INSTITUTE *for* SUPERCONDUCTING *and* ELECTRONIC MATERIALS

UNIVERSITY OF WOLLONGONG AUSTRALIA

Institute for Superconducting and Electronic Materials

Annual Report 2020

isem.uow.edu.au

Contents

Director's Report

Dear All

The COVID-19 pandemic has made 2020 a very hard year for the whole world, with no person nor organisation free from the impacts of this unprecedented event. As for many of our colleagues at UOW, in Australia and around the world, 2020 has been a tough and challenging year for ISEM. We all have experienced and suffered from isolation, stress, depression, uncertainty, job security concerns, anxiety, and many other mixed feelings. COVID-19 has brought unprecedented changes to our daily life and work. Despite the COVID-19 impacts, ISEM staff and students alike have shown great resilience and adaptability to the 'new normal', overcoming hardships and transitions to working tirelessly in our laboratories, from their homes, and from remote locations around the world to continue to make significant contributions to ISEM, AIIM, and the University of Wollongong.

I would like to extend my gratitude to all our staff and students, visiting and honorary fellows for their hard work, cooperation, and contribution to ISEM's continued success and smooth operations during the difficult year. I would like to take this opportunity to highlight some activities, outcomes and wonderful achievements made possible through the dedication and hard work of the ISEM community

In March 2020 UOW introduced strict COVID-19 laboratory and workplace restrictions for the safety of staff and students, and I'm proud of the efforts of the ISEM community to continue smooth operations with minimal impact to research progress – resulting in ISEM and all labs remaining open and accessible to all users through appropriate safety protocols. ISEM's team of laboratory and equipment supervisors showed great commitment to their roles, and facilitated continuing access to – and maintenance of – our suite of more than 40 specialist labs, allowing business and out-of-hours experiments to be conducted. This has been critical to maintaining a high productivity of research outcomes and high rate of on-time Higher Degree Research (HDR) student completion.

While most of the ISEM community have been able to continue their work here in Wollongong, some of our staff and students have been stranded abroad due to travel restrictions and other difficulties. UOW and ISEM have put in place measures to support the ISEM community in these difficult circumstances, and I would like to especially thank ISEM HDR student supervisors that have continued to provide excellent research guidance and support to their students from their locations around the world.

I am delighted to report ISEM saw 22 HDR students graduate in 2020, bringing the total ISEM PhD completions to more than 240. High-quality research training is one of the ISEM's core activities and a pillar of our success, and I have high hopes for these latest graduates as they go on to make significant contributions in academia and industry – here in Australia and around the world.

Another pillar is high-impact research outputs, and in 2020 ISEM continued a track record of high-quality publications and citations. ISEM continues its breakthrough publications in top journals such as Nature, Nature Materials, Nature Energy, Science Advances, Nature Communications, Advanced Materials, Advanced Energy Materials, PNAS, Physical Review Letters, Physics Report, Physical Review X, and many other high-impact journals. Professor Shujun Zhang is a key driver and contributor to ISEM publications in Nature (1), Nature Materials (2), Nature Communications (2), and Science Advances (1) – I would like to congratulate Professor Zhang on this significant achievement, and thank him for his hard work and contribution to the ISEM and UOW research reputation. In total, ISEM produced 381 scholarly publications in 2020 in journals with an average Impact Factor of 11.95, a strong performance in terms of number and quality of publications – highlighting the impact ISEM is having in pushing the boundaries of research in Australia and around the world.

As the world looks to consider the value of research not only in terms of numbers and citations, but also in impact on big challenges, we have undertaken a survey of ISEM publications through the lens of the United Nations Sustainable Development Goals (UN SDGs). I am proud to report that for the period 2011-2020, ISEM produced more than 1,000 publications directly related to UN SDGs, and was the source of more than 45% of UOWs publications on Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all for that period. The city of Wollongong has recently been ranked 88th in the world in the nature index 'Leading 200 science cities in SDG research', underscoring the societal value of the research being undertaken at the ISEM.

Yet more recognition of the high standard of research undertaken at ISEM was the announcement of the 2020 Clarivate Highly Cited Researchers – which included six researchers from UOW, of which five are from ISEM: Distinguished Professor Shi Xue Dou, Distinguished Professor Hua Kun Liu, Distinguished Professor Yoshio Bando, Distinguished Professor Zaiping Guo and Professor Shulei Chou. This is the third consecutive year these researchers have been named in this list, a truly outstanding achievement.

ISEM has continued in 2020 its track record of securing external research funding, including being part of the consortium for an Australian Research Council (ARC) Industrial Transformation Research Hub, securing three ARC Discovery Projects, and securing a Linkage Infrastructure, Equipment and Facilities (LIEF) grant.

Undertaking translational research and industry engagement is an important part of ISEM activities, and 2020 has brought unique challenges in this area as our industry partners face uncertainty and new realities. I extend my heartfelt thanks to our continuing and new industry partners for their commitment to research activities, and would like to thank Distinguished Professor Shi Xue Dou, Professor Shujun Zhang and Dr Khay See for guiding their translational research projects and activities through these challenges.

ISEM continues to play a significant role as a node of the ARC Centre of Excellence in Future Low Energy Electronic Technologies (FLEET). The node has produced a number of ground-breaking discoveries and a patent on new concepts and novel nano-engineered topological insulators for both low energy applications and power generation. Many of the node's work have attracted extensive media coverage and a few industry's interests for potential applications and commercialization.

I am thrilled to highlight some of the awards and recognition bestowed on members of the ISEM student community in 2020, including HDR students Mingzhe Chen, Weihong Lai, and Mengmeng Lao receiving the 2019 Chinese Government Award of Outstanding Self-financed Students Abroad, China Scholarship Council (CSC); Wafa Afzal being awarded the FLEET "Owning the future award" at the Fleet 2020 annual workshop; and Yaser Rehman and Jicheng Jiang receiving the 'Runner up' and 'People's choice' awards respectively at the AIIM Three-Minute Thesis competition.

ISEM staff also received many accolades throughout 2020, including Distinguished Professor Zaiping Guo receiving the 2020 New South Wales Premier's Prize for Excellence in Engineering or Information and Communications Technology; Professor Shujun Zhang being nominated as an IEEE Fellow for his contributions to the development of advanced piezoelectrics for transducers; Associate Professor Konstantin Konstantinov receiving the UOW 2020 Vice-Chancellor's Interdisciplinary Research Excellence Award as a leading CI of the Global Challenge project "Next Generation Sunscreens"; Dr. Wei Kong Pang being awarded the 2020 Australian Synchrotron Research Award; and Dr. David Cortie receiving the ANBUG Young Scientist Award for 2020.

Although 2020 has been a year of many challenges and uncertainties, I have been both proud of, and humbled by, the strength, resilience and resolve shown by the ISEM community. Many ISEM staff have joint teaching appointments with the Faculty of Engineering and Information Sciences, and have had to pivot to delivering lectures and supporting students remotely. Despite the COVID-19 restrictions, many of our staff have been actively participating in outreach and governance activities, playing an important role in contributing to the University, community and various academic societies including the UOW academic senate, national and international conferences/symposia/workshops, public lectures to local communities and broad range of scientific communities, donating to charities, engaging with both national and international industrials, HDR student marketing, and signing MOU with new international collaborators and institutions.

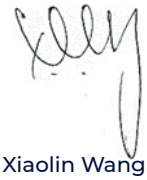
The events of 2020 have shown that, more than ever, the successes of the ISEM are supported by the contributions and effort of many people and organisations across AIIM. I extend my heartfelt thanks to AIIM Executive Director Professor Will Price, AIIM Business Manager Libby McMahon, and the AIIM Operations Staff including Narelle, Naomi, Mat and his Workshop team, Joanne George, and Candace Gabelish. In addition, I gratefully acknowledge IPRI and EMC colleagues for their continued support to ISEM staff and students during this challenging time. I would like to make special mention of the ISEM Administration Officer, Crystal Mahfouz, who has been a mainstay of the ISEM for over 10 years – playing a major role in supporting research activities and making the ISEM a welcoming and memorable place to work and study.

This year, as in every year since the founding of the ISEM more than 27 years ago, the ISEM has received unwavering support from the University of Wollongong, including from the Vice-Chancellor Professor Paul Wellings CBE, the Deputy Vice-Chancellor (Research and Innovation) Professor Jennifer L Martin AC, the UOW Executive team, Graduate Research School, Faculty of Engineering and Information Sciences, Innovation and Commercial Research Unit, Workplace Health and Safety Unit, and other operations and administrative units. My sincere appreciation to these people that support and facilitate the cutting-edge research activities we undertake at the ISEM.

Much of the impact of ISEM research activities is made possible and amplified by our national and international industry and academic collaborators, for whom I am especially grateful in 2020 – as we all navigated the troubled times together. Our 200+ ISEM Alumni continue to amaze me in their passion and excellence as they forge ahead across five continents and show great leadership in roles across academia, industry, and research sectors. That so many Alumni and collaborators worldwide maintain strong links with the ISEM is a testament to their commitment to collegiality, and the position of the ISEM at the forefront of research across our ten Research Programs.

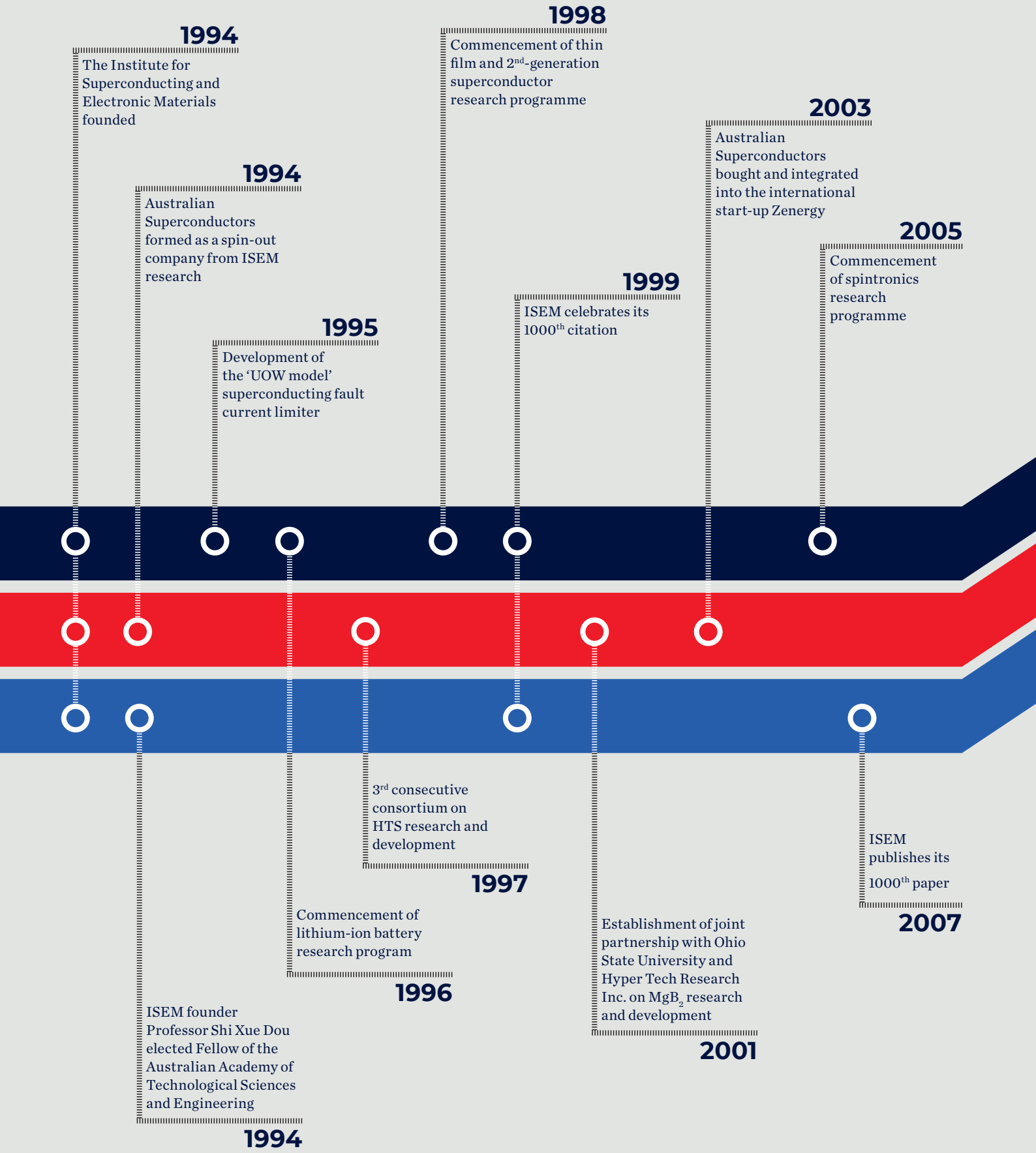
I would like to express my deepest gratitude to my colleagues on the ISEM Executive Committee, who have played a major role in steering the ISEM through the tumultuous 2020. The Executive Committee have shown great flexibility and resolve in dealing with the many operational and strategic issues that have arisen throughout the year, and in developing new strategies to ensure that all staff and student are continuously supported.

While 2020 has been a year of uncertainty and great difficulty for many, I have taken great energy from the resilience, flexibility and outpouring of support for one another I have seen in the ISEM community. This gives me great hope that the world-class research being undertaken at ISEM will continue to make an impact in the world in 2021 and beyond.



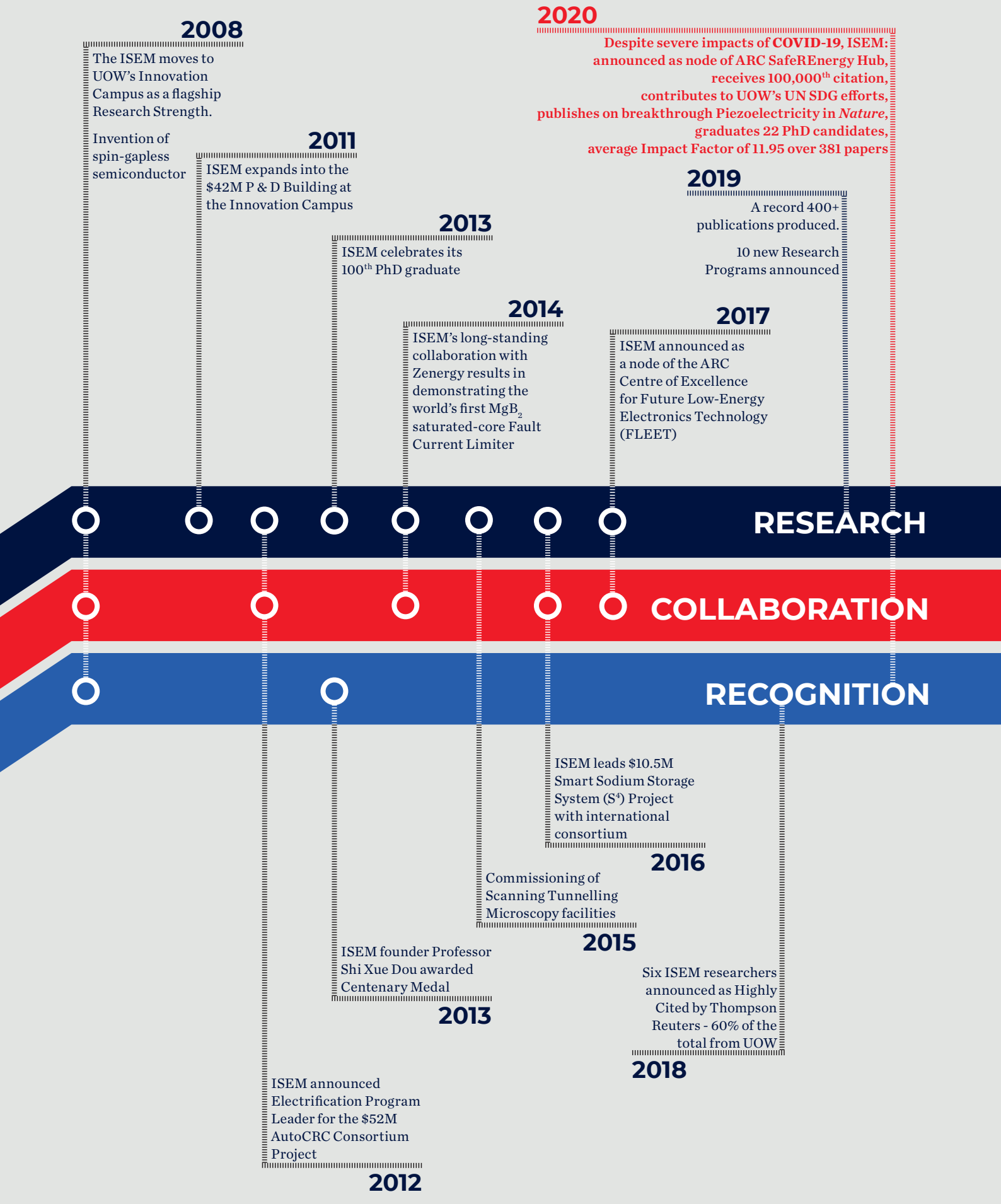
Xiaolin Wang
Director and Distinguished Professor

27+ Years of Success



THE EARLY YEARS

DEVELOPING INTERNATIONAL REPUTATION



EXPANDING RESEARCH EXCELLENCE

TRANSLATING RESEARCH INTO IMPACT

Our Vision

To be leaders in high impact training, research, application, collaborations, community engagement, diversity and inclusion.

Our Mission

- Identify and foster new research areas and global challenges;
- Expand our research collaborations;
- Produce high output through high impact publications;
- Excel in HDR student training;
- Promote the translation of scientific developments into technological platforms;
- Promote our reputation in research excellence;
- Improve our operations and governance;
- Promote diversity and gender equity;
- Connect with our local community.

High Impact Research

Our internationally recognised team of researchers and students have led to our strong record of research impact, with more than 4,000 refereed papers attracting more than 110,000 citations.

In the 2018 Australian Government Excellence in Research (ERA) ratings, the University of Wollongong was rated as 'well above world standard' in the following ISEM-relevant areas: Condensed Matter Physics, Other physical sciences, Inorganic Chemistry, Environmental Engineering, and Materials Engineering. ISEM also strongly contributed to UOW outputs in Electrical Engineering, Nanotechnology, and Other Engineering.

ISEM has attracted considerable research funding, with researchers receiving more than $32 million in research funding over the last decade.

Strong National And International Links

ISEM's track record of high quality research has attracted strong interest from national and international partners and collaborators. It has struck partnering or collaborative research arrangements with more than 70 companies and research institutions in Australia and throughout the world.

These collaborations are producing results with patented technology developed by ISEM, allowing the University of Wollongong to enter into one of its largest licensing deals with HyperTech Research, Inc. in the United States. The goal is to improve the transmission and storage of power, generating energy savings and associated environmental benefits.

In Australia, the ISEM is focusing on translating technology from lab-based successes to commercial impact. Spin-out company Sicona Battery Technology is commercialising an innovative silicon-composite battery anode technology, developed and perfected over the last ten years at the ISEM to enable electric-mobility and storage of renewable energy.

Our Major Initiatives

ARC CENTRE OF EXCELLENCE IN FUTURE LOW ELECTRONIC MATERIALS

The ARC Centre of Excellence in Future Low-Energy Electronics Technologies (FLEET) addresses a grand challenge: reducing the energy used in information and communication technology (ICT), which now accounts for 8% of the electricity use on Earth, and is doubling every 10 years. The current, silicon-based technology is 40 years old, and reaching the limits of its efficiency. To allow computing to continue to grow, we need a new generation of ultralow energy electronics. FLEET is pursuing the three approaches to develop systems in which electrical current can flow with near-zero resistance: Topological materials, exciton superfluids, and light-transformed materials.

ISEM hosts the University of Wollongong node of FLEET, under the leadership of ISEM Director, Professor Xiaolin Wang. Professor Wang is also a theme leader of FLEET's efforts in developing the novel topological materials, new class of materials, and 2D materials that will underpin a new generation of ultra-low energy electronics. The ISEM team is investigating the electronic, spintronic, and superconducting properties of novel electronic and spintronic systems such as topological insulators, high spin polarised materials, spin gapless semicondutors, superconductors, multi-ferroic materials, and new energy materials in various forms such as single crystals, atomically thin (2D) and thin films, and nano-devices.

2020 HIGHLIGHTS:

In 2020, the UOW FLEET node published a number of review articles and theoretical works on the fundamental and application significance of spin gapless semiconductors. Our studies showed that the Dirac-type spin gapless semiconductor (invented by Prof. Xiaolin Wang, *Physical Review Letters*, 2008) and magnetic topological insulators are most important platforms for facilitating the Quantum Anomalous Hall Effect (QAHE), which allows zero-resistance electrical 'edge paths'.

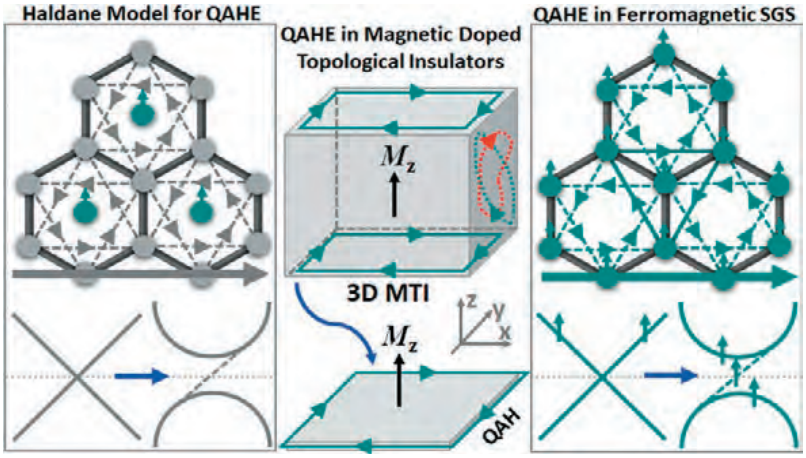


Figure 1 – Quantum Anomalous Hall Effect (QAHE) descriptions in Haldane mode, magnetic topological insulator, and spin gapless semiconductors, from Nadeem et al. 2020 publication

The QAHE was first proposed by 2016 Nobel Prize recipient Professor Duncan Haldane (Princeton University) in the 1980s, although it subsequently proved challenging to realise QAHE in real materials. Magnetic-doped topological insulators and spin-gapless semiconductors are the two best candidates for QAHE. QAHE describes an 'unexpected' (i.e. 'anomalous') quantisation of the transverse 'Hall' resistance, accompanied by a considerable drop in longitudinal resistance. Researchers at the ISEM seek to enhance these two driving factors in order to strengthen QAHE and make topological electronics viable for room-temperature operation. A number of theoretical models were reviewed and a new model was proposed that could enhance QAHE, allowing topological insulators and spin fully-polarised, zero-gap materials (spin-gapless semiconductors) to function at higher temperatures.

- **Review Article:** Muhammad Nadeem, Alex R. Hamilton, Michael S. Fuhrer, and Xiaolin Wang, "Quantum Anomalous Hall Effect in Magnetic Doped Topological Insulators and Ferromagnetic Spin-Gapless Semiconductors—A Perspective Review", *Small* **2020**, 1904322.
- **Review Article:** Zengji Yue, Zhi Li, Lina Sang, and Xiaolin Wang, "Spin gapless semiconductors", *Small* **2020**, 1905155.
- **Review Article:** Qiang Cao, Weiming Lu, X. Renshaw Wang, Xinwei Guan, Lan Wang, Shishen Yan, Tom Wu, Xiaolin Wang, "Nonvolatile Multistates Memories for High-Density Data Storage", *ACS Appl. Mater. Interfaces* **2020**, 42449–42471.
- **Review Article:** Xiaotian Wang, Zhenxiang Cheng, Gang Zhang, Hongkuan Yuan, Hong Chen, and Xiaolin Wang, "Spin-gapless semiconductors for future spintronics and electronics", *Physics Reports* **2020**, (888) 1-57.
- **Review Article:** Zhi Li, Lina Sang, Peng Liu, Zengji Yue, Michael S. Fuhrer, Qikun Xue, and Xiaolin Wang, "Atomically thin superconductors", *Small* **2020**, 1904788.

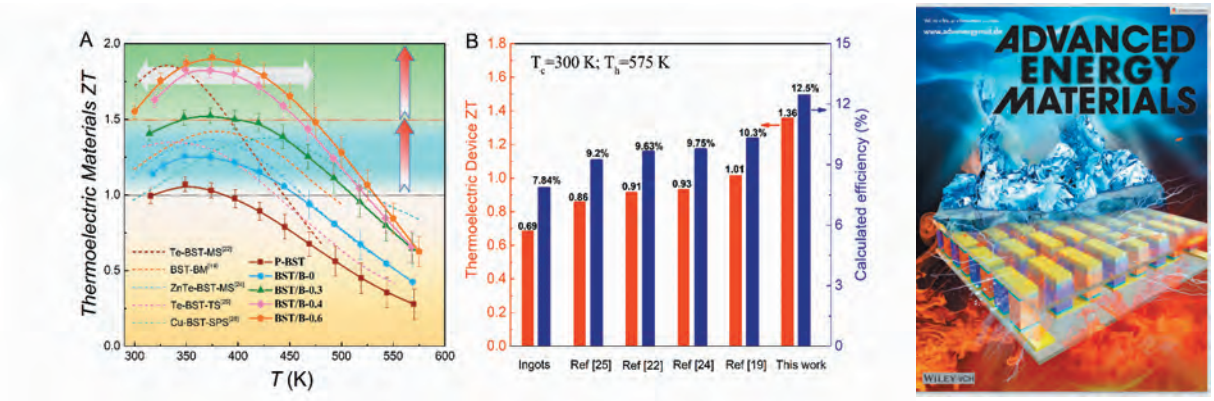


Figure 2 – breakthrough ultra-high thermoelectric performance material from Yang et al. publication (left), and Advanced Energy Materials cover page highlighting this work (right). This invention was patented.

The UOW FLEET node has made a breakthrough in ultra-high thermoelectric conversion efficiency in the novel nanoparticle-incorporated topological material BiSbTe, with a publication showing a world record figure of merit, ZT. This discovery will open new opportunities for a wider range of applications including power generation from waste heat, and noise-free refrigeration at room temperature.

- Guangsai Yang, Ranming Niu, Lina Sang, Xiaozhou Liao, David R. G. Mitchell, Ning Ye, Jun Pei, Jing-Feng Li, Xiaolin Wang, "Ultra-High Thermoelectric Performance in Bulk BiSbTe/Amorphous Boron Composites with Nano-Defect Architectures", Advanced Energy Materials **2020**, 2000757 (Australian Provisional Patent Application, Aug. 2020).

PIEZOELECTRIC AND DIELECTRIC MATERIAL RESEARCH

The Piezoelectric and Dielectric Materials Research Program at the ISEM has been developed and expanded based on the research by coordinator Professor Shujun Zhang and his team. This Research Program has a portfolio of projects funded by the Australian Research Council (ARC), DMTC, Australian Government Defence Science and Technology group, US Government Office of Naval Research Global and others. These projects cover a range of topics and focus areas, from an ARC Linkage Project on solid state crystal growth of lead-free ferroelectrics – in collaboration with Thales Australia; to building a fundamental understanding of the microstructure in relaxor ferroelectric materials for their applications of ultrasonic transducers – funded by Office of Naval Research Global; to a PhD project on the texturing of relaxor ferroelectric ceramics – supported by DMTC. Professor Shujun Zhang has also been awarded major equipment grants to support and facilitate crystal growth projects in this Research Program.

2020 HIGHLIGHTS:

In 2020, the Piezoelectric and Dielectric Material team published many high-impact papers in peer-reviewed journals, including in *Nature*, *Nature Materials*, *Nature Communications* and *Science Advances*.

In a demonstration of the successful collaborations forged by the team, a paper highlighting the remarkable discovery of simultaneous near-perfect light transparency and ultrahigh piezoelectricity in relaxor ferroelectric PMN-PT crystals was published in 2020. PMN-PT belongs to a class of relaxor ferroelectric crystals discovered about 30 years ago to possess the highest piezoelectricity with numerous electromechanical applications. However, these crystals have always been opaque due to the presence of light-scattering internal interfaces, called domain walls, between regions with electric polarization orientated along different directions. In this research, ac field polling was employed to remove the domain which severely scatter the light, meanwhile greatly enhancing the piezoelectricity, making the transparent crystal promising for emergent hybrid ultrasonic-optical applications – such as photoacoustic transducers.

- Chaorui Qiu, Bo Wang, Nan Zhang, Shujun Zhang, Jinfeng Liu, David Walker, Yu Wang, Hao Tian, Thomas R. Shrout, Zhuo Xu, Long-Qing Chen, and Fei Li, "Transparent ferroelectric crystals with ultrahigh piezoelectricity", Nature **2020**, 577, 350-354.

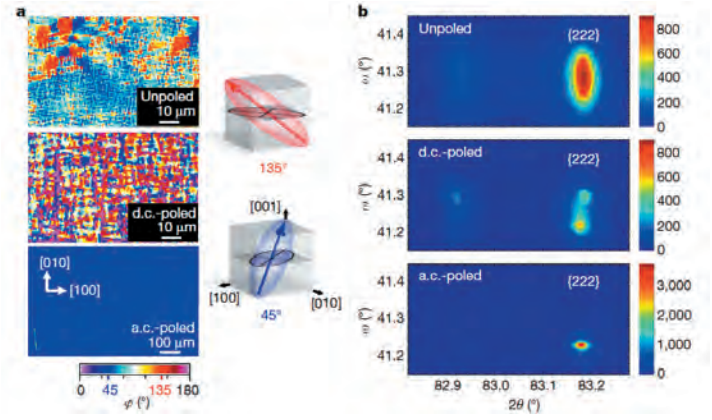


Figure 3 – key figure from the 2020 Qui et al. paper, showing the novel PNM-PT material presented

BATTERY MANAGEMENT SYSTEMS AND ELECTRIC VEHICLES FOR HAZARDOUS ENVIRONMENTS

Since 2012, Battery Management Systems Research Program coordinator Dr Khay See and his team have been at the forefront of Electric Vehicle (EV) research and development. The team successfully developed and retrofitted the first road registered EV in Wollongong with custom-designed technology that has been running smoothly until today. The project was supported by the $52M AutoCRC Cooperative Research Centre under the Vehicle Electrification program.

Figure 4 – Battery Management Systems Research Program coordinator Dr Khay See

Following on from this success and further achievements in developing the advanced battery management system for large scale battery utilisation, the team garnered attention from several coal-mining organisation and equipment manufacturers and distributors. Dr See was asked to design a 120 kWh of lithium-ion battery pack and management system for the fully electrify personnel/material transporter that heavily utilised in the underground coal environment. For many years, the underground coal mines have been dealing with diesel pollution that caused uncountable health issues to underground workers or miners. The heavy dependency on diesel fuel also causes substantial usage of energy to ventilate and significantly reduced operational efficiency and reliability. Although various emission control technologies have been relentlessly adopted and practiced, it is still a major challenge for the mining industry to reduce the exposure of underground miners to diesel engine emission products. The industries are also facing the uphill challenges poses by the State's legislation and regulation that the conventional design of battery pack as in the road electric vehicle is indisputably not acceptable and accredited for use in underground coal mines, for the reasons that it is categorised as highly explosive and hazardous environment. Hence, until today, there are no manufacturers or organisations that has been successful in the accreditation process to employ battery electric vehicles for underground coal mining in Australia. Dr See has been instrumental in leading a team of engineers and researchers from both the academic and industry to build a fully accredited battery powered 7 tonnes personnel/material transporter for the underground coal mining industries in Australia. The progress is currently on-going with very promising results from the conformity of the design to the require Standards and the pre-approval assessment from the certifying body in regards to the battery system. This importance milestone will path the way for the industries to phase out diesel-powered machines in the immediate future and the first step towards revolution of digital and autonomous mining. Together with the team effort, he has secured more than $ 2.5million of contribution, all together, including the 2021 ARC Research Hub from both the industry and Australian Government to undertake this very impactful development and globally it is the first vehicle for underground coal that has the approval from IEC and ANZ standards.

THE SMART SODIUM STORAGE SYSTEM (S⁴) PROJECT

The Smart Sodium Storage System (S⁴) Project is a $10.6M project which aims to develop and demonstrate novel sodium-ion battery technologies for use in renewable energy storage applications. The S⁴ Project is funded in part by the Australian Renewable Energy Agency (ARENA), and is being led by the University of Wollongong. Our Consortium Partners include Liao Ning Hong Cheng Electric Power Co., Hebei ANZ New Energy Technology Co., and Sydney Water.

The core focus of the S⁴ Project is to translate research successes in developing novel sodium-ion battery materials at the ISEM into commercial-ready batteries. Project activities have centred on scaling production of materials and sodium-ion battery cells in partnership with our Industry Partners, leveraging their expertise in large-scale development and manufacturing.

We'll be demonstrating these innovative sodium-ion batteries at the Illawarra Flame House in Wollongong, and the Bondi Sewage Pumping Station - located just behind Sydney's iconic Bondi Beach.

The S⁴ Project commenced in early 2016 and was scheduled to conclude in 2020, however this timeline was extended due to COVID-19 impacting on battery production and delivery schedules.

2020 ISEM staff recognition

2020 HIGHLY CITED RESEARCHERS

The list of Highly Cited Researchers 2020 from Clarivate identifies scientists and social scientists who have demonstrated significant and broad influence, reflected in the publication of multiple papers frequently cited by their peers during the last decade. 6,389 researchers were named Highly Cited Researchers in 2020, of which six were from UOW and five were from ISEM:

1. Distinguished Professor Shi Xue Dou **2.** Distinguished Professor Hua Kun Liu **3.** Distinguished Professor Yoshio Bando **4.** Distinguished Professor Zaiping Guo **5.** Professor Shulei Chou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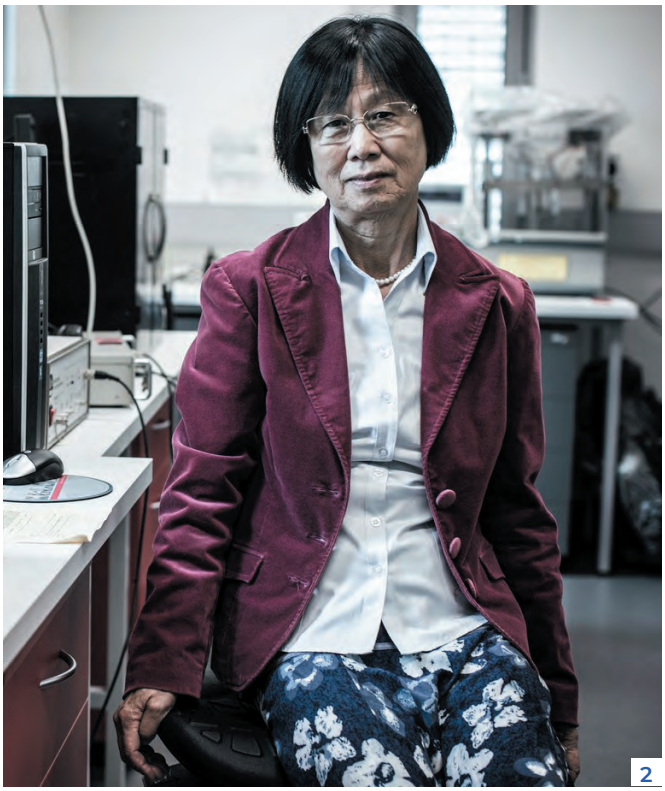
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NATIONAL AND INTERNATIONAL RECOGNITION

NSW Premier's Prizes for Science & Engineering

The NSW Premier's Prizes for Science & Engineering seek to recognise excellence in science and engineering, and reward leading researchers for cutting-edge work that has generated economic, environmental, health, social or technological benefits for New South Wales. In 2020, Distinguished Professor Zaiping Guo was the recipient of the Category 4: Excellence in Engineering or Information and Communications Technology Award, recognising her work in the development of next generation batteries that are safe, clean, high performing and low cost, with the aim of finding the most promising large-scale electrical energy storage solutions using renewable energy sources.

Institute of Electrical and Electronics Engineers Fellowship

The Institute of Electrical and Electronics Engineers (IEEE) has more than 400,000 members in 160 countries, and is a leading authority on a wide variety of areas ranging from aerospace systems, computers and telecommunications to biomedical engineering, electric power and consumer electronics. The title of IEEE Fellow is conferred upon a person with an outstanding record of accomplishments in any of the IEEE fields of interest and is recognised by the technical community as a prestigious honour and an important career achievement. In 2020, Professor Shujun Zhang was made IEEE Fellow in recognition of r his contributions to the development of advanced piezoelectrics for transducers.

2020 UOW Vice-Chancellor's Awards

The University of Wollongong Vice-Chancellor's Awards aim to encourage and recognise exceptional performance from University staff members who demonstrate outstanding achievement in activities that are aligned to the University's vision and strategic goals. In 2020 Associate Professor Konstantin Konstantinov led the teams that received the Vice-Chancellor's Interdisciplinary Research Excellence Award for their UOW Global Challenges project on "Next Generation Sunscreens".

Australian Synchrotron Research Award

The Australian Synchrotron Research Award is awarded by the Australian Nuclear Science and Technology Organisation (ANSTO) every year to an emerging leader in synchrotron research with less than 10 years of post-PhD experience. In 2020, Dr Wei Kong Pang was the recipient of this award in recognition of his significant advances in understanding the relationship of structure to chemistry in metal-ion battery technologies using a variety of X-ray scattering methods and other techniques.

Australian Neutron Beam Users Group Young Scientist Award

The Australian Neutron Beam Users Group (ANBUG) is a society aimed at the advancement of Australian and New Zealand neutron beam research. In 2020, Dr David Cortie was the recipient of the ANBUG Young Scientist Award for his work in the use of polarised neutron scattering technique to investigate the properties of materials from the bulk scale down to the nanoscale, and his key contributions to the emerging fields of nanostructures and thin films.

2020 ISEM student awards

EXCELLENCE AWARD

The ISEM Student Excellence Award acknowledges outstanding academic performance, the highest level of dedication towards work culture, laboratory and equipment maintenance, extra-curricular career development, and esteem from the recipient's peers. The 2020 ISEM Student Excellence Award recipients were Antony Jones, Nana Liu, Guangsai Yang, and Xiaohui Zeng.


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Figure 1 - Antony Jones, Figure 2 - Nana Liu, Figure 3 - Guangsai Yang, Figure 4 - Xiaohui Zeng

STUDENT BEST PAPER AWARD

The Student Best Paper Award acknowledges an original work published in scientific journals of the highest academic standing and reputation. To be eligible for this award, publication must have appeared in printed form in 2020 and the recipient must be either first or corresponding author. The 2020 ISEM Student Best Paper Award recipients were Peter Kabakov, Hanwen Liu and Yueyu Tong for their publications:

- **Peter Kabakov**, Christopher Dean, Valsala Kurusingal, Zhenxiang Cheng, Ho-Yong Lee and Shujun Zhang, 'Solid-state crystal growth of lead-free Ferroelectrics', J. Mater. Chem. C, 2020, 8, 7606.
- **Hanwen Liu**, Wei Pei, Wei-Hong Lai, Zichao Yan, Huiling Yang, Yaojie Lei, Yun-Xiao Wang, Qinfen Gu, Si Zhou, Shulei Chou, Hua Kun Liu, Shi Xue Dou, 'Electrocatalyzing S Cathodes via Multisulfiphilic Sites for Superior Room Temperature Sodium–Sulfur Batteries', ACS Nano 14 (6), 2020, 7259-7268.
- **Yueyu Tong**, Haipeng Guo, Daolan Liu, Ji Liang, Xiao Yan, Panpan Su, Si Zhou, Jian Liu, Gao Qing (Max) Lu, Shi Xue Dou, 'Vacancy Engineering of Fe-doped W18O49 Nanoreactors for Low-barrier Electrochemical Nitrogen Reduction', Angewandte Chemie International Edition, 2020, 59, 7356.


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Figure 5 - , Yueyu Tong, Figure 6 - Hanwen Liu: , Figure 7 - Peter Kabakov

STUDENT MERIT AWARD

The Student Merit Award acknowledges excellent academic performance, active participation in day-to-day life of the institute, and shows great potential to excel even further in the near future. In 2020 the ISEM Student Merit Award recipients were Abdulhakim Bake, Mengmeng Lao, Jian Peng, Yaser Rehman, Lina Sang, Yanyan Wang, Jingsing Wu, Qiuran Yang, and Huiling Yang.


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Figure 8 - Mengmeng Lao, Figure 9 - Abdulhakim Bake, Figure 10 - Jian Peng, Figure 11 - Yaser Rehman, Figure 12 - Lina Sang, Figure 13 - Yanyan Wang, Figure 14 - Jingxing Wu, Figure 15 - Qiuran Yang, Figure 16 - Huiling Yang

ISEM Governance

MANAGEMENT COMMITTEE

Chairperson:	Prof. Jennifer Martin AC	Deputy Vice Chancellor (Research and Innovation)
	Prof. Xiaolin Wang	Director, ISEM
	Prof. Will Price	Executive Director, AIIM
	Prof. Valerie Linton	Executive Dean, Faculty of Engineering and Information Science, UOW
	A/Prof. Germanas Peleckis	Assistant Director, ISEM; Chair, AIIM Research & Training Committee
	A/Prof. Konstantin Konstantinov	Head of Postgraduate Studies, ISEM

INDUSTRY ADVISORY COMMITTEE

Mr. B. Lynch	CEO, Valley International Ltd, Newcastle, Australia
Mr. M. Sahar	CEO, Malaysian Automotive Institute, Malaysia
Mr. R. Huang	President, Australian Innovative Industry Park, Australia
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ISEM 2020 at a glance

SUCCESSFUL ARC FUNDING APPLICATIONS

ARC Industrial Transformation Research Hubs

ARC Research Hub in New Safe and Reliable Energy Storage and Conversion Technologies

Total Funding: $5,000,000

Project ID: IH200100035

Lead CI: Y. Chen (Deakin University)

UOW CIs: Z.P Guo, H. K. Liu, C. Cook, J. C. Knott

Project Summary: ARC Research Hub in New Safe and Reliable Energy Storage and Conversion Technologies. This Research Hub addresses safety and reliability issues, and environmental impact of current energy storage and conversion technologies. The research will deliver a new generation of technologies for storage from small scale portable devices to large scale industrial applications, using recycled and natural materials, and eliminating the serious fire risk in current technologies. Outcomes include innovative integrated energy conversion and storage technologies and new energy materials and devices designed for different scale applications, leading to creation of start up companies and commercialisation opportunities for existing partners, benefiting both the Australian economy and potentially transforming the energy industry landscape.

ARC DISCOVERY PROJECTS

Carbon-free Energy Storage and Conversion Using Ammonia as a Mediator

Total Funding: $573,778

Project ID: DP210102215

Lead CI: S. X. Dou

UOW CIs: J. Liang, W. J. Li

Project Summary: This project aims to develop essential technologies for ammonia-mediated energy storage, hydrogen production, and electricity generation. This project expects to generate new understandings on designing novel multi-atom-cluster catalysts for the critical ammonia synthesis, electrolysis, and oxidation processes using interdisciplinary approaches. The expected outcomes of this project include multi-functional electrocatalysts, fundamental insights of principles for electrocatalyst design, and prototype technologies. This should provide significant benefits for the harvest of clean energy, the safe utilization of hydrogen, and the development of carbon-free fuels, which are essential for optimizing the energy structure of Australia.

Hot Topic: Quantum Design of Phononic Heat Filters

Total Funding: $315,000

Project ID: DP210101436

Lead CI: D. A. Cortie

UOW CIs: Z. Yue, Z. X. Cheng, R. A. Lewis, C. Zhang

Project Summary: Heat management is critical to many technologies for sustainable energy, electronics, protective equipment and energy-efficient buildings. The phonon is the quantum particle representing a travelling vibration and is responsible for the transmission of heat in solids. This project will study the new mechanisms for phonon transport in solids modified with embedded nanoparticles, which operate as phononic filters. Neutron spectroscopy provides a tool to measure the phonon density of states which is critical for developing a mathematical model of thermal boundary resistance. This is expected to identify mechanisms for ultra-low thermal conductivity leading to potential applications in thermoelectric generators and heat-resistant materials.

Batteries of the future-a new strategy for CO_2 fixation and energy storage

Total Funding: $492,255

Project ID: DP210101486

Lead CI: Z. P. Guo

UOW CIs: T. Zhou, Y. Lu, D. Wexler

Project Summary: This project aims to develop metal-carbon dioxide batteries with high specific energy densities for carbon dioxide capture as well as energy conversion and storage. Metal-carbon dioxide batteries are promising not only for conversion of waste carbon dioxide to value-added chemicals, but also for storage of electricity from renewable power and balancing of the carbon cycle. By combining experimental work and theoretical modelling, this study will explore novel electrode materials via catalyst design and understanding of the underlying reaction mechanisms. The outcomes will revolutionize battery technology and position Australia as a global leader in the critical transition to a decarbonized economy.

ARC LