assembly of self-assembling block copolymers composed of chiral segment (denoted as BCP\*). Gyroid-structured materials can be found in nature and synthetic materials, with the far most common form that double gyroid (DG). This achiral structure is composed of a pair of enantiomorphic chiral networks and is widely formed by self-assembly of achiral diblock copolymers. For triblock terpolymers, an alternating DG (aDG) with two chiral networks from distinct end blocks (with distinct chemical compositions), but the chirality is the alternating network is randomly selective, giving a macroscopically achiral phase. Recent experimental and theoretical efforts have illuminated a new mechanism of mesochiral control via BCP\* assembly. In particular, various self-assembled phases including double gyroid (DG), double diamond (DD) and helical (H\*) phases were observed by **Ho** from the self-assembly of *chiral diblock copolymers* with equivalent composition, giving building blocks with nearly identical optical activities for self-assembly. Significant enhancement of vibrational circular dichroism (VCD) measured for DG relative to DD, in combination with self-consistent field modeling by **Grason** reveals the emergence of weak structural chiral bias toward volume asymmetric (i.e. chiral) DG phases. By taking advantage of homochiral evolution at different length scale through chirality transfer from self-assembly of triblock terpolymers composed of a chiral end block, an alternating DG (aDG) giving the chiral block with a gyroid network of controlled chirality we experimentally realized by **Ho** and confirmed by reconstructions of morphologies electron. To understand the chirality transfer mechanism in the chiral triblock mechanism, **Grason** used self-consistent field methods to explore the underlying complex texture of twisted segmental packing threaded within tubular gyroid domains, revealing, for the first time, the emergence of strongly biaxial twist in a BCP morphology. Using the platform technologies developed by **Ho**, well-defined nanoporous polymers with SG nanochannel can be used as a template for templated syntheses, giving nanohybrids. As a first demonstration, **Ho** developed templated synthesis of Au nanohelices, giving chiroptical properties in a thin-film state experimentally, with the theoretical prediction via finite-difference time domain (FDTD) computations by **Hung**. More recently, templated synthesis of Au- and TiO<sub>2</sub>-based single gyroids have been created by chirality controlled triblock assembly, creating a pathway for chiral metamaterials with predicted optical and plasmonic properties.



# Profiles

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<p>[Taiwan]</p>  <p><b>Contact Details</b>  <b>Organization Name:</b>          National Cheng Kung University  <b>Address:</b> No 1 University Road,          Tainan City 70101, Taiwan  <b>Phone:</b> +886-6-2757575 ext. 63928  <b>Fax:</b> +886-6-2095040  <b>Email:</b> pcwu@gs.ncku.edu.tw</p>	<p><b>Dr. Pin-Chieh Wu</b>  <b>Assistant Professor</b>  <b>National Cheng Kung University</b></p> <p>Dr. Wu received his Ph.D. in Applied Physics from National Taiwan University. Dr. Wu is now an assistant professor in the Department of Photonics at National Cheng Kung University. He is also a visiting associate in the Department of Applied Physics and Materials Science at Caltech.</p> <p>Dr. Wu has published more 45 technical papers with h-index of 33 (from google scholar, &gt;4900 citations) in the area of nano-photonics. His research has primarily focused on the nano-optics and nano-photonics, especially for the field of plasmonics, metamaterials and metasurfaces for light manipulation. In addition, Dr. Wu dedicate to develop a highly interdisciplinary field which incorporates with the active materials, metasurface/metamaterials, and quantum optics for the investigation of light-induced processes at nano-scale.</p> <p>Dr. Wu is award the Yushan Young Scholar (2019-2024) supported by Ministry of Education (MOE), Taiwan. He is an invited reviewer of several scientific journal such as <i>Science</i>, <i>Nature Communications</i>, <i>ACS Nano</i>, <i>ACS Photonics</i>, etc.</p>

# NANOPHOTONIC ARCHITECTURES FOR QUANTUM CONTROL OF LIGHT EMISSION

[USA]

Harry A. Atwater

California Institute of Technology

[Taiwan]

Pin-Chieh Wu

National Cheng Kung University

## ABSTRACT


In 2019, we experimentally demonstrated the design of tunable nanophotonic structures with electrically tunable III-V multiple-quantum-well-based metasurfaces and VO<sub>2</sub> based metasurfaces for dynamic control of light (amplitude, phase, deflected angle, *etc.*). This past year, we experimentally extended the scheme of active metasurface to a *multifunctional* (both beam steering and focusing) metasurface that enables active switching of optical functionality. We also developed an ITO-based active metasurface operating at the epsilon-near-zero condition to dynamically control the polarization state of reflected light in the near-infrared. In addition, we systematically explored the broadening mechanisms of spectral lines of quantum emitter single photon sources in hexagonal boron nitride (hBN). The linewidth of zero phonon line emission is studied at temperatures ranging 4K-300K and effect of thermal broadening and spectral diffusion is extracted. We have also investigated the photon statistics of photoluminescence from single photon emitters in hBN and compared the result to a beam of thermal light and a coherent laser light. In another work, we experimentally demonstrated determination of nanometric axial location (down to  $\sim 7$  nm) of these color centers with 3D characterization of their dipole orientation using a phase change material.

One of the major challenges in quantum photonics and photonic quantum technology is efficiently collection of emitted photons. In our recent work, we addressed this problem by designing a hybrid coupler for efficiently directing photons from an hBN quantum emitter with high radiative Purcell enhancement to a dielectric metasurface lens. We reported radiative Purcell factors up to 285 and photon collection efficiencies up to 89% for a lossless metasurface, applying a continuous hyperboloidal phase front.

We also developed high index dielectric TiO<sub>2</sub> based metasurface optimized to support strong Mie resonances at wavelength for photon emission from hBN quantum emitter, enabling the control of photon emission. The antenna-emitter interaction has also been investigated by incorporating dielectric metasurface arrays with photoluminescence (PL) dye molecules. We found that the antenna-emitter coupling can be artificially modulated by tuning the metasurface aperture size.

In the next steps, we plan to measure the dependence of photon statistics on the temperature and investigate single photon emission from a statistically significant number of quantum emitters. We also are working to experimentally realize our theoretical proposal to demonstrate efficient collection of photons at high Purcell enhancement. Using emission polarimetry, we will determine the orientation of the quantum emitter and select the ones with strong *very* components. Benefitting from our group's work on silicon carbide (SiC) for lossless dielectric metasurfaces we will design, fabricate and test a SiC-metasurface lens suitable for photon collection from hBN quantum emitters. We will perform lifetime measurements to demonstrate the Purcell enhancement of emission, and highly directional emission will be quantified using back focal plane imaging.

## Profiles

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<p>[USA]</p>  <p><b>Contact Details</b>  <b>Organization Name:</b>  University of Michigan  <b>Address:</b>  450 Church Street, Ann  Arbor, MI 48109 USA  <b>Phone:</b> +1 734.763.7835  <b>Email:</b> dengh@umich.edu</p>	<p><b>Dr. Hui Deng</b>  <b>Professor of Physics</b>  <b>University of Michigan</b></p> <p>Dr. Deng received her Ph.D. in Applied Physics from Stanford University.</p> <p>Dr. Deng has published more than 50 technical papers in quantum optics and semiconductor physics. Her research has focused on quantum phenomena in solid state systems, such as polariton Bose-Einstein condensation, quantum dots, and quantum memories for quantum networks.</p> <p>Dr. Deng was a postdoc at California Institute of Technology from 2006 to 2008. She joined the University of Michigan, Ann Arbor in 2008 as an assistant professor and was promoted to associate professor in 2015 and to full professor since 2020.</p> <p>Dr. Deng received the Air Force Office of Scientific Research Young Investigator Program award and NSF Career Award in 2012, and the Humboldt Foundation's Friedrich Wilhelm Bessel Research Award in 2017. She is an elected fellow of the American Physical Society (2017) and the Optical Society of American (2018).</p>

# SCALABLE SINGLE PHOTON SOURCE USING CVD-GROWN 2D TMDs ON NANO-ROD LATTICES

[USA]

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**University of Michigan, Ann Arbor**

[Taiwan]

**Yi-Hsien Lee**

**National Tsinghua University**

## ABSTRACT

Single photon source (SPS) is an essential building block for quantum information systems and related technologies. Despite tremendous progress on SPS in a variety of materials and structures, most of them are limited in scalability and working temperature. A technologically viable SPS remains a grand challenge. The newly emerged monolayer transitional metal dichalcogenides (TMDs) feature single photon emission up to the room temperature and unprecedented flexibility of integration. Seizing this opportunity, we aim to develop on-chip, high temperature SPSs through a collaborative effort that leverages the Lee's world-renowned expertise on chemical vapor deposition (CVD) growth of vdW materials and Deng's expertise on quantum optics and site controlled SPSs.

In the first two years, Lee group has achieved promoter-assisted CVD of high-quality TMDs, identified the critical role of interface cleanness in determining structural and emission properties of TMD heterostructures, developed methods of ultraclean transfer of large-area TMDs that enabled direct STM imaging of moiré patterns<sup>1</sup>, and developed plasmonic structures to induce quantum dot (QD) arrays in TMDs and enhance single photon emission. Deng group has performed optical characterization of the TMD monolayers and heterostructures, and has been exploring new methods to create TMD SPSs, including developing nanoimprint method using templates fabricated in Lee lab and demonstrating the first interlayer exciton laser in WSe<sub>2</sub>/MoSe<sub>2</sub> hetero-bilayers<sup>2</sup>, potentially originating from moiré QD arrays.



In the past year, the team has been collaborating on interface engineering and heterogeneous integration of TMDs to realize scalable QD arrays. Lee's method to create ultraclean interfaces has enable the observation of nonlinear phonon scattering in monolayer MoS<sub>2</sub><sup>3</sup>. With the nanoimprint method, we have demonstrated a scalable, erasable and rewritable way of creating SPS in 2D materials. Using WS<sub>2</sub>/MoSe<sub>2</sub> bilayers, we have demonstrated a tunable QD-array polariton system, featuring simultaneous collective light-matter coupling and a strong nonlinearity due to quantum-confinement<sup>4,5</sup>.

These works would not have been possible without the frequent exchanges of samples, know-hows, and understandings, and have been coordinated by a Postdoc co-supervised and co-supported by Deng and Lee, who spend a few months in each lab every year. They have also led to multiple other grants on the Taiwan side.

The growth and transfer techniques developed will provide critical technologies for future work on large-area TMD monolayers and heterostructures with ultraclean interfaces, including scalable strain- and moiré-induced QD arrays. The demonstration of interlayer exciton lasers and QD-array polaritons lay the ground for SPS based on tunable, densely-packed QD-arrays; they may also enable the intensively sought after quantum polaritonics, and may lead to quantum-dot array lasers with higher efficiency and power output than existing ones that are all based on random quantum dot ensembles.

[1] Adv. Mater. **31**, 1901077 (2019). [2] Nature **576**, 80 (2019). [3] Nat. Mater. (2021) 10.1038/s41563-021-00972-x [4] Nat. Commun. **11**, 5888 (2020). [5] Nature **591**, 61 (2021).

## Profiles

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# ARTIFICIALLY ENGINEERED EXCITON QUANTUM DOT ARRAYS FOR QUANTUM INFORMATION SCIENCE APPLICATIONS

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## ABSTRACT

This proposal is aimed at developing a new material platform for quantum information processors. The platform is based upon vertically stacked, hetero-bilayers where each layer is an atomically thin direct gap semiconductor (in our case, group VI transition metal dichalcogenides (TMDs) such as  $\text{MoS}_2$  and  $\text{MoSe}_2$ ). The most appealing feature for this platform is the ability to create a 2D electronic/photonic superlattice through the formation of moire superlattice either through the lattice mismatch or twist-angle, or both. The moire superlattice creates a 2D periodic potential that can confine excitons thus creating an effective exciton quantum dot array.

Over the last few years, this research team has accomplished the majority of our research goals. Major accomplishments include: (a) Engineering interlayer hybrid excitons in hetero-bilayers through control of *stacking configuration, band alignment, and valley-spin* [Science Advances 5, eaax7407 (2019)]; (b) Systematically controlling the formation of inter- and intra-layer moire exciton minibands as a function of twist angle in  $\text{MoSe}_2/\text{MoS}_2$  hetero-bilayers from which we reveal a rather surprisingly deep intra-layer moire potential landscape (unpublished); (c) Investigations of how moire potential impede the exciton diffusion [Science Advances 6, eaba8866 (2020)]; (d) Determination of how dielectric environment impacts the exciton binding energy and quasi-particle band gap [2D Materials 6, 025028 (2019)]; and (e) Pressure tuning of interlayer spacing to achieve a three-fold enhancement of interlayer coupling strength, the key parameter which controls the moire potential (unpublished). The scientific impacts of these five papers are directly mapped to our original proposal goals. Most importantly, these major accomplishments are all carried out through the US-Taiwan bilateral collaborations.

In addition to fulfilling the original research objectives. The bilateral collaborations also enabled us to pursue related research activities (not outlined in the original objectives). Key results from those related research activities include achieving (a) “Chiral second-harmonic generation from monolayer  $\text{WS}_2$ /aluminum plasmonic vortex metalens,” [Nano Lett. 20, 2857-2864 (2020)]; (b) “Engineering Giant Rabi Splitting via Strong Coupling between Localized and Propagating Plasmon Modes on Metal Surface Lattices: Observation of  $\sqrt{N}$  scaling Rule,” [Nano Lett. 21, 605–611 (2021)]; and (c) Direct mapping of momentum resolved ground/excited states and the ultra-fast excited state dynamics of monolayer  $\text{MoS}_2$  using time-resolved Angle-resolved photoelectron spectroscopy.

With the majority of research goals accomplished, one key item remains: achieving resonance fluorescence of interlayer moire excitons. This turns out to be far more challenging than originally anticipated. The interlayer exciton has a vertical dipole moment which is difficult to couple resonantly to the excitation photons. Nevertheless, it might be possible to utilize an optical vortex beam to manipulate the selection rule. This will be pursued in the remaining project time.