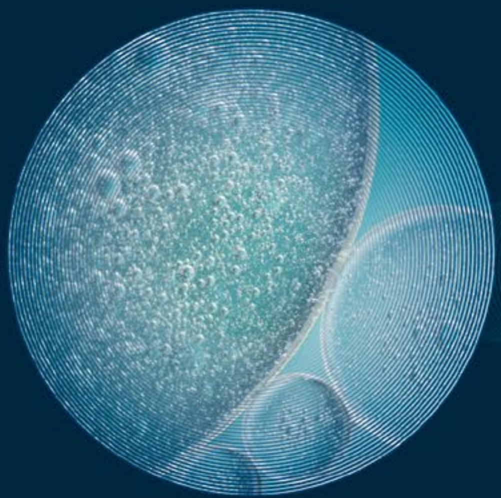
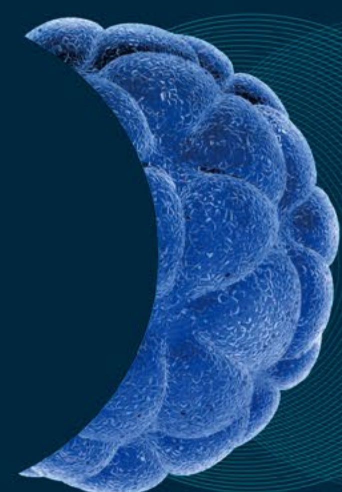
NATIONAL TSING HUA UNIVERSITY
R&D REPORT

2023 ______ 2024





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About NTHU

Message from the President

R&D Facts and Figures

Nature and Life Science

Engineering

Biomedical Technology

Materials Science

Humanities and Social Sciences

About NTHU

National Tsing Hua University (NTHU) has a long and proud history. First established as the Tsing Hua Academy at Tsing Hua Garden in Beijing in 1911, the Academy was renamed as National Tsing Hua University in 1928 as its curricula expanded to that of comprehensive university.

In 1956, NTHU was reinstalled on its current campus in Hsinchu, Taiwan. Since its reinstallation, NTHU has developed from an institute focusing on nuclear science and technology to that of a comprehensive research university offering degree programs ranging from baccalaureate to doctorate in science, technology, engineering, humanities and social sciences as well as management.

NTHU has been consistently ranked as one of the premier universities in Taiwan and is widely recognized as the best incubator for future leaders in industries as well as academics. Such stellar records are particularly exemplified by the outstanding achievements of our alumni, including two Nobel laureates in physics Drs. Cheng-Ning Yang and Tsung-Dao Lee, one Nobel laureate in chemistry Dr. Yuan-Tseh Lee and one Wolf Prize winner in mathematics Dr. Shiing-Shen Chern. On the first of November 2016, NTHU formally incorporated the National Hsinchu University of Education. This merger further diversifies and expands its curricula include arts and education to better prepare our students to take on the challenge of a changing world.

President
Dr. W. John Kao
National Tsing Hua University Hsinchu, Taiwan
January 2025

Message from the President

National Tsing Hua University (NTHU) is a research-intensive university with a long and proud tradition. Since the reestablishment in Hsinchu in 1956, NTHU is known for academic excellence, stellar research output as well as outstanding alumni.

NTHU 's core values are shared governance, academic freedom and inclusivity- equality-diversity. NTHU values academic freedom and provides a diverse environment within which our faculty can offer quality teaching and conduct innovative research. Regarded as one of the top tier research universities, our research activities emphasize fundamental discoveries at the forefront of basic sciences and exploration of breakthrough technologies with high impact. These are reflected in our publications in preeminent journals, international patents received, and technology transferred. In the 2023-2024 R&D annual report, we highlight several important breakthroughs in five fields and also provide the facts and figures related to other important R&D activities.

This volume provides a glimpse into our recent achievements. Hopefully, this can serve as a catalyst for further interactions, exchange of ideas, and establishment of collaborations.

We believe that everyone deserves an opportunity to explore and to realize their unique potential. NTHU will uphold our core values—inclusivity, equality, and diversity in everything we do. We will diligently safeguard academic freedom and shared governance as an integral part of our social responsibility and sustainable development.

R&D Facts and Figures

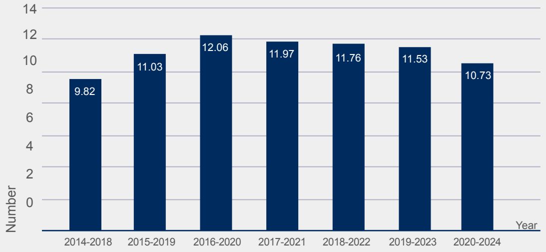
2024 World Rankings

Rankings	Rank
QS World University Rankings	233
QS Asia University Rankings	39
THE Asia University Rankings	71
THE Impact Rankings	201–300

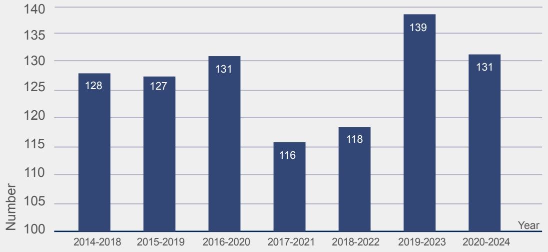
2024 QS World University Rankings by Subject

Top 50-100	Top 100-150
▪ Linguistics (86) ▪ Physics & Astronomy (97)	▪ Engineering - Electrical ▪ Materials Sciences ▪ Computer Science & Information Systems ▪ Engineering - Mechanical,Aeronautical & Manufacturing ▪ Engineering - Chemical ▪ Modern languages

Citations Per Paper



Highly Cited Papers



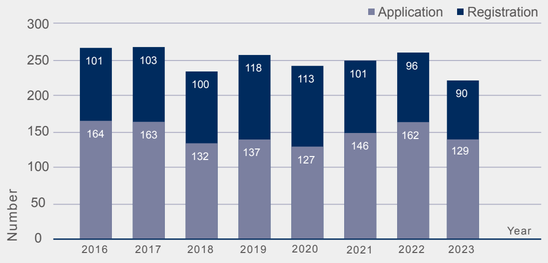
note1. Last updated November 14th, 2024
note2. Data covers a 10-year and 8-month period: January 1, 2014 - August 31, 2024

2023 Highly Cited Researchers:
Professor. Horng-Tay Jeng (Department of Physics)

2023 Ranking of U.S. Patents

	2016	2017	2018	2019	2020	2021	2022	2023
World Ranking	25	23	24	31	38	46	46	61
Taiwan Ranking	1	1	1	1	1	1	2	2

International Patent Application and Registration (2016-2023)

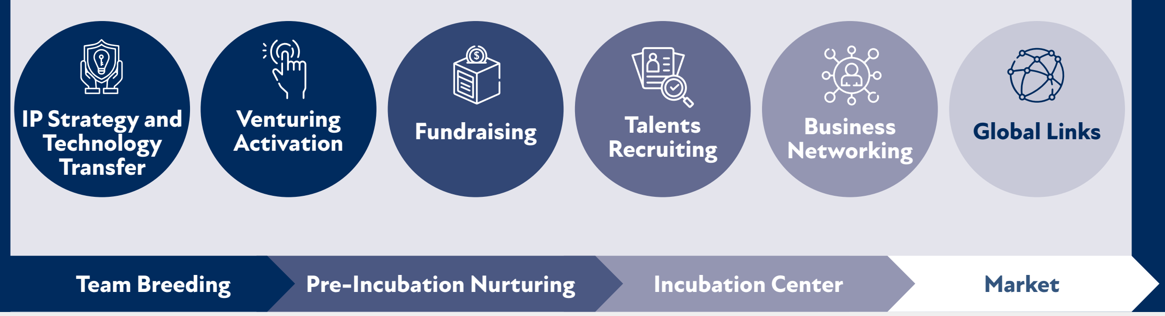


Incubation Programme

NTHU creates possibilities for startups to obtain necessary resources for developing its sustainable core competence in the market.

53	41	22	29
Startups Admitted in 2024	Entrepreneurship by Professors and Students in 2024	Professor's technology patents transferred to new startups 2019-2024	Industry-university cooperation with professors 2019-2024

Entrepreneurship Avenue



Nature and Life Science

01

NTHU Cracks the Dioxin Pollution Challenge

Ultrahigh zT from strong electron-phonon interactions and a low-dimensional Fermi surface

Dual-clamped one-pot SERS-based biosensors for rapid and sensitive detection of SARS-CoV-2 using portable Raman spectrometer

NTHU Cracks the Dioxin Pollution Challenge

Professor Kuo Chu Hwang
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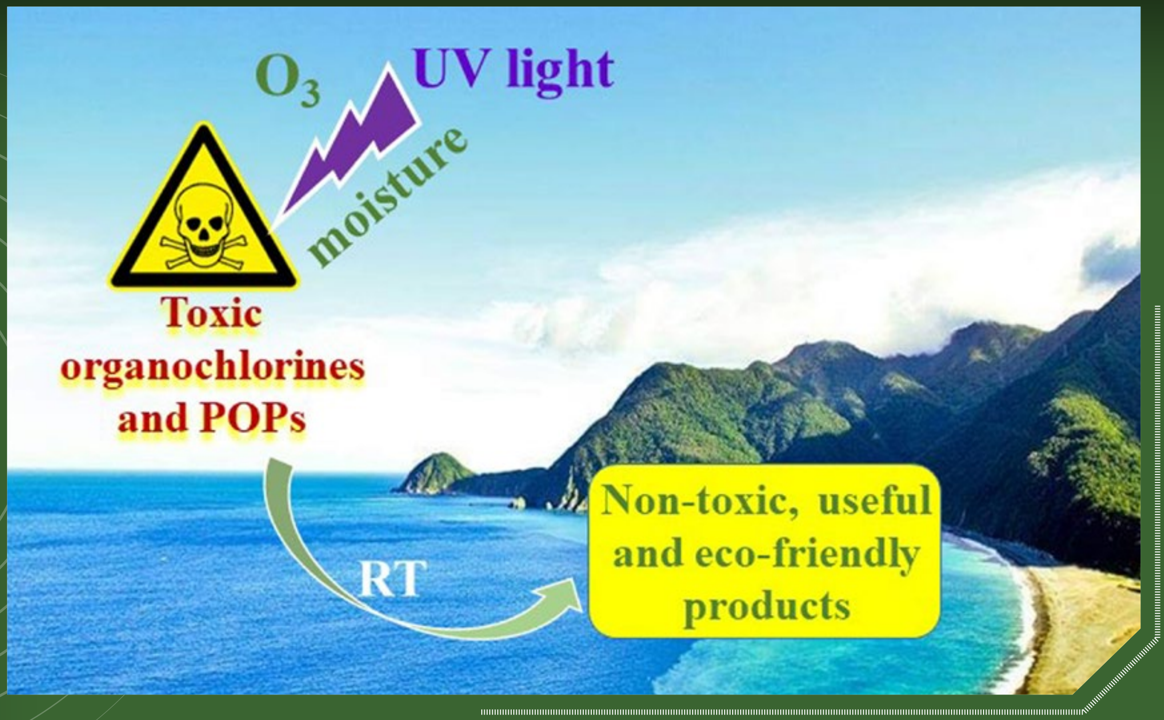


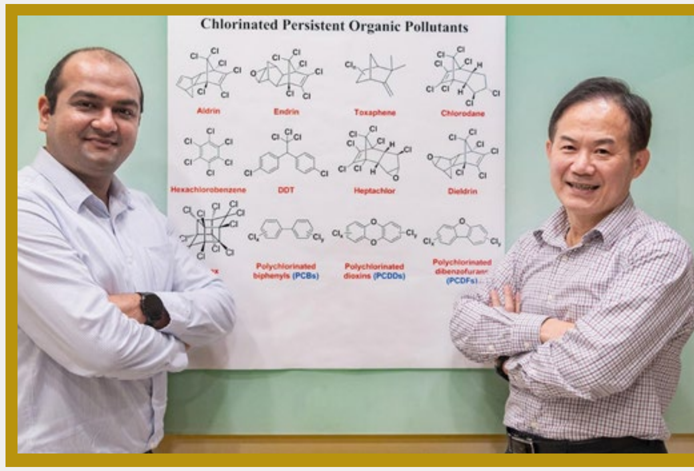
Showcasing a simple, mild, metal-free, highly efficient, and economically feasible method for oxidative degradation of super-stable organochlorinated compounds and persistent organic pollutants (POPs) at room temperature using inexpensive, eco-friendly ozone gas under ultraviolet (UV) irradiation. In-situ generated hydroxyl radicals degrade tough and difficult-to-be oxidized organochlorines/POPs into useful and non-toxic products using ozone gas, which is eco-friendly and helps in remediation of Earth's atmosphere.

National Tsing Hua University (NTHU) in Taiwan has achieved a milestone in addressing persistent organic pollutants (POPs), including the "Century Toxins"—dioxins, PCBs, and pesticides (DDT). These highly toxic and hard-to-degrade pollutants have posed a major threat to ecosystems and human health. The team simulated atmospheric ozone-ultraviolet light reactions to transform dioxins into harmless oxalic acid at room temperature. The research, which offers a promising solution to the global challenge of POPs, appeared in the December 2023 issue of the esteemed journal Green Chemistry. Led by Professor Kuo Chu Hwang (黃國柱) from the Department of Chemistry, the research team was assisted by the expertise of Ph.D. student Ayyakkannu Ragupathi and postdoctoral researcher Vaibhav Pramod Charpe. The study primarily focuses on degrading pollutants like dioxins, known for their resilience to high temperatures and resistance to traditional decomposition methods. Dioxins pose severe risks to both the environment and human health, triggering gene mutations, congenital disorders, miscarriages, cancers, and neurological disorders.

The research team demonstrated the ability of this method to reduce the concentration of "2,3,7,8-tetrachlorodibenzo-p-dioxin" by 47% after 16 hours of mercury lamp exposure. Additionally, the chemical "hexachlorobenzene" underwent a remarkable 98% decomposition into non-toxic oxalate after 20 hours of ozone-ultraviolet irradiation. The adverse effects of POPs on both the environment and human health are well documented. Hwang recalled the PCB poisoning incident in Taiwan in 1979, where over 2,000 people consumed rice bran oil contaminated with PCBs, resulting in 16 deaths and long-term genetic repercussions for the affected and their descendants. Additionally, the widespread use of Agent Orange during the Vietnam War led to severe deformities in 150,000 Vietnamese newborns, perpetuating the impact across generations. These incidents underscore the urgency of finding solutions for the elimination of POPs. The research outcome showcases the potential of this environmentally friendly approach to tackle longstanding challenges in organic chemistry. Hwang anticipates that this research will pave the way for numerous practical applications, significantly contributing to global efforts to mitigate the environmental burden from these POPs.

Research Output

- Ayyakkannu Ragupathi, Vaibhav Pramod Charpe, Jih Ru Reuben Hwu, and Kuo Chu Hwang*, Oxidative Destruction of Chlorinated Persistent Organic Pollutants by Hydroxyl Radicals via Ozone and UV Light Irradiation; Green Chem., 2023, 25, 9695.



Dr. Vaibhav Charpe, and Professor K. C. Hwang

Ultrahigh zT from strong electron-phonon interactions and a low-dimensional Fermi surface

Professor Horng-Tay Jeng
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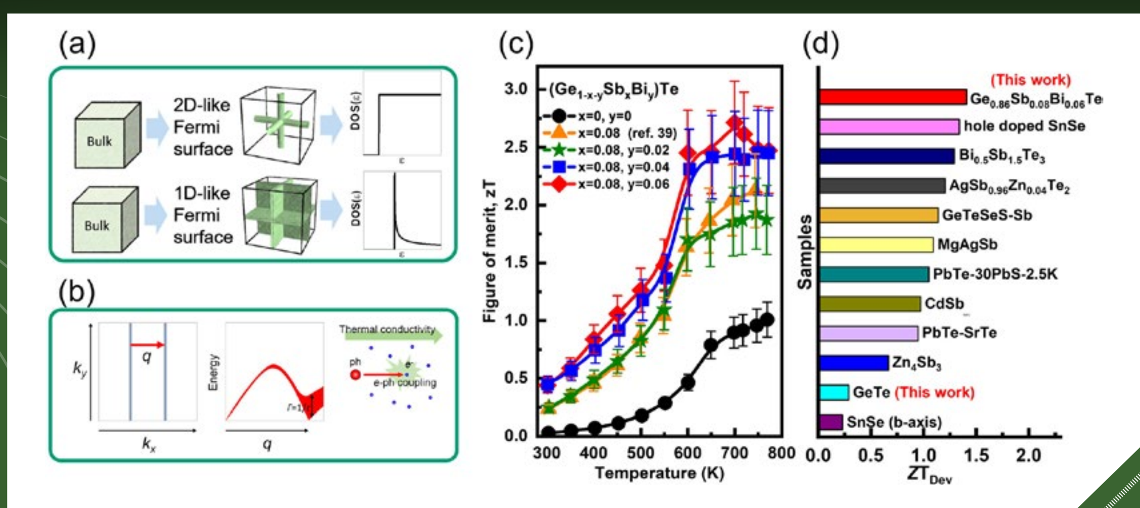
Facing global climate change and the urgent need for carbon reduction, the development of renewable energy has become an even more pressing mission than ever before. Thermoelectric (TE) materials, which enable the direct and reversible conversion between heat and electricity without moving parts, hold high potential to become one of the promising technologies for solving the energy crisis. The TE performance of materials is generally evaluated by the dimensionless figure-of-merit $zT=S^2\sigma T/\kappa$, where S, T, σ, and κ represent the Seebeck coefficient, absolute temperature, electrical and thermal conductivity, respectively. The thermal conductivity κ is the sum of the electronic (κ_e) and lattice (κ_{lat}) contributions, given by $\kappa=\kappa_e+\kappa_{lat}$. Most of the thermoelectric materials, such as Bi_2Te_3, Zn_4Sb_3, $CoSb_3$, Mg_3Sb_2, and SiGe, have thermoelectric zT values that are less than 2. However, for a few examples like PbTe and Cu_2Se, their highest zT values can exceed 2. Moreover, in the case of alloy materials like $AgSbTe_2$, SnSe, and GeTe, they have achieved remarkably high zT values surpassing 2.5.

Recent studies show that the nesting feature of parallel sheets of the Fermi surface will trigger unusually strong electron-phonon (EP) interactions that suppress phonon heat transport. EP scattering which is generally observed at low temperatures has recently been found to play an important role in phonon heat transport of certain doped semiconductors, especially above room temperature. In the metallic niobium carbide, a two-orders-of-magnitude reduction in lattice thermal conductivity is predicted because of the EP interaction. In the semi-metallic 1T-TaS_2 and the semiconducting $Pb_7Bi_4Se_{13}$, EP scattering stronger than phonon–phonon scattering is suggested above the Debye temperature by the measured nearly temperature-independent low lattice thermal conductivity.

The outstanding thermoelectric performance of GeTe has attracted significant attention in the research community in recent years. However, many of the underlying physical mechanisms that contribute to GeTe's exceptionally high figure of merit (zT) remain not fully understood. In this study, an Sb-Bi codoped GeTe single crystal $Ge_{0.86}Sb_{0.08}Bi_{0.06}Te$ with an ultrahigh zT of 2.7 at 700 K and a record high device zT of 1.41 in the temperature range of 300-773 K was synthesized and investigated. The ultrahigh zT is attributed to the extremely low lattice thermal conductivity induced by strong electron-phonon interactions as revealed by the experimentally observed Kohn anomaly, through inelastic neutron scattering (INS) measurements. First-principles calculations further demonstrate that the remarkable EP interaction arises from the Fermi surface nesting featured in a one-dimensional (double-walled) topology. Our finding unravels the ultrahigh-zT mechanism in GeTe-based materials, serving as an inspiring guide toward high thermoelectric performance. This newfound understanding is also poised to inspire continued exploration and innovation, propelling the field toward heightened energy conversion technologies and sustainable solutions.



Thermoelectric figure of merit of GeTe and the schematic illustration of the electron-phonon scattering mechanisms therein. (a) Schematic diagram illustrating the features of the Fermi surface and density of states exhibited by a bulk material with a 2D- or 1D-like electronic structure. (b) Fermi nesting vector q connecting two parallel 1D-like Fermi surfaces (left panel) would lead to Kohn anomaly with phonon softening and widened phonon linewidth (middle panel), indicating strong electron-phonon interactions with enhanced phonon scattering-derived low lattice thermal conductivity (right panel). (c) Temperature dependence of the zT values of $(Ge_{1-x-y}Sb_xBi_y)Te$ crystals. (d) The device ZT_{Dev} for the 300-773 K temperature range in $Ge_{0.86}Sb_{0.08}Bi_{0.06}Te$ and other known thermoelectric materials reported in previous literature.

Research Highlights

- 2023 Outstanding Research Awards (NSTC, Taiwan)
- 2019-2023 Highly Cited Researcher (Web of Science)
- 2021-2022 World's Top 2% Scientists list (Stanford University)
- 2022 CTCI Outstanding Physics Research Award (Taiwan Physical Society)

Research Output

- V. K. Ranganayakulu, Te-Hsien Wang, Cheng-Lung Chen, Angus Huang, Ma-Hsuan Ma, Chun-Min Wu, Wei-Han Tsai, Tsu-Lien Hung, Min-Nan Ou, Horng-Tay Jeng, Chih-Hao Lee, Kuei-Hsien Chen, Wen-Hsien Li, Madison K. Brod, G. Jeffrey Snyder and Yang-Yuan Chen, "Ultrahigh zT from strong electron-phonon interactions and a low-dimensional Fermi surface", Energy Environ. Sci. 17, 1904–1915 (2024).
- Nikhil Tilak, MichaelAltvater, Sheng-Hsiung Hung, Choong-Jae Won, Guohong Li, Taha Kaleem, Sang-Wook Cheong, Chung-Hou Chung, Horng-Tay Jeng, & Eva Y. Andrei, "Proximity induced charge density wave in a graphene/1T-TaS_2 heterostructure", Nature Communications 15:8056 (2024).
- Ye-Shun Lan, Chia-Ju Chen, Shu-Hua Kuo, Yen-Hui Lin, Angus Huang, Jing-Yue Huang, Pin-Jui Hsu, Cheng-Maw Cheng, and Horng-Tay Jeng, "Dual Dirac Nodal Line in Nearly Freestanding Electronic Structure of β-Sn Monolayer", ACS Nano 18, 20990−20998 (2024).
- Ming-Wei Liao, Horng-Tay Jeng, and Tsong-Pyng Perng, "Formation Mechanism and Bandgap Reduction of GaN-ZnO Solid-Solution Thin Films Fabricated by Nanolamination of Atomic Layer Deposition", Adv. Mater. 35, 2207849 (2023).

Professor Horng-Tay Jeng

Dual-clamped one-pot SERS-based biosensors for rapid and sensitive detection of SARS-CoV-2 using portable Raman spectrometer

Professor Fan-Gang Tseng
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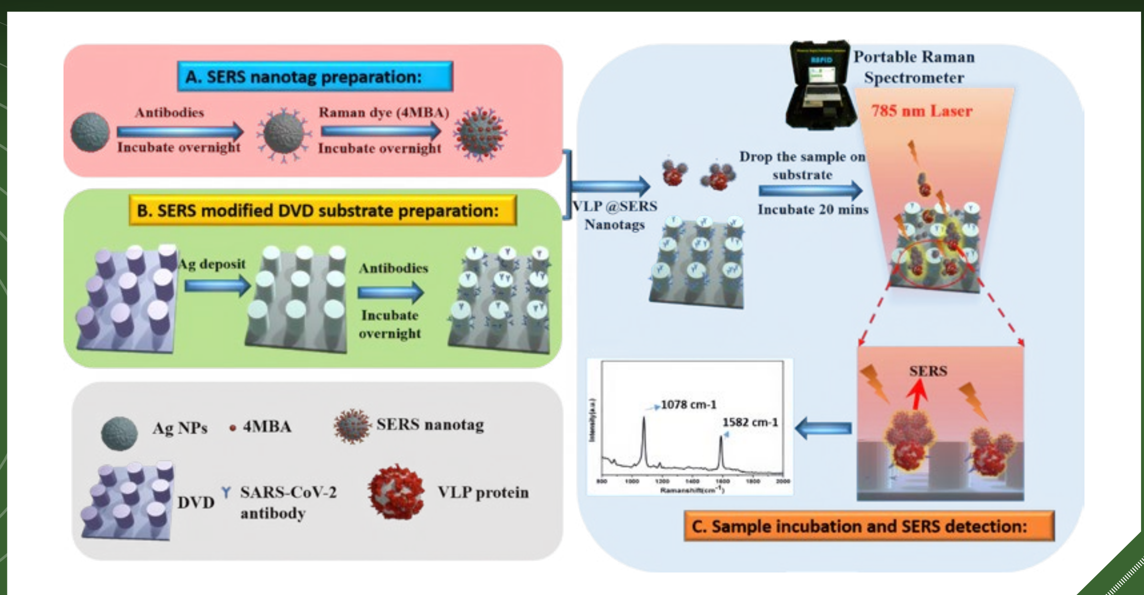
The COVID-19 pandemic has underscored the urgent need for reliable, rapid, and sensitive diagnostic tools to control viral transmission effectively. While RT-PCR remains the gold standard for SARS-CoV-2 detection, its high cost, time requirements, and reliance on skilled personnel pose significant challenges for large-scale and point-of-care applications. Commercial antigen tests, although faster, often lack the sensitivity required for early-stage infection detection. This creates a demand for innovative diagnostic platforms that combine speed, sensitivity, specificity, and cost-effectiveness. Surface-Enhanced Raman Scattering (SERS) biosensors are emerging as promising candidates due to their ability to amplify weak Raman signals and provide ultrasensitive detection of biomolecules. However, existing SERS platforms face limitations such as poor reproducibility, high cost, and labor-intensive washing processes.

Our research demonstrated a novel dual-clamped one-pot SERS-based biosensor for the rapid and sensitive detection of SARS-CoV-2 antigens using a portable Raman spectrometer. The platform integrates a microstructured DVD substrate, functionalized with antibodies, and Raman reporter-labeled silver nanoparticles (AgNPs) to create a dual-clamped sandwich immunoassay structure. This innovative design eliminates the need for washing steps, reducing complexity and enhancing usability for point-of-care applications. DVD substrates were structured with nanopillars and coated with silver to generate plasmonic hotspots, enhancing signal sensitivity. These substrates were functionalized with SARS-CoV-2 antibodies for specific antigen recognition. AgNPs were conjugated with Raman reporters and antibodies to amplify the SERS signal upon interaction with target antigens. The one-pot approach involves mixing the target antigen, SERS nanotags, and substrate in a single reaction, followed by a 20-minute incubation and measurement under a near-infrared (785 nm) laser.

The biosensor achieved a limit of detection (LoD) of 50 pg/mL for SARS-CoV-2 spike protein in phosphate-buffered saline and 400 pg/mL in untreated saliva. Sensitivity cycle threshold value (Ct: 30-32) exceeded those of commercial antigen tests (Ct: 25-28) by approximately 100 times but slightly less than RT-PCR tests (Ct: 35-40). Specificity tests confirmed reliable discrimination between SARS-CoV-2 antigens and non-specific proteins, and reproducibility tests showed minimal variability with relative standard deviations (RSDs) around 10%, meeting the criteria for reliable SERS assays. The use of DVD-based substrates ensures cost-effectiveness, allowing up to 300 SERS chips to be produced from a single commercial DVD.

This dual-clamped, one-pot SERS-based biosensor provides a rapid, sensitive, and cost-effective platform for SARS-CoV-2 detection, making it suitable for both clinical and point-of-care settings. Further validation with clinical samples and optimization for multiplex detection can enhance its utility in combating COVID-19 and other infectious diseases.



Schematic illustration of dual-clamped one-pot SERS based immunoassay platform for rapid and sensitive detection of SARS-CoV-2

Research Highlights

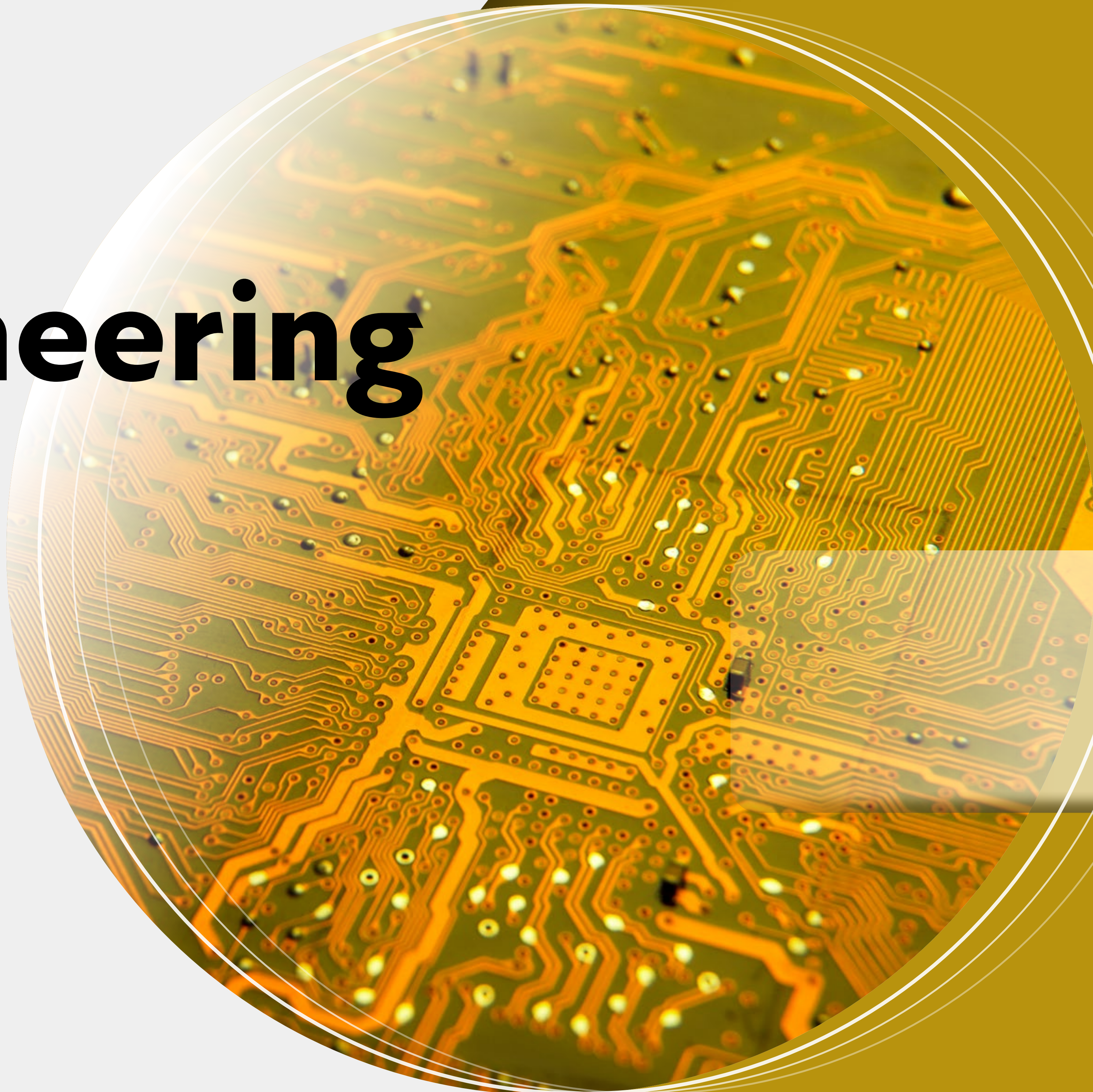
- Young Investigator Competition Award (3rd prize), The 6th Global Conference on Biomedical Engineering (GCBME 2024)
- CTCI Foundation Science and Technology Research Scholarship (2023)
- Outstanding Student Paper Award, Annual Conference of Taiwanese Society of Biomedical Engineering (TSBME 2023)

Research Output

- Kiran Kaladharan, Kuan-Hung Chen, Pin-Han Chen, Venkanagouda S. Goudar, Tseren-Onolt Ishdorj, Tuhin Subhra Santra, Fan-Gang Tseng, “Dual-clamped one-pot SERS-based biosensors for rapid and sensitive detection of SARS-CoV-2 using portable Raman spectrometer,” Sensors and Actuators B: Chemical, vol. 393, p. 134 172, 2023.

Prof. Fan-Gang Tseng, Kiran Kaladharan

Engineering



Multimodal machine intelligence for human-centered signal and information processing

Synergistic Effect of Crown Ether and Main-Chain Engineering for Boosting Hydrogen Evolution of Polymer Photocatalysts in Seawater

02

Multimodal machine intelligence for human-centered signal and information processing

Professor Jeremy Chi-Chun Lee
cclee@ee.nthu.edu.tw

Our project has demonstrated pioneering advancements in multimodal machine intelligence focusing on human-centered signal and information processing. This interdisciplinary initiative integrates engineering techniques, such as signal processing and machine learning, with behavioral and applied sciences, including psychology, healthcare, and human-computer interaction, to analyze human-generated signals like speech, physiological responses, and gestures. The project bridges academic research and practical applications, advancing areas like paralinguistic computing, intelligent healthcare, and speech emotion recognition (SER).

One of the project's most impactful outcomes is its contribution to the field of speech emotion recognition. A notable research, published in The Proceedings of the IEEE, addresses the challenges of SER in diverse real-world contexts, emphasizing robustness, generalization, and ethical considerations. This work lays the foundation for responsible human-centered AI applications in sectors like healthcare and education while paving the direction of future SER.

We have made significant advancements in various fields, including speech processing, emotion recognition, clinical AI application, and physiological signals analysis.

In healthcare, the project introduced cutting-edge automated flow cytometry interpretation for clinical decision-making and disease classification, specially focusing on hematological malignancies. For instance, we collaborated with international medical center to develop a chunking-for-pooling strategy for cytometric representation learning, enabling automated hematologic malignancy classification with over 98% accuracy on specific datasets. This technology was transferred to an international medical AI startup, representing a significant step toward FDA certification.

Various other behavior computing algorithms have been developed. For example, our project also achieved breakthroughs in autism subgroup classification using a multimodal attention mechanism that captured subtle behavioral interactions during clinical interviews. This approach improved diagnostic precision for autism spectrum disorders and provided insights into the dynamics of clinician-patient communication. Additionally, this project developed a multi-source Cycle-GAN for unsupervised cross-corpus speech emotion recognition. This model addresses domain mismatches between training and testing datasets, achieving state-of-the-art performance on several benchmarks and enhancing the scalability and practicality of emotion-aware AI systems.

Beyond academic research, we have engaged in substantial industrial innovations through collaborations with corporations such as Qualcomm, Johnson & Johnson, and Allianz Taiwan. These efforts include privacy-preserving federated learning, cancer risk prediction, and consumer health indices. Notable large-scale projects include the AI Health Index with Allianz Taiwan and predictive algorithms for oncology in partnership with Johnson & Johnson. Our research has been featured in international media, including Discovery Channel and Scientific American. Lastly, through educational efforts, mentoring, and promoting international collaboration, the project has solidified Taiwan's standing this emerging research field globally.

Overall, our project has not only advanced human-centered AI technologies but also fostered impactful collaborations across academia, industry, and public sectors, underscoring its pivotal role in shaping the future of this emerging computational field.

Research Highlights

- OUTSTANDING RESEARCH AWARD
  National Science and Technology Council (2024)
- SENIOR MEMBER
  Institute of Electrical and Electronics Engineers (2020)
- YOUNG INNOVATOR AWARD
  Foundation of Outstanding Scholar (2020)
- K.T. Li CORNERSTONE AWARD
  Institute of Information & Computing Machinery (2024)
- 2024 NTHU-NOVATEK DISTINGUISHED TALENT CHAIR
  National Tsing Hua University (2025)

Current Members of BIIC Lab

Research Output

< Patent >

- General Machine Intelligence
  TWI860054B / Method, Device And Computer Program Product For Training Machine Learning Models
- Speech Emotion Recognition
  TW202449770A / Method, Model Training Method And Computer Program Product For Speech Emotion Recognition

  TW202447616A / A Method, System, And Computer Program Product For Cross-Task Unseen Emotion Class Recognition
- Healthcare
  TW202345159A / Methods And Devices Of Processing Cytometric Data

  TW202311742A / Automated Classification Of Immunophenotypes Represented In Flow Cytometry Data

< Paper >

- Speech Emotion Recognition
  Chi-Chun Lee, Theodora Chaspari, Emily Mower Provost and Shrikanth S Narayanan", An Engineering View on Emotions and Speech: From Analysis and Predictive Models to Responsible Human-Centered Applications," *The Proceedings of the IEEE*, pp. 1-17, 2023. doi: 10.1109/JPROC.2023.3276209.

  Chi-Chun Lee, Kusha Sridhar, Jeng-Lin Li, Wei-Cheng Lin, Bo-Hao Su, and Carlos Busso, "Deep Representation Learning for Affective Speech Signal Analysis and Processing: Preventing unwanted signal disparities", *IEEE Signal Processing Magazine*, vol. 38, no. 6, pp. 22-38, 2021. doi: 10.1109/MSP.2021.3105939.

  Bo-Hao Su and Chi-Chun Lee, "Unsupervised Cross-Corpus Speech Emotion Recognition Using a Multi-Source Cycle-GAN", *IEEE Transactions on Affective Computing*, no. 01, pp. 1-1, 2022. doi: 10.1109/TAFFC.2022.3146325.
- Healthcare
  Jeng-Lin Li, Yun-Chun Lin, Yu-Fen Wang, Sara A. Monaghan, Bor-Sheng Ko, and Chi-Chun Lee, "A Chunking-for-Pooling Strategy for Cytometric Representation Learning for Automatic Hematologic Malignancy Classification", *IEEE Journal of Biomedical and Health Informatics*, pp. 1-1, 2022. doi: 10.1109/JBHI.2022.3175514.

  Yun-Shao Lin, Susan Shur-Fen Gau, and Chi-Chun Lee, "A Multimodal Interlocutor-Modulated Attentional BLSTM for Classifying Autism Subgroups During Clinical Interviews", *IEEE Journal of Selected Topics in Signal Processing*, vol. 14, no. 2, pp. 299-311, 2020. doi: 10.1109/JSTSP.2020.2970578.

Synergistic Effect of Crown Ether and Main-Chain Engineering for Boosting Hydrogen Evolution of Polymer Photocatalysts in Seawater

Professor Ho-Hsiu Chou
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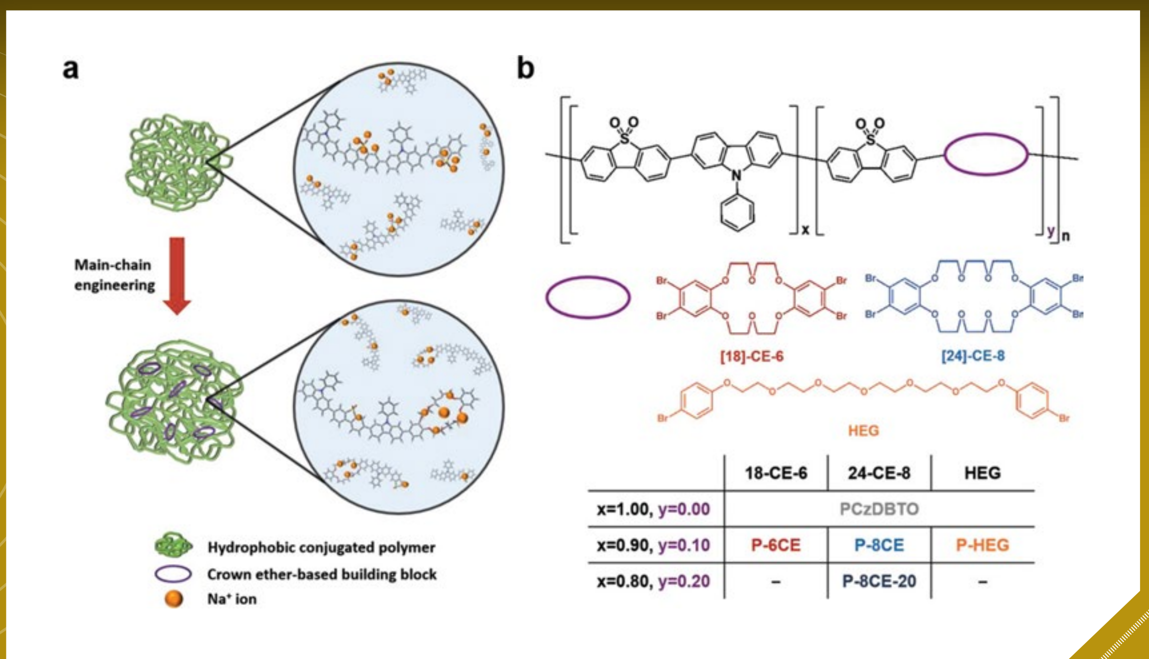
We have first integrated CE into conjugated polymers to construct a series of main-chain-engineered DCPs for photocatalytic hydrogen evolution. Particularly, in natural seawater, bifunctional CE played an important role in the photocatalytic hydrogen evolution reaction. The hydrophilic CE not only effectively brought water into the inner polymer chains but also successfully inhibited the aggregation of polymers. Meanwhile, the excellent cation adsorption capacity of CE can strongly adsorb cations, which reduced the adsorption of cations on the active sites with a high density of negative charge. The presence of CE indeed increases the photocatalytic HERs and reduces the HER roll-off in natural seawater whether CE is chemically linked or physically blended with the polymer photocatalysts. Importantly, chemically linked CEs can more effectively increase the affinity of polymer photocatalysts to water compared with physically blended CEs, resulting in superior photocatalytic performance. Furthermore, the lower the HER roll-off of DCPs, making the main chain engineering strategy more effective for HER enhancement in natural seawater systems. The combination of bifunctional CE and the main-chain engineering approach enriches the family of flexible polymer photocatalysts and provides a new insight into developing high-performance photocatalysts by molecular design strategies. This study is believed to promote the realization of industrial applications of clean and renewable energy produced from abundant natural seawater.



a. Schematic illustration of the adsorption of sodium ions to polymer photocatalysts.

b. The molecular structures of hydrophilic building blocks and the corresponding polymers.

Research Highlights

- This representative research work was published in Advanced Energy Materials and received coverage from domestic and international media outlets, including the Associated Press (AP), Boston Herald, FOX 40 (U.S. FOX 40 TV station), Bakersfield (California-based media), Milwaukee Wisconsin Journal Sentinel (the largest newspaper in Wisconsin, USA), Telegraph (Australia's Daily Telegraph), Malaysia Global Business Forum, Liberty Times, United Daily News, and more than ten other media outlets. This recognition showcased Taiwan's research achievements to the world.

Research Output

- Chih-Li Chang, Tse-Fu Huang, Wei-Cheng Lin, Li-Yu Ting, Chin-Hsuan Shih, Yan-Heng Chen, Jia-Jen Liu, Yu-Tung Lin, Yuang-Ting Tseng, Yi-Hsiang Wu, Yu-En Sun, Mohamed Hammad Elsayed, Chin-Wen Chen*, Chi-Hua Yu*, Ho-Hsiu Chou*, "Synergistic Effect of Crown Ether and Main-Chain Engineering for Boosting Hydrogen Evolution of Polymer Photocatalysts in Seawater" Advanced Energy Materials, 2023, 13, 2300986 (Back cover)

Professor Ho-Hsiu Chou

Biomedical Technology

Molecular Mechanism of the ParABS System in Prokaryotic Chromosome Partitioning

Ultracold Nanofibers to Provide Buildings with Cooling Shirts

Targeting Hydrogen Sulfide Offers New Therapeutic opportunities through Rewiring Cancer Glucose Metabolism

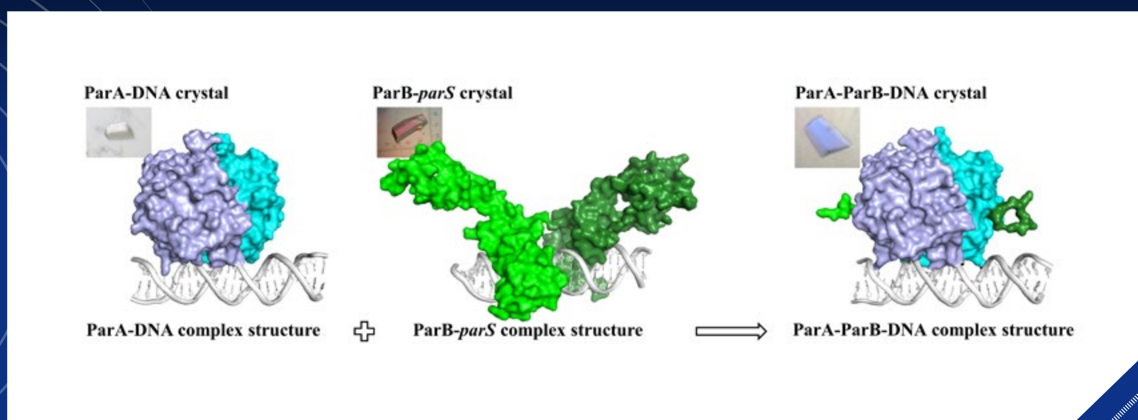
Multiplex, Multiscale Microscopy Imaging

03

Molecular Mechanism of the ParABS System in Prokaryotic Chromosome Partitioning

Professor Yuh-Ju Sun
yjsun@life.nthu.edu.tw

HpParA shares about 23% of sequence identity with the 'deviant' Walker A motif superfamily. HpParA achieved ATP hydrolysis similar to that of other ParA superfamilies. The presence of DNA and HpParB, particularly the N-terminus of HpParB, enhances ATPase activity of HpParA. HpParA demonstrates a non-specific, ATP-dependent DNA-binding ability. The crystal structure of HpParA reveals a typical Rossmann fold nucleotide-binding protein, forming an ATP-dependent sandwich dimer. The crystal structure of the HpParA-DNA complex indicates that DNA-binding of HpParA occurs in the dimeric conformation. A continuous basic patch formed by the HpParA dimer is essential for DNA binding. This continuous basic patch may play a crucial role in DNA binding among the bacterial ParA superfamily.



The chromosome partition system, ParABS by ParA and ParB in Helicobacter pylori

ParB consists of three major functional domains: a ParA-interacting peptide, an N-terminal CTPase domain involved in protein-protein interactions (NTD), a middle parS-binding domain (DBD), a C-terminal dimerization domain (CTD), and a flexible linker connecting the DBD and CTD domains. HpParB shares about 27% of sequence identity with the ParB superfamily. Two conserved motifs in the NTD, GxxRxxA and ENLQRE, are identified involving CTP binding and hydrolysis. The corresponding motifs are also observed in HpParB. We assayed the CTPase activity of HpParB. Additionally, the parS might specifically stimulate the CTPase activity of HpParB. We also investigated the regulatory role of CTP in the HpParB DNA binding ability. We found two DNA binding modes regulated by CTP in HpParB: specific and non-specific DNA (nsDNA) binding. In the absence of CTP, HpParB exhibits a specific DNA-binding mode, interacting with parS to form a specific DNA-binding complex. In the presence of CTP, HpParB switches to a non-specific DNA-binding mode, binding both parS and nsDNA to form a non-specific DNA-binding complex. To understand the specific DNA-binding mode of HpParB, we solved the crystal structure of the Ct-HpParB-parS complex. Two Ct-HpSpo0J molecules array on opposite sides of parS, with each protomer interacting with half of the parS site. Four Ct-HpParB protomers bind to four parS molecules, forming an oligomeric structure that might mimic higher-order complexes essential for ParB spreading in the ParABS system.

Using electron microscopy, we captured the nucleoid-adaptor complex (NAC) formation, involving HpParB and HpParA in association with DNA, particularly facilitated by the presence of parS-containing DNA. Electrophoretic mobility shift assays revealed that the [HpParB-parS] complex tends to interact with [HpParA-nsDNA] complex and to form NAC. Understanding the molecular mechanism of NAC formation in the chromosome partition necessitates structural information. HpParAD41A, the ATP hydrolysis deficient mutant, was expected to form a more stable ATP-bound dimer than HpParA to interact with HpParB. We determined the crystal structure of the HpParAD41A–DNA–HpParBN10 complex, showing that the DNA-bound HpParA dimer is capable of interacting with HpParB. Additionally, cation-π interactions between HpParB Arg9 and HpParA Phe52 appear to play an essential role in stabilizing the interaction. Arg9 of HpParBN10 likely contributes by enhancing binding affinity with HpParA. HpParB binding may stimulate the ATP hydrolysis of HpParA, triggering its dissociation from the nucleoid and facilitating the partitioning of the chromosome/plasmid.

Research Highlights

- Taiwan Outstanding Women in Science Award from Wu Chien-Shiung Education Foundation and L'Oreal Taiwan, 2024
- Outstanding Research Awards from Ministry of Science and Technology, 2022
- Outstanding Award, The 17th Tien Te Lee Biomedical Awards, 2021
- The 64th Academic Awards from The Ministry of Education, 2020

Group photo of Prof. Yuh-Ju Sun's team

Research Output

- Chen-Hsi Chu, Che-Ting Wu, Min-Guan Lin, Cheng-Yi Yen, Yi-Zhan Wu, Chwan-Deng Hsiao* and Yuh-Ju Sun*. Insights into the molecular mechanism of ParABS system in chromosome partition by HpParA and HpParB. Nucleic Acid Res. 2024, 52:7321-7336
- Min-Guan Lin, Cheng-Yi Yen, Yo-You Shen, Yu-Sung Huang, Irene W. Ng, Daniela Barillà, Yuh-Ju Sun* and Chwan-Deng Hsiao*. Unraveling the structure and function of a novel SegC protein interacting with the SegAB chromosome segregation complex in Archaea. Nucleic Acid Res. 2024, 52:9966-9977
- Cheng-Yi Yen, Min-Guan Lin, Bo-Wei Chen, Irene W. Ng, Nicholas Read, Azhar F. Kabli, Che-Ting Wu, Yo-You Shen, Chen-Hao Chen, Daniela Barill`a, Yuh-Ju Sun* and Chwan-Deng Hsiao*. Chromosome segregation in Archaea: SegA– and SegB–DNA complex structures provide insights into segrosome assembly. Nucleic Acid Res. 2021, 49:13150-13164
- Chen-Hsi Chu, Cheng-Yi Yen, Bo-Wei Chen, Min-Guan Lin, Lyu-Han Wang, Kai-Zhi Tang, Chwan-Deng Hsiao* and Yuh-Ju Sun*. Crystal structures of HpSoj–DNA complexes and the nucleoid-adaptor complex formation in chromosome segregation. Nucleic Acid Res. 2019, 47:2113-2129

Ultracold Nanofibers to Provide Buildings with Cooling Shirts

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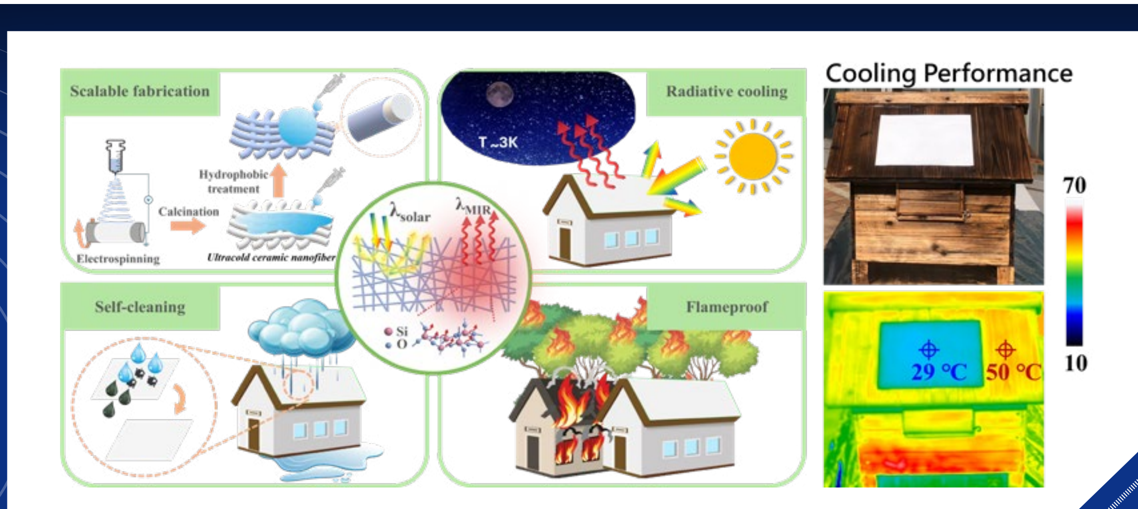
Global warming has exacerbated environmental crises, including rising sea levels, biodiversity loss, severe heatwaves, and catastrophic wildfires. These challenges have driven an unprecedented demand for cooling technologies, particularly in energy-intensive sectors like air conditioning and artificial intelligence. Ironically, conventional cooling methods often intensify the global energy burden, increasing greenhouse gas emissions and accelerating climate change. This paradox underscores the urgent need for sustainable, electricity-free alternatives. Radiative cooling, a process that uses engineered radiation to reflect sunlight and emit heat into outer space, offers a groundbreaking solution that requires no external energy input.

Inspired by the unique thermoregulation mechanisms of the Sahara silver ant—known for its triangular hair structure that achieves superior solar reflectivity and thermal emissivity—our research team has focused on developing scalable radiative cooling materials. Using electrospinning, a cutting-edge nanofabrication technique, we successfully created ultracold ceramic nanofibers with a controlled average diameter of 400 nm. This precision design optimizes Mie scattering, a phenomenon that maximizes the reflection of the whole solar spectrum. Our choice of silica as the primary material further enhances the mid-infrared emissivity of the nanofibers, achieving an impressive thermal radiation efficiency of 90%. These combined properties enable the nanofibers to reflect up to 97% of solar radiation while efficiently emitting heat in the mid-infrared range, a spectral region that allows thermal radiation to escape directly into space through the atmospheric transparency window.



Schematic of the scalable production process of ultracold ceramic nanofibers, showcasing the exceptional radiative cooling efficiency, self-cleaning, and flameproof capabilities, especially suitable for durable outdoor building applications. The self-cleaning properties are attributed to the hydrophobic treatment, while the flameproof capabilities result from the intrinsically high melting point of the ceramic material. Inset: Ultracold ceramic nanofibers demonstrate extensive sunlight backscattering at air-fiber interfaces and exhibit strong thermal emissivity within the mid-infrared region, attributed to the high density of Si–O bonds. (Right) From the thermal images, the ultracold nanofibers can maintain a low temperature of 29°C, even when the surrounding cabin roof has reached 50°C under sunlight exposure.

Outdoor temperature measurement demonstrated the transformative potential of ultracold ceramic nanofibers. When applied to building models, the material reduced surface temperatures by 12.7°C under direct sunlight. On vehicle models, the nanofibers achieved a temperature reduction of 17°C, showcasing their versatility across diverse applications. Beyond their cooling performance, the ceramic nanofibers exhibit exceptional durability, including resistance to UV radiation, fire, corrosion, and acid rain. These attributes ensure long-term reliability, making the material suitable for diverse environmental conditions and applications.

To address the specific cooling needs of transparent surfaces, such as windows, solar panels, and electronic displays, we further developed a silk fibroin-based transparent cooling film. Traditional opaque cooling materials are unsuitable for these applications as they block visible light transmission. By deconstructing natural silk fibers into a water-soluble solution, we created a thin, transparent layer that retains 92% mid-infrared emissivity while allowing visible light transmission.

Field evaluations highlighted the practical benefits of this innovation. When applied to a smartphone surface, the transparent cooling film reduced device temperatures by 5.1°C, mitigating overheating issues that often degrade performance and longevity in consumer electronics. Similarly, when deployed on silicon solar panels, the film lowered surface temperatures by 14°C, significantly improving photovoltaic conversion efficiency. These results imply the potential of transparent cooling film for widespread application in both technological and architectural contexts.

As interdisciplinary efforts advance, radiative cooling materials promise to revolutionize sustainable cooling, addressing critical energy and climate challenges. By providing efficient, scalable, and eco-friendly solutions, these innovations have the potential to mitigate global warming and pave the way for a more sustainable future.

Research Highlights

- 2024 Future Tech Award
- 2024 Young Chemist Award from Chemical Soiety Located in Taipei
- 2023 Young Investigator Award from Nanotechnolgy and Micro System Association

Research Output

- M.-T. Tsai, S.-W. Chang, Y.-J. Chen, H.-L. Chen, P.-H. Lan, D.-C. Chen, F.-H. Ko, Y.-C. Lo, H.-C. Wang, Dehui Wan*."Scalable, Flame-resistant, Superhydrophobic Ceramic Metafibers for Sustainable All-day Radiative Cooling", Nano Today, 2023, 48, 101745.
- Y.-H. Chen, C.-W. Hwang, S.-W. Chang, M.-T. Tsai, K. N. Jayakumaran, L.-C. Yang, Y.-C. Lo, F.-H. Ko, H.-C. Wang, H.-L. Chen,* Dehui Wan* "Eco-Friendly Transparent Silk Fibroin Radiative Cooling Film for Thermal Management of Optoelectronics", Advanced Functional Materials, 2023, 33, 2301924 (highlighted on the Journal Inside Back Cover).

Professor Dehui Wan

- P.-H. Lan, C.-W. Hwang, T.-C. Chen, T.-W. Wang, H.-L. Chen*, Dehui Wan* "Hierarchical Ceramic Nanofibrous Aerogels for Universal Passive Radiative Cooling", Advanced Functional Materials, 2024, 2410285.

Targeting Hydrogen Sulfide Offers New Therapeutic opportunities through Rewiring Cancer Glucose Metabolism

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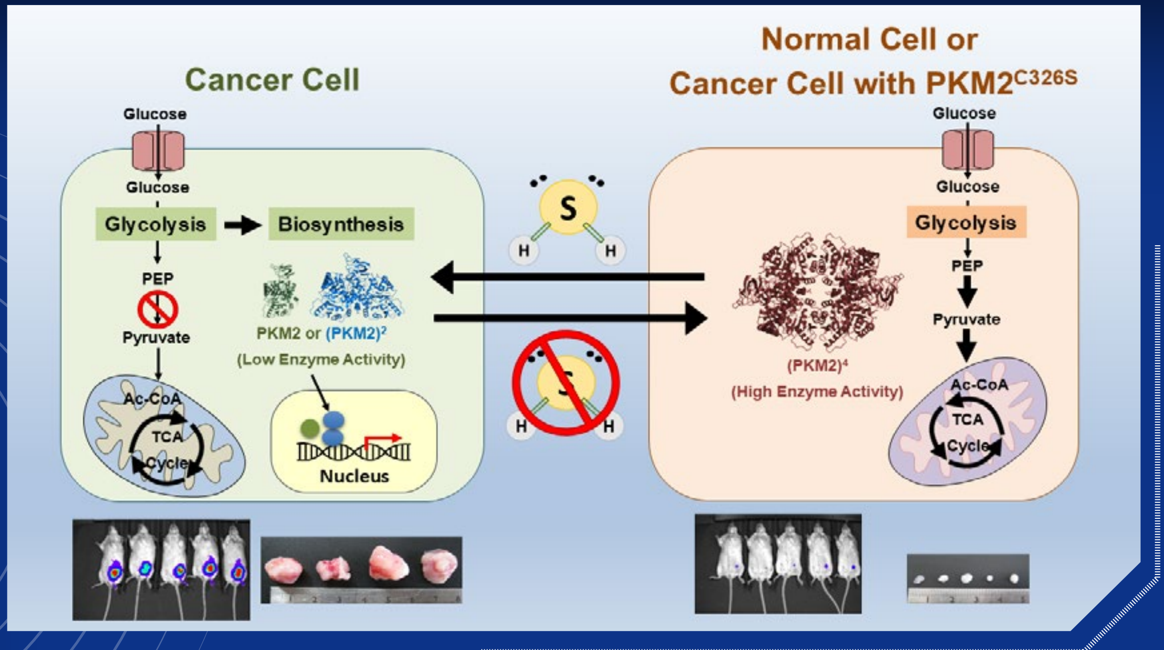

A schematic illustration revealing H_2S modulates glucose metabolism switch through destabilizing PKM2 oligomerization. Left: In cancer cells, H_2S promotes dissociation of PKM2 tetramer to monomer/dimer through protein sulfhydration. Inhibition of PKM2 activity results in the accumulation of metabolic intermediates required for biosynthesis. Meanwhile, the PKM2 monomers or dimers translocate into the nucleus to facilitate multiple gene expressions to promote tumor growth. Right: Blockade of PKM2 sulfhydration at cysteine 326 by mutation stabilizes PKM2 tetramer to maintain high PK activity, resulting in high energy generation, low biosynthesis, and inhibition of tumor growth.

Cancer cells reprogram their metabolism to acquire nutrients necessary for biomass synthesis. Specifically, they prioritize glucose utilization via aerobic glycolysis over oxidative phosphorylation, leading to the accumulation of glycolytic intermediates. These intermediates support macromolecule biosynthesis required for rapid proliferation, making metabolic rewiring a hallmark of cancer. A key player in this process is pyruvate kinase M2 (PKM2), the rate-limiting enzyme in glucose metabolism that converts phosphoenolpyruvate (PEP) to pyruvate. Reduced PKM2 activity enables cancer cells to use glycolytic metabolites for macromolecule synthesis, enhancing their proliferative efficiency.

Our study reveals that the hypoxic tumor microenvironment induces the production of hydrogen sulfide (H_2S), a gaseous signaling molecule, which modifies PKM2 through protein sulfhydration. This modification shifts PKM2 from a highly active tetramer to a less active dimer, increasing glucose uptake for glycolysis to meet the demands of high biosynthesis and low energy production in cancer cells. Blocking PKM2 sulfhydration at C326, either by mutation or by depleting H_2S through inhibitors or siRNA knockdown, prevents tetramer dissociation and nuclear translocation of PKM2. This promotes oxidative phosphorylation, shifting metabolism towards high energy production with reduced biosynthesis, and significantly inhibits tumor growth.

In addition to its role in cancer metabolism, endogenous H_2S is also essential for lifespan extension, vasodilation, immunomodulation, and pro-survival signaling. Our discovery that H_2S facilitates the OXPHOS/glycolysis switch by destabilizing PKM2 tetramers provides a compelling explanation for its biological significance. Future research should investigate the mechanisms of PKM2 sulfhydration under both normal physiological and pathological conditions. Overall, targeting H_2S-mediated PKM2 sulfhydration offers a promising therapeutic strategy to reprogram glucose metabolism in cancer, as well as in other diseases.

Research Highlights

- 14th Y. Z. Hsu Science Award

Research Output

- Wang, R. H., P.-R. Chen, Y.-T. Chen, Y.-C. Chen, Y.-H. Chu, C.-C. Chien, P.-C. Chien, S.-Y. Lo, Z.-L. Wang, M.-C. Tsou, S.-Y. Chen, G.-S. Chiu, W.-L. Chen, Y.-H. Wu, L. H.-C. Wang, W.-C. Wang, S.-Y. Lin, H.-J. Kung, L.-H. Wang, H.-C. Cheng and Lin, K. T. "Hydrogen Sulfide Coordinates Glucose Metabolism Switch through Destabilizing Tetrameric Pyruvate Kinase M2. Nature Communications. 2024. 15, 7463.
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- Chu, Y. H., Huang, Y. C., Chiu, P. Y., Kuo, W. H., Pan, Y. R., Kuo, Y. T, Wang, R. H., Kao, Y. C., Wang, Y. H., Lin, Y. F., and Lin, K. T., Combating breast cancer progression through combination therapy with hypomethylating agent and glucocorticoid. iScience. 2023. 26: 106597.

Professor Wen-Ching Wang, Professor Lily Hui-Ching Wang, Professor Kai-Ti Lin, and professor Hui-Chun Cheng

Multiplex, Multiscale Microscopy Imaging

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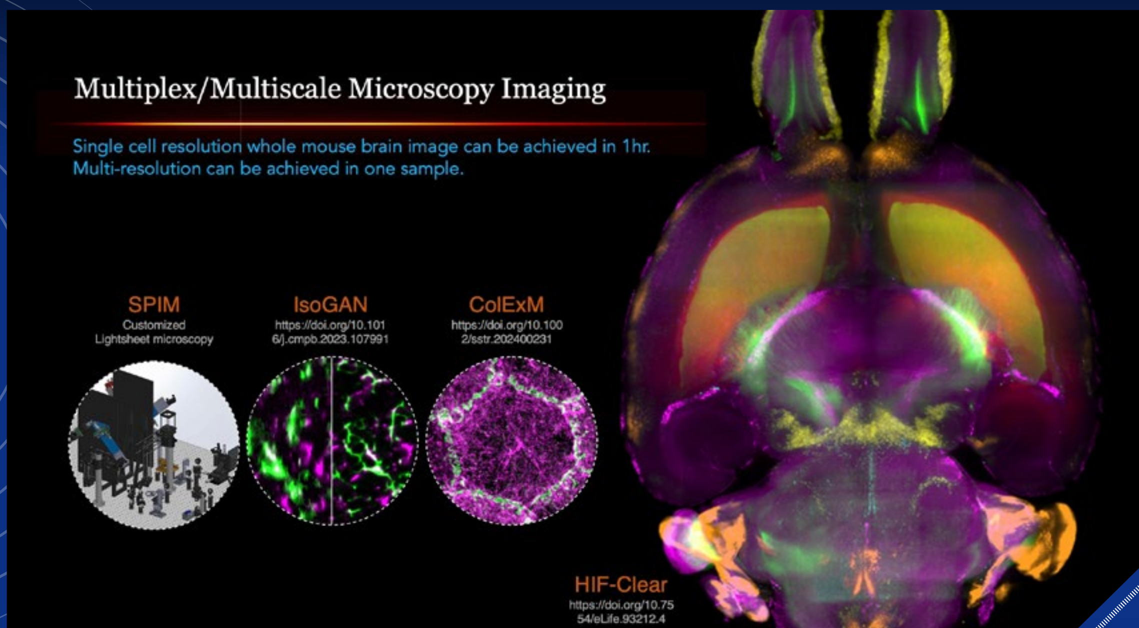
Multi-scale and multiplexed staining microscopy techniques have a profound impact on neuroscience and drug development, as they provide comprehensive information spanning from macroscopic to microscopic levels, revealing the connections between neural structures and functions, and supporting multi-layered evaluations of drug effects. In neuroscience research, the scale of neural structures, including neurons, synapses, and vasculature, varies widely. Relying on a single-resolution imaging technique cannot simultaneously capture the overall distribution of whole-brain tissues and the fine details of local structures. Multi-scale microscopy techniques enable rapid acquisition of whole-brain overviews at low resolution and detailed analysis of specific regions at high resolution, uncovering the functional connectivity and regional specificity of neural networks.



These images showcase a range of technologies we have developed for advancing brain research and drug delivery studies.

Moreover, multiplexed staining techniques allow the labeling of multiple biomarkers within the same sample, such as cFOS proteins related to neuronal activity, neurotransmitters, and vascular structures. This facilitates integrated analysis of neural functions, molecular expressions, and microenvironments. In drug development, these techniques enable precise tracking of drug distribution within tissues, metabolic pathways, and their effects on neurons and supporting cells. For instance, observing vascular remodeling and neural repair processes simultaneously can reveal the critical role of neurovascular coupling in drug treatments, optimizing drug design and dosage.

In summary, multi-scale and multiplexed staining microscopy techniques not only provide powerful tools for deciphering complex neural systems in neuroscience but also offer comprehensive and precise data for drug development, accelerating the discovery of new therapies and their clinical applications.

In this year, we have published the HIF-Clear multiplex staining technique, which is specifically designed for large tissue samples. This technique enables visualization of different neural responses to drugs and treatments in studies of wound healing and neural repair. By leveraging HIF-Clear, researchers can gain deeper insights into how various therapeutic strategies influence neural recovery and regeneration.

Additionally, we introduced the ColExM technique, which allows for super-resolution imaging of tissues with high collagen concentrations, such as skin and cornea. This innovation provides unprecedented detail of molecular deformations between cells and reveals the unique alignment patterns of collagen in tumor tissues. These advancements not only enhance our understanding of tissue dynamics and cellular interactions but also offer powerful tools for exploring the structural and molecular intricacies of complex biological systems, furthering both basic research and translational applications.

Research Highlights

- Best Technology Breakthrough Award at Future Technology Exhibition
- Young Scholar Award, Biomaterials and Control Released Society, Taiwan
- National innovation award, Clinical applications

Research Output

- 乳癌風險評估方法 (初審審定：准予發明專利), 申請日 2024, 5, 30. 發明人：朱麗安、黃兆寅、林佳蓉
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- Li-An Chu, Chu-Yi Tai, Ann-Shyn Chiang*, Thirst-driven hygrosensory suppression promotes water seeking in Drosophila. (Aug. 2024). PNAS, 121 (34) e2404454121.
- Ya-Hui Lin , Li-Wen Wang , Yen-Hui Chen , Yi-Chieh Chan , Shang-Hsiu Hu , Sheng-Yan Wu , Chi-Shiun Chiang , Guan-Jie Huang , Shang-Da Yang , Shi-Wei Chu , Kuo-Chuan Wang , Dr. Chin-Hsien Lin , Pei-Hsin Huang , Hwai-Jong Cheng , Bi-Chang Chen*, Li-An Chu*, (May 2024), Revealing intact neuronal circuitry in centimeter-sized formalin-fixed paraffin-embedded brain, eLife, 13:RP93212
- Gary-Han Chang, Meng-Yun Wu, Ling-Hui Yen, Da-Yu Huang, Ya-Hui Lin, Yi-Ru Luo, Ya-Ding Liu, Bin Xu, KamW. Leong, Wen-Sung Lai, Ann-Shyn Chiang, Kuo-Chuan Wang, Chin-Hsien Lin, Shih-Luen Wang, Li-An Chu* (Feb. 2024) “Isotropic multi-scale neuronal reconstruction from high-ratio expansion microscopy with contrastive unsupervised deep generative models”, Computer Methods and Programs in Biomedicine, 244, 107991
- Min-Ren Chiang*, Ya-Hui Lin*, Wei-Jie Zhao, Hsiu-Ching Liu, Ru-Siou Hsu, Tsu-Chin Chou, Tsai-Te Lu, I-Chi Lee, Lun-De Liao, Shih-Hwa Chiou, Li-An Chu*, Shang-Hsiu Hu*, (Oct, 2023) “In Situ Forming of Nitric Oxide and Electric Stimulus for Nerve Therapy by Wireless Chargeable Gold Yarn-Dynamos”, Advanced Science, 22
- Yi-Chieh Chan*, Ya-Hui Lin *, Hsiu-Ching Liu, Ru-Siou Hsu, Min-Ren Chiang, Li-Wen Wang, Tsu-Chin Chou, Tsai-Te Lu e f g, I-Chi Lee a, Li-An Chu*, Shang-Hsiu Hu*, (Aug, 2023) “In situ magnetoelectric generation of nitric oxide and electric stimulus for nerve therapy by wireless chargeable molybdenum carbide octahedrons”, Nanotoday, (51) 101935

Upright, Prof. Li-An Chu

Materials Science

04

Advancing Next-Generation Integrated Circuits: Valleytronics and Nonlinear Plasmonic Nanocircuits

Advancing Aqueous Zinc-Ion Energy Storage: Unveiling the Potential of 3D rGO-Coated Zinc Anodes and Innovative Pretreatment Techniques

Wafer-Scale Janus Transition Metal Dichalcogenides with Highly Electrocatalytic Faradaic Efficiency for Nitrogen Reduction

Lithium-ion storage mechanism in closed pore-rich hard carbon with ultrahigh extra plateau capacity

Advancing Next-Generation Integrated Circuits: Valleytronics and Nonlinear Plasmonic Nanocircuits

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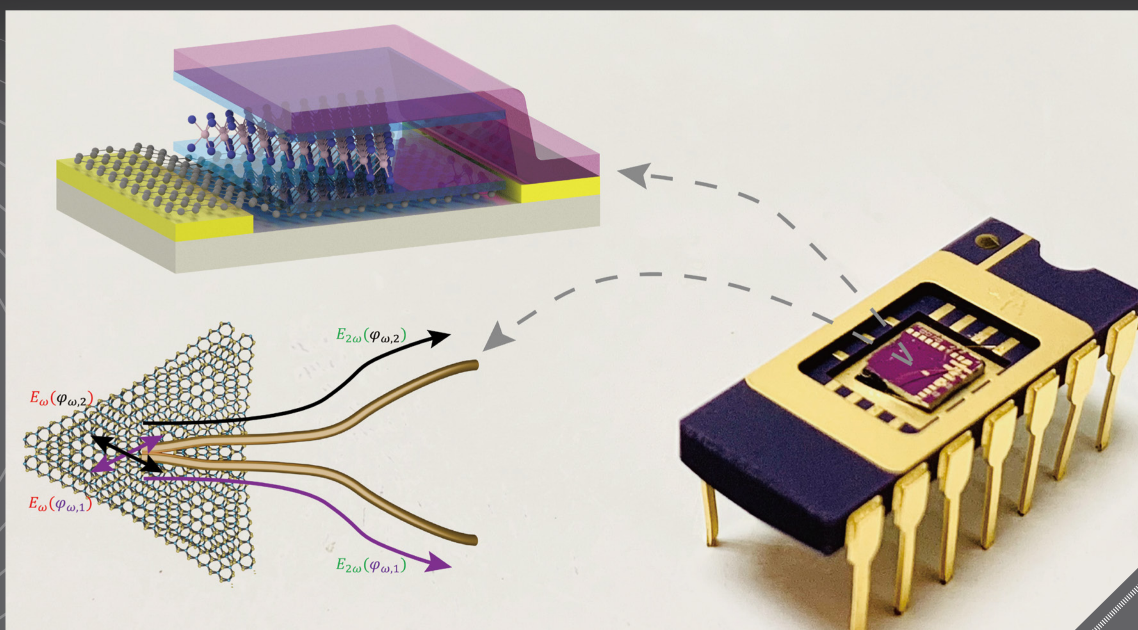
To meet the ever-growing demands for computing power, next-generation integrated circuits must achieve reduced power consumption, smaller device footprints, and enhanced performance. These advancements are essential to sustain the rapid pace of technological progress in areas such as artificial intelligence, big data, and high-speed communication. Current silicon-based technologies face physical and material limitations, making it increasingly challenging to balance energy efficiency, device miniaturization, and computational speed. This pressing need has driven the exploration of innovative solutions that go beyond conventional charge-based electronics, incorporating new physical principles and material systems. Our research takes on this challenge by focusing on two transformative approaches: valleytronics and nonlinear plasmonic nanocircuits. These strategies leverage the unique properties of 2D materials and hybrid systems to push the boundaries of what is achievable in nanoscale electronic and photonic devices.



Leveraging Emerging 2D Materials and Van der Waals Heterostructures for Next-Generation Nanoelectronics and Integrated Circuits

The first approach leverages the valley degree of freedom in 2D transition metal dichalcogenides (TMDs), such as MoS_2 and WSe_2, to encode information. This method, known as valleytronics, utilizes the electronic band structure's valleys as information carriers, providing a low-energy, high-speed alternative to conventional charge-based electronics. While valleytronics holds great promise, its practical implementation has been hampered by a reliance on optical control, which is less efficient and less compatible with existing nanoelectronic systems. To overcome this limitation, we explored the 2D van der Waals (vdW) magnet Fe_3GeTe_2, identifying it as a high-efficiency spin source. By exploiting this material's unique properties, we achieved electrical control of the valley degree of freedom, marking a significant step toward realizing valleytronic devices suitable for practical nanoelectronics.

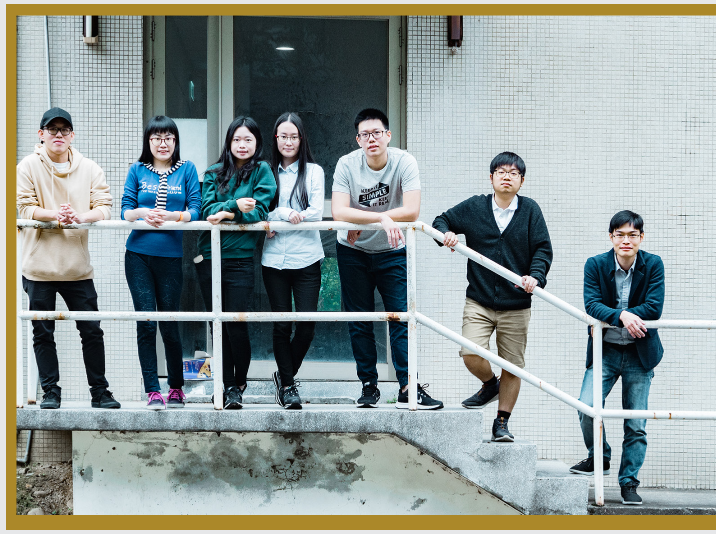
The second approach focuses on advancing plasmonic nanocircuits by enhancing their performance in nonlinear optical regimes. Nonlinear plasmonic circuits are promising for high-capacity optical signal processing, but their development has been constrained by limited nonlinear conversion efficiency. To address this challenge, we developed a hybrid photonic nanocircuit by integrating TMD materials, known for their inherently large second-order nonlinear susceptibility (χ^2), with functional plasmonic structures. This innovative integration resulted in a remarkable 13.8-fold enhancement in second-harmonic generation (SHG) compared to pristine plasmonic circuits. Furthermore, the hybrid design enabled selective routing of SHG signals, which is crucial for practical applications. The key features of our hybrid nanocircuit include significantly enhanced SHG, efficient coupling between photonic and plasmonic components, and controllable routing of optical signals. These advancements open new possibilities for on-chip optical frequency conversion, optical switching, and logic operations, paving the way for next-generation information processing and communication technologies.

Research Highlights

- Young Scholar Innovation Award, Foundation of the Advancement of Outstanding Scholarship, 2023
- Y. Z. Hsu Scientific Paper Award, 2023
- Ta-You Wu Memorial Award, 2022

Research Output

- Pei-Yuan Wu, Wei-Qing Lee, Chang-Hua Liu*, Chen-Bin Huang*, "Coherent control of enhanced second-harmonic generation in a plasmonic nanocircuit using a transition metal dichalcogenide monolayer", Nature Communications 15, 1855 (2024).
- Jia-Xin Li, Wei-Qing Li, Sheng-Hsiung Hung, Po-Liang Chen, Yueh-Chiang Yang, Tian-Yun Chang, Po-Wen Chiu, Horng-Tay Jeng*, Chang-Hua Liu*, "Electric control of valley polarization in monolayer WSe2 using a van der Waals magnet", Nature Nanotechnology 17, 721-728 (2022). (Selected as the Cover Image of Nature Nanotechnology July 2022 Issue)



Chang-Hua Liu's team, Co PI: Prof. Po-Wen Chiu, Prof. Horng-Tay Jeng and Prof. Chen-Bin Huang

Advancing Aqueous Zinc-Ion Energy Storage: Unveiling the Potential of 3D rGO-Coated Zinc Anodes and Innovative Pretreatment Techniques

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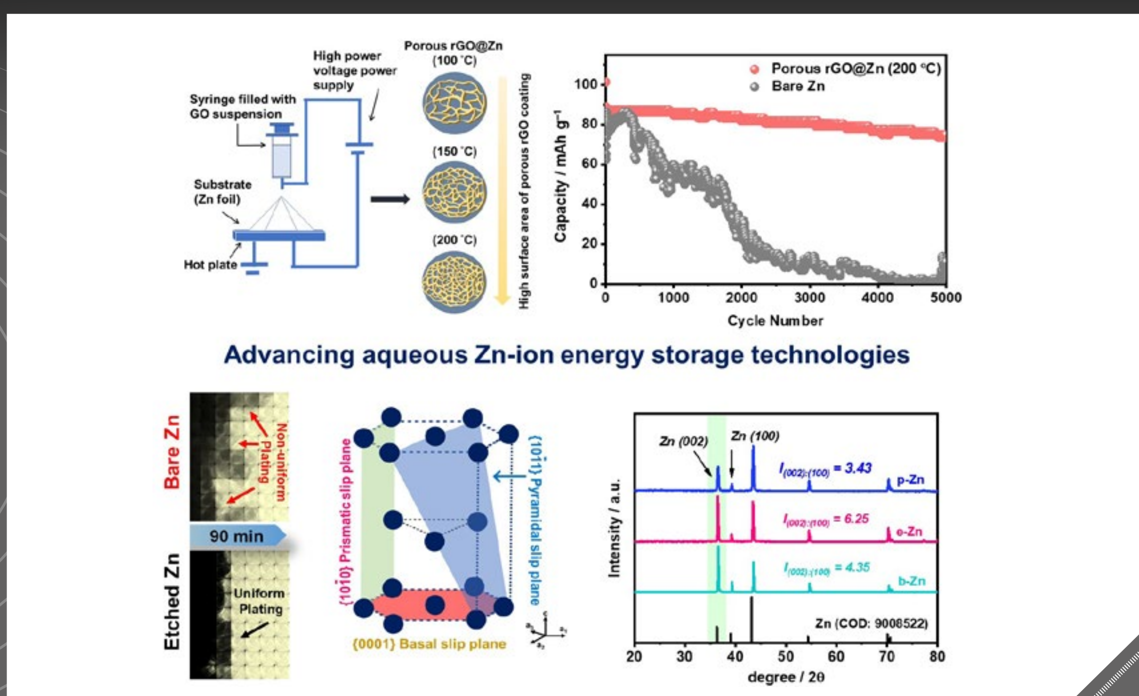
Zinc-ion energy storage devices, including zinc-ion batteries (ZIBs) and zinc-ion capacitors (ZICs), are known for their cost-effectiveness and safety, owing to the abundance and chemical stability of zinc metal. Nonetheless, their electrochemical performance is hindered by challenges such as dendrite formation, uneven charge distribution, and undesirable side reactions. We demonstrate two innovative strategies to enhance the performance of Zn-based anodes in aqueous ZICs and ZIBs: (1) the fabrication of 3D porous reduced graphene oxide-coated Zn (rGO@Zn) anodes via electrostatic spray deposition (ESD) and (2) a facile pretreatment of Zn foil using ammonium persulfate.



Advancing aqueous Zn-ion energy storage technologies

The 3D porous rGO-coated Zn anode, investigated in the first study, exhibits superior electrochemical performance due to its high surface area and polar functional groups, which guide Zn^{2+} deposition pathways. Varying the ESD substrate temperature (100–200 °C) revealed that higher temperatures increased the electrochemical surface area (ECSA), resulting in uniform Zn deposition and suppressed dendrite growth. This enhancement minimized voltage hysteresis (44.5 mV) and reduced charge transfer resistance (30 Ω). The symmetric cell extended its cycle life to over 3000 hours at a current density of 0.2 mA cm^{-2}, while ZICs paired with an active carbon (AC) cathode sustained 5000 cycles with 84.5% capacity retention. Advanced characterization techniques, such as in situ transmission X-ray microscopy (TXM) and optical microscopy, confirmed the inhibition of dendrite formation and the stabilization of Zn stripping/plating processes.

In the second study, the enhanced Zn anodes were further developed using a scalable chemical etching approach. The use of ammonium persulfate, a cost-effective and widely available etchant, produced chemically etched Zn (e-Zn) with significantly improved properties. The e-Zn exhibited a remarkable life cycle of up to 5000 cycles with ~71% capacity retention at a high current density of 5 A g^{-1} using $V_2O_5{\cdot}nH_2O$ as a cathode material. Additionally, e-Znlle-Zn symmetric cells demonstrated excellent stability, with over 300 cycles at 10 mA cm^{-2} while effectively suppressing hydrogen evolution during Zn plating/stripping. The pretreatment increased nucleation sites, leading to smoother initial surfaces and uniform Zn deposition along the (002) plane, as confirmed by TXM and ex situ atomic force microscopy (AFM). This work showcases the potential of combining advanced surface coating and scalable chemical pretreatment methods to address critical challenges in Zn anodes, such as dendrite suppression, uniform charge distribution, and extended cycling stability. The approach is not limited to ZIBs and ZICs but can also be applied to other energy storage systems requiring high-performance Zn anodes.

In conclusion, our approaches involving 3D porous rGO@Zn coating and the chemically etched Zn foil demonstrate a reliable and industrially feasible pathway to enhance the electrochemical performance of aqueous Zn-ion energy storage devices. These strategies not only improve Zn anode stability and performance but also establish a robust foundation for future innovations in practical and scalable Zn-ion energy storage technologies.

Professor Han-Yi Chen's group (CEM lab).

Research Highlights

- 2023 NSTC Ta-You Wu Memorial Award
- 2030 NSTC Cross-Generation Young Scholars Program-Excellent Young Scholars
- 2030 NSTC Cross-Generation Young Scholars Program-Emerging Young Scholars

Research Output

- Sanna Gull, Chi-Yu Lai, Wen-Hsuan Lu, Bushra Rehman, Wan-Ju Chiu and Han-Yi Chen*, “Beyond conventional: unveiling the impact of Zn anode pretreatment in aqueous zinc-ion batteries”, Journal of Materials Chemistry A, 2024, 12,28919–28929
- Tzu-Chi Su, Sanna Gull, Wei-Hsiang Lin, Yen-Shuo Huang, Chung-Sheng Ni, Chun-Chieh Wang, Han-Yi Chen*, “3D porous reduced graphene oxide-coated zinc anodes for highly-stable aqueous zinc-ion capacitors via electrostatic spray deposition” Carbon, 2024, 229, 119467
- Chi-Yu Lai, Yin-Song Liao, Hao-Yu Ku, Sanna Gull, Han-Yi Chen*, Jyh-Pin Chou,*, Chi-Chang Hu*, "Enhancing Zinc Electrode Stability through Pre-Desolvation and Accelerated Charge Transfer via a Polyimide Interface for Zinc-Ion Batteries", Small, 2024, 20, 2401713.

Wafer-Scale Janus Transition Metal Dichalcogenides with Highly Electrocatalytic Faradaic Efficiency for Nitrogen Reduction

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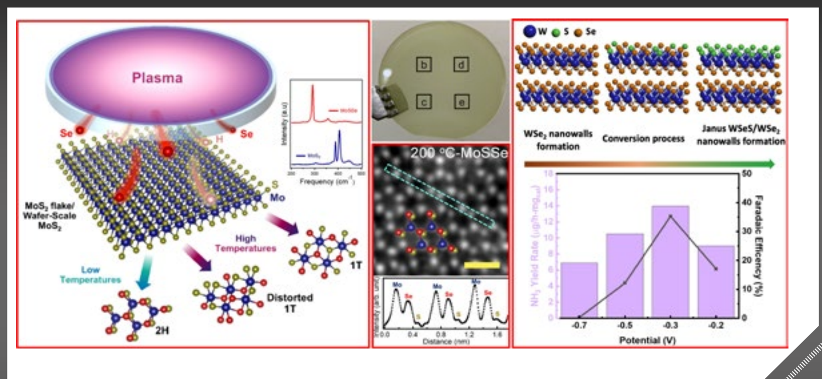
Schematic illustration of plasma-assisted selenization process for converting ML MoS_2 to Janus and Alloy MoSSe. Wafer-scale Janus MoSSe and corresponding. TEM results of MoS_2 and MoSSe. Electrochemical NRR performance of Janus WSeS/ WSe_2 heterostructure.



A new class of two-dimensional (2D) materials called Janus TMDs has sparked research interest recently due to their myriad possible applications, including photocatalysis, optoelectronics, valleytronics, water splitting, and sensing. Compared to traditional TMDs, Janus TMDs are composed of different chalcogen atoms, which breaks the out-of-plane symmetry. Like in Janus MoSSe, the asymmetrical structure generates out-of-plane dipoles between the top Se and bottom S atoms. This intrinsic dipole moment contributes to efficient charge separation, enhancement of Raman scattering, and large Rashba splitting.

The synthesis of monolayer Janus TMDs has only been investigated in limited-size samples, and large scale, e.g., wafer-scale, has not been realized yet, and there are no reports yet on the high-yield production of Janus TMDs. Here, we demonstrate the synthesis of Janus MoSSe by a top-down method for high-yield and wafer-scale production. In particular, we replace the top S atom of monolayer molybdenum disulfide (MoS_2) with Se by a controlled plasma-assisted selenization process (PASP). A set of microscopies, spectroscopies, and electrical measurements showed that low synthesis temperature (200 °C) leads to the formation of Janus MoSSe while high temperatures (400 and 600 °C) lead to the formation of alloy MoSSe configuration. Furthermore, we present here that PASP is suitable for high-yield and wafer-scale production of Janus MoSSe. Apart from this, we demonstrate that Janus WSSe can likewise be obtained by PASP, indicating the universality of the process.

With the development of the electrocatalytic nitrogen reduction reaction (NRR), some practical schemes have been reported based on the concept of an environmentally friendly alternative process that can substitute the conventional energy-intensive Haber-Bosch (H-B) process, which requires high energy consumption and is commonly used in industrial ammonia production. Due to increased global demands and environmental crises, catalysts demonstrating high performance and electrocatalytic activity have been widely investigated under ambient conditions. These catalysts include transition metal-based, single-atom, and p-block element-based materials. TMDs exhibit excellent stability and improved catalytic cycle times and are among the most promising catalysts for NRR research. Because the basal plane of a TMD is inert, most of the active sites are exposed by tuning the catalyst structure or via interface and defect engineering to enhance N_2 adsorption and NRR activity. Therefore, active sites can only be found at the edges of the plane. Here, two issues associated with NRR and JTMD heterostructure, including the synthesis of Janus WSeS/WSe_2 heterostructures and systematical studies on catalytic performance in NRR, which inspired the development of a new strategy, were investigated. The Gibbs free energies of the NRR using Janus WSeS and Janus WSeS/WSe_2 heterostructures as catalysts were analyzed. Furthermore, an in-depth understanding of the potential of Janus WSeS/WSe_2 heterostructures in nitrogen fixation was investigated. These Janus WSeS/WSe_2 were used as a nitrogen fixation catalyst in 0.1 M HCl electrolytes. The Janus WSeS/WSe_2 exhibited a high NH3 yield rate and Faradaic efficiency of 13.97 µg/h-mgcat and 35.24 % at -0.3 V, respectively.

Research Highlights

- 2022 Ministry of Science and Technology Outstanding Research Award (110 MOST Research Award)
- 2022 Selected as the first place in the Corning Innovator-Innovative Application Competition
- 2023 Selected for the Future Technology Award
- 2024 Selected for the Future Technology Award
- 2024 Y.Z. Hsu foundation Technologic Paper Award
- 2024 National Innovation Award

Professor Yu-Lun Chueh (center) together with members of NNL

Research Output

- Paul Albert L. Sino, Tzu-Chieh Lin, Sumayah Wani, Ling Lee, Chieh-Ting Chen, Mingjin Liu, Yao-Zen Kuo, Bushra Rehman, Kim Tuyen Le, Jyh-Ming Wu, Feng-Chuan Chuang* and Yu-Lun Chueh*, "High-Yield and Wafer-Scale Controllable Structure-Engineered Janus and Alloy Polymorphic Monolayer Transition Metal Dichalcogenides by Plasma-Assisted Selenization Process" Materials Today, 2023, 69: 97-106
- Yu-Ren Peng, Shin-Yi Tang, Tzi-Yi Yang, Paul Albert Sino, Yuan-Chun, Chen, Mayur Chaudhary, Chieh-Ting Chen, Ruei-Hong, Cyu, Chia-Chen Chung, Bing-Ni Gu, Ming-Jing Liu, Che-Hua Hsu, Hung-Yi, Huang, Ling Lee, Shu-Chi Wu, Yu-Yi, Jen, You-Song Cheng, Chi-Chang Hu, Wen-Chien Miao, Hao-Chung Kuo, Yu-Lun Chueh*, "Design of Electrocatalytic Janus WSeS/ WSe2 Heterostructure Nanowall Electrodes with High Selectivity and Faradaic Efficiency for Nitrogen Reduction" Advanced Energy Materials, 2023, 13.46: 2301979
- Mayur Chaudhary, Tzu-Yi Yang, Chieh-Ting Chen, Po-Chien Lai, Yu-Chieh Hsu, Yu-Ren Peng, Ashish Kumar, Chih-Hao Lee, and Yu-Lun Chueh*, "Emulating Neuromorphic and In-memory Computing Utilizing Defect Engineering in 2D-Layered WSeOx and WSe2 Thin Films by Plasma-Assisted Selenization Process" Advanced Functional Materials, 2023
- KMMDK Kimbulapitiya, Bushra Rehman, Sumayah Shakil Wani, Chieh-Ting Chen, Ruei-Hong Cyu, Arumugam Manikandan, Manisha Kondiba Date, Yu-Ren Peng, RJGLR Kumara, Feng-Chuan Chuang*, Yu-Lun Chueh*, "Phase-engineered heterostructures of Mo2C by plasma-assisted selenization and sulfurization processes toward excellent hydrogen evolution reaction", Nano Energy 122, 109235, 2024.

Lithium-ion storage mechanism in closed pore-rich hard carbon with ultrahigh extra plateau capacity

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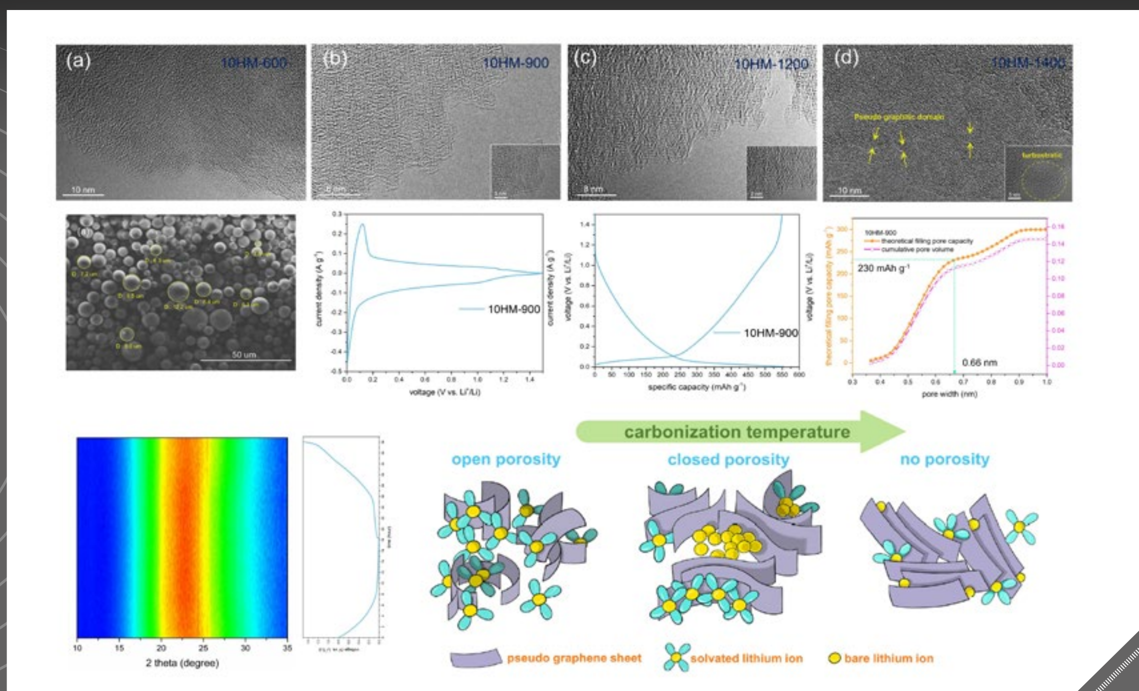

Schematic illustration depicting the porosity evolution in hard carbons as well as the lithium-ion storage mechanisms in them.

Hard carbons (HC) are promising materials for LIBs, LICs, and sodium-ion batteries (SIBs). HC possesses a large interlayer spacing that facilitates ion diffusion and features a unique closed pore structure that enables it to achieve a larger theoretical capacity than graphite. These advantages make HC a promising candidate for overcoming the limitations associated with traditional graphite-based electrodes in LIBs. However, most HC delivers the completely sloping galvanostatic charge-discharge (GCD) curves, indicating the defect-Li-capturing responses and limiting the cell voltage in LIBs.

Herein, the closed pores of PF resin-derived HC microbeads are well manipulated by tailoring chemically cross-linked environments. HCs show increased crystallinity with elevated calcination temperatures. N_2 adsorption effectively characterizes open pore structures, while O_2 adsorption is suitable for identifying closed pores. CO_2 adsorption is employed to distinguish ultramicropores (diameter<0.7nm). By combining the results of multiple gas adsorption isotherms with in situ X-ray diffraction, porosity in HC can be changed with the calcination temperature. With increasing calcination temperatures, open pores are initially transformed into closed pores, and ultimately, non-porous structure are detected. Closed ultramicropores are termed as “active closed pores”, because they facilitate the Li-ion insertion and mitigate substantial initial irreversible capacity by blocking solvent penetration. HC calcinated at 900°C (HC-900) exhibits the closed pore volume of 0.336 cm^{3}g^{-1}. HC-900 with abundant active closed pores can deliver a reversible capacity of 550 mAh g^{-1} at 50 mA g^{-1} in 0.001–1.5 V (vs. Li+ /Li) with an ultrahigh low-voltage plateau capacity of 230 mAh g^{-1} contributed by the faradic reaction of Li-ion insertion in active closed pores. The Li-ion insertion of active closed pores is easily unlocked at 50 mA g^{-1}. HC-900 also demonstrates excellent rate capability (210 mAh g^{-1} at 2 A g^{-1}) and cycling stability (90% capacity retention after 200 cycles at 0.1 A g^{-1} and 86% after 1500 cycles at 1 A g^{-1}), ensuring it as an ideal negative electrode material for LIBs.

Research Highlights

- Sustainable, environmentally friendly, safe, and high energy density lithium batteries: materials, cells and models (Phase III) (台德雙邊協議專案型國際合作計畫第三期)
- 2024- Fellow of the Royal Society of Chemistry, UK.
- 2024- Fellow of the Taiwan Institute of Chemical Engineers, Taiwan.
- 2024- Taiwan Leader in Materials Science (recognized by Research.com in 2024).

Research Output

- Tai, C. W., Jao, W. Y., Tseng, L. C., Wang, P. C., Tu, A. P., & Hu, C. C. (2023). Lithium-ion storage mechanism in closed pore-rich hard carbon with ultrahigh extra plateau capacity. Journal of Materials Chemistry A, 11(36), 19669-19684.
- US Patent 11,855,274, HARD CARBON BEADS, THEIR PREPARATION, AND ENERGY STORAGE DEVICE COMPRISING THE SAME, 2023/12/26-2042/01/26.
- ROC Patent I763592, HARD CARBON BEADS, THEIR PREPARATION, AND ENERGY STORAGE DEVICE COMPRISING THE SAME, 2022/05/01-2041/09/23.

Prof. HU and the students attending the 64th battery symposium presenting the research about the hard carbon material.

Humanities and Social Sciences

How Did 17th-Century Hokkiens and Spaniards Learn Each Other's Languages? Language contact and language ecology in interdisciplinary research.

On Mapping the Causality Structure in Cartographic Terms

Critical review of the effects and role of the Climate Change Response Act of 2023 in Taiwan's net-zero ambition of 2050

05

How Did 17th-Century Hokkiens and Spaniards Learn Each Other's Languages? Language contact and language ecology in interdisciplinary research

Professor Fabio Yuchung Lee
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Received recognition from the Spanish Royal Family and was awarded the First Prize in the "Primer Certamen de Seminarios Duques de Soria de Hispanismo Internacional." Pictured: The "Hokkien-Spanish Historical Document Research Group" with Carlos Emilio Juan Zurita y Delgado, Duke of Soria and Hernani.

Since the establishment of a Spanish colonial base in Manila in the 16th century, the lure of American silver attracted Sangleyes (Hokkien merchants) to engage in trade, while Spanish missionaries sought to convert these Sangleyes into Catholicism. The Spaniards in the Philippines and the Sangleyes represented the peripheries of two "empires," and their connections facilitated the emergence of truly global trade. Their language contact and cultural interactions have also become significant subjects of scholarly inquiry.

During the late 16th and early 17th centuries, Spaniards and Sangleyes collaboratively produced numerous documents. These texts were created primarily to facilitate mutual language learning, supporting missionary efforts and commercial activities. This research team, in close collaboration with scholars from Spain, the Philippines, and Germany, has established the "Hokkien-Spanish Historical Document Research Group." The group is dedicated to studying and publishing the Hokkien Spanish Historical Document Series. By adopting both macro and micro perspectives and integrating approaches from history and linguistics, the team investigates linguistic and cultural exchanges between Hokkiens and Spaniards, and introduce a new approach for academic research in this field.

The primary objective of this research team is to uncover how Hokkiens and Spaniards learned each other's languages and to reveal the dynamics of cultural exchange and interaction during their period of linguistic contact. The study has yielded three primary contributions:

1. Broadening the scope of language contact studies: This research transcends the traditional academic focus on the interaction between Mandarin (the koine of Chinese) and European languages. Instead, it centers on the linguistic contact between 17th-century Hokkien (a vulgar language of Chinese) and Spanish. By integrating perspectives from history and linguistics, the study reconstructs the diverse and complex processes of historical language contact, offering a more comprehensive understanding of multilingual interactions in the past.
2. Highlighting Hokkien's role in cultural exchanges: Through the analysis of the Hokkien Spanish Historical Documents, the research reveals the significant role of Hokkien in cultural exchanges between East Asia and Europe. This work updates the academic value of "dialects" by demonstrating their importance in historical contexts and cross-cultural interactions.
3. Reassessing the academic value of the Hokkien Spanish Historical Documents: The study redefines the scholarly significance of these documents by publishing original historical materials and presenting preliminary research findings. This effort revitalizes academic interest in the results of language contact and cultural exchange, offering new insights into the field.

Research Highlights

- Received recognition from the Spanish Royal Family and was awarded the First Prize in the "Primer Certamen de Seminarios Duques de Soria de Hispanismo Internacional."
- Centered on the members of this project, an international research group, the "Hokkien-Spanish Historical Document Research Group," has been formed in collaboration with scholars from Spain, the Philippines, Germany.
- Owing to its internationally recognized publications and research contributions, the team is honored to host the renowned "12th International Conference on Missionary Linguistics: Early Linguistic Encounters between Europe and Asia," scheduled for March next year. This prestigious conference will feature presentations from approximately 30 scholars representing 10 countries and will attract distinguished international academics, including Uchida Keiichi, Christine Lamarre, and Henning Klöter, who will travel to Taiwan to participate in this significant academic event.

Research Output

- Lee, Fabio Yuchung, Klöter, Henning, Chen, Tsung-jen, Caño Ortigosa, José Luis, Shih, Wen-cheng, José, Regalado Trota, and Ng, Louis Ianchun (eds.). 2023. Vocabulary & Grammar Chin-Cheu. In Hokkien Spanish Historical Document Series V (閩南—西班牙歷史文獻系列五：漳州話詞彙與語法). Hsinchu: National Tsing Hua University Press.

Professor Ying Cheng, Professor Chinfa Lien, Professor Fabio Yuchung Lee.

- Lee, Fabio Yuchung, Chen, Tsung-jen, Klöter, Henning, Caño Ortigosa, José Luis, José, Regalado T., Shih, Wen-cheng, and Ng, Louis Ianchun (eds.). 2024. Memorial de la vida christiana en lengua china. In Hokkien Spanish Historical Document Series VI (閩南—西班牙歷史文獻系列六：新刊僚氏正教便覽). Hsinchu: National Tsing Hua University Press.
- Lien, Chinfa 2023. Studies on Multilingual Ecologies: Language Dissemination, Interaction, Adaptation, and Glocalization (多元語言生態研究：語言的傳播、交流、適應和全球在地化). In Su, Jia-Hong (ed.), Isla Hermosa of the Spanish Era (西班牙時代的艾爾摩莎) (pp. 301-337). Kaohsiung: National Academy of Marine Research.
- Cheng, Ying. 2023. When Hokkien Meets Foreign Languages: A Case Study Based on 17th- and 18th-Century Records from Luzon and Taiwan (當閩南語遇見外語—以十七、十八世紀呂宋與臺灣的資料為例). In Su, Jia-Hong (ed.), Isla Hermosa of the Spanish Era (西班牙時代的艾爾摩莎) (pp. 339-366). Kaohsiung: National Academy of Marine Research.

On Mapping the Causality Structure in Cartographic Terms

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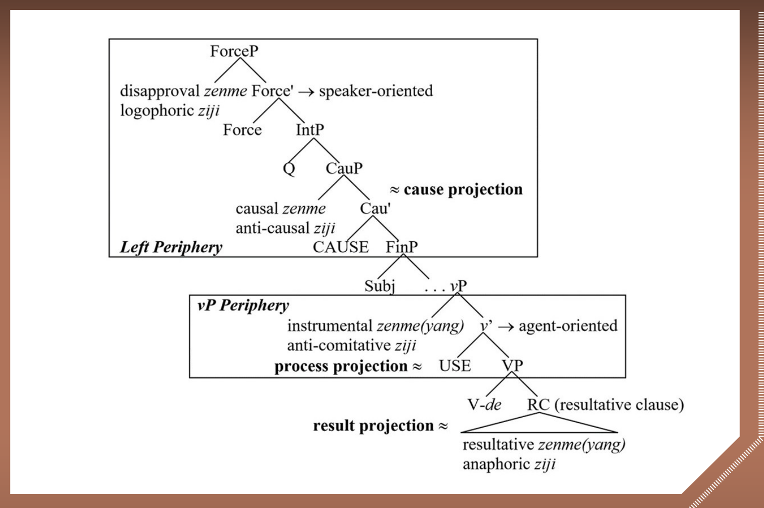
We put forth the claim that the ontological hierarchy of (perceptual) causality can be internalized in cartographic terms. This arrangement in turn may be linearized via antisymmetry (Kayne 1994), hence the surface iconicity in question. Along this line, a coarse-grained structural hierarchy of zenme(yang) 'how(manner)' is of particular interest, as illustrated below:

disapproval how > causal how > instrumental how > resultative how

Topography of Wh and Self along the Clausal Spine in relation to the Causality Hierarchy



For one thing, it is not unreasonable to liken internalization to the process of psychological imprinting, which is of both nature and nurture. In other words, the causality hierarchy in syntax may well reflect the causal-effect relationship in the real world perceived by children. Since the eventuality causation is to be internalized in terms of syntactic hierarchy, inter-modular considerations such as Interface Economy would play an important role. For another, the actual encoding of the cause-effect relationship in individual languages may well be either stretched or contracted according to the macro parameter-setting of analyticity. Consequently, the syntactic projection of cause, process and result is implemented not only according to their ontological arrangement, but also by means of the morpho-syntactic setup of individual languages. In this sense, the surface iconicity "cause > process > result" in temporal terms is simply the result of linearizing the causality hierarchy, which is in itself a reflection of real-world ontology.

As a first approximation, we start with hypothesizing that both causality-encoding and parameter-setting constitute part of the internalization process. It follows that the cause-process-result hierarchy is established in syntax throughout the development of children's cognitive and linguistic capacity, and that they learn the cause-effect relationship through their interaction with the outside world (e.g., kicking a ball results in its rolling to stop at some distance).

In light of the above findings, we investigate a peculiar case of force/attitude embedding, in particular, non-canonical wh-construals in complement clauses. From the vantage point of comparative syntax, we offer a selection-truncation analysis along the line of the Cartographic Approach. This move provides a coherent account of the embeddability of disapproval/whining wh-expressions, which in turn reveals that the root-subordinate asymmetry is not as clear-cut as previously thought, where prominent features such as causality and mirativity play an important role across-the-board. This line of research may well shed new light on the nature of syntax-pragmatics mapping, and advance our understanding of how s-selection and c-selection work together to license syntactic complementation.

Furthermore, interrogative sentences in Formosan languages raise many interesting issues on both the empirical and theoretical fronts. First, they pattern with wh-movement languages such as English in requiring certain types of wh-expressions to appear in the sentence-initial position. They also pattern with wh-in-situ languages such as Chinese in licensing other types of wh-expressions in their base positions. Second, the line is often drawn between subject and non-subject wh's with respect to their ability to undergo (pseudo-)clefting, relativization and topicalization. In the future, we plan to pursue these issues by factoring in prosody, focus, modality, and applicativization from a cross-linguistic perspective.

Research Highlights

- President, GLOW in Asia
- Outstanding Research Award from National Science and Technology Council in 2020
- Invited Speaker, 2023 Society of Modern Grammar (SMOG) Conference, Seoul.
- Invited Speaker, The Foundations of Extended Projections, University of Tromsø.

Research Output

- Tsai, Wei-Tien Dylan (2023) "Wh & Self: On Correlating Wh-conditionals and Reflexive Doubling," Journal of Chinese Linguistics 51.2: 467−482.
- Tsai, Wei-Tien Dylan (2023) "Embedding Force and Attitude: Evidence from Chinese and Vietnamese non-canonical wh-expressions," in Lukasz Jedrzejowski and Carla Umbach (eds.), Non-interrogative Subordinate Wh-clauses, 365-380. Oxford: Oxford University Press.
- Tsai, Wei-Tien Dylan (2023) "Interrogative Clauses in Formosan Languages," in Paul Jen-kuei Li, Elizabeth Zeitoun and Rik De Busser (eds.), Handbook of Formosan Languages: The Indigenous Languages of Taiwan, Part 1, Chapter 23, 749-772. Leiden: Brill.

Celebration of GLOW in Asia XIV, Professor Wei-Tien Dylan Tsai (left) with Professor Victor Junnan Pan

Critical review of the effects and role of the Climate Change Response Act of 2023 in Taiwan’s net-zero ambition of 2050

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Despite the emphasis on the introduction of carbon fees, the main measures that could contribute to large-scale emission reductions might be Mandatory Emission Performance Standards for new industrial installations, vehicles, and buildings. Carbon fees and partial offsets for new installations may come next but should have a relatively minimal impact on emission reduction. Therefore, even though the government claims to adopt market mechanisms to deal with the net-zero challenge, substantial measure seemed to incline to the traditional ‘command and control approach’ by Mandatory Emission Performance Standards, paying a fee, or forcing the purchase of offsets. The subsidy may come only from the GHG(green house gas) Management Fund run by the EPA.

Table 1. Effects of measures in 2023CCRA on achieving the 2050 net-zero target.

Reform	Measures in the CCRA	Measures in GHGRMA	Contribution to further emission reduction
Reinforcement of Administrative Regulations	Mandatory Emission Performance Standards for new industrial installations, vehicles, and buildings *	voluntary	★★★
	Partial offsets for new installations**	N/A	★★
	Carbon footprints of products***	N/A	★
	Regulating high global warming potential GHGs and their products	N/A	★
	The Legal Basis for Carbon Utilisation and Carbon Storage	N/A	★
Carbon Price Scheme	Carbon fee/tax in the 2023 Climate Change Response Act	ETS****	★★
Reinforcement of institutional design	Central Competent Climate Change Authority and the GHG Management Fund	EPA	0 or ★
	Central Coordinating Authority: from Cabinet Office to NCSD	Cabinet Office	0 or ★
	Relevant central government agencies	Similar	0 or ★
	Central industry authorities		0 or ★
	Local government	Similar	0
Other Measures	Change the title of the act	GHGRMA	0
	Net-Zero Ambition	50% by 2050	★
	Adding many more climate change and energy principles	Fewer principles	0
	Taiwan carbon border tax	N/A	0 or ★
	Soft rules: Education and grants	Similar	0

(Source: Compiled by the authors.).
*Performance standard refers to the allowable emissions for a unit of product, unit of raw material, unit of mileage or other unit of usage for an emission source.
**Entities with newly installed or modified Emission Sources that reach a certain scale shall offset their increased GHG emissions based on a certain percentage of increased emissions.
***Carbon footprint refers to the amount of total carbon emissions released throughout the life cycle of a product from raw material acquisition, manufacturing, distribution and sale, use and waste treatment, calculated by total CO_2 equivalent.
****An ETS has never been implemented.

The predictions remain uncertain, because the detailed rules are incomplete. It may take some time for this new Act to be fully implemented, leading to an inability to obtain empirical data to sustain the analysis in Table 1. Therefore, the authors welcome future researchers to conduct quantitative research to verify the predictions of this study. However, based on our previous predictions, when the 2015 GHG Act was adopted , such a would have enabled its implementation. Thus, the promotion of further emissions reduction should rely on other legislation such as the Renewable Energy Development Act or the Energy Saving Act. However, the cabinet adopted the energy-saving bill in March 2018, but it was not completely adopted by the Parliament . Thus, it seems that we could only rely on the recently passed Renewable Energy Act of 2023 in May 2023, particularly the mandatory rooftop solar panels for new buildings in Taiwan, to impede the net-zero ambition .

In addition to an insufficient legal strategy, the recent energy transition and nuclear-free homeland policy since 2016 have posed tremendous challenges to Taiwan’s 2050 net-zero ambition. According to this policy, Taiwan will phase out all nuclear power (originally approximately 10–15% of the electricity mix) to an electricity mix of 50% gas-fired, 30% coal-fired, and 20% renewable electricity. With the continuing growth of electricity consumption from the prospering semiconductor and other high-technology industries, and perhaps the highest ratio of fossil fuel-fired power in the electricity mix (e.g., 82.4% in 2022) among manufacturing-based countries, the only or easiest way for Taiwan to meet such a rigid 2050 challenge would be to buy global offsets. If this is the case, then it seems to come into a full circle with a large-scale revision of the 2023 Climate Change Response Act (CCRA). However, there is a need to implement and fine-tune the ETS scheme in the GHGRMA by removing the 10% import offset ceiling. Therefore, the CCRA may give the impression of an exaggerated attack gesture without hitting the targets.

Research Highlights

- The first to adopt a comprehensive approach to evaluate how and to what extent this legal strategy could contribute to the 2050 net-zero ambition.
- Updated overview of climate change legislation of the newly adopted Climate Change Response Act of 2023 in Taiwan
- Evaluation of the effects of this legislation to meet its 2050 net zero goal.
- Potential challenges to achieve 2050 net zero target.
- Introduction of the first carbon fee scheme in the world.

Professor J. Ma, Professor K. M. Chang, Dr. W. Yeh.

Research Output

- Gao, A. M. Z., Fan, C. T., Yeh, T. K., & Liao, C. N. (2024). Critical review of the effects and role of the Climate Change Response Act of 2023 in Taiwan's net-zero ambition of 2050. Carbon Management, 15(1), 2306319.
- Hughes, L., Cheng, W., Do, T. N., Gao, A. M. Z., Gosens, J., Kim, S. Y., & Longden, T. (2024). Governing offshore wind: is an ‘Asia-Pacific Model’emerging?. Climate Policy, 1-11.
- Anton Ming-Zhi Gao, Tsung Kuang Yeh, Jong-Shun Chen, An unjust and failed energy transition strategy? Taiwan's goal of becoming nuclear-free by 2025, Energy Strategy Reviews, Volume 44, 2022, 100991, ISSN 2211-467X, https://doi.org/10.1016/j.esr.2022.100991.
- Gao, A. M. Z.*, Huang, C. H., Lin, J. C., & Su, W. N. (2021). Review of recent offshore wind power strategy in Taiwan: Onshore wind power comparison. Energy Strategy Reviews, 38, 100747.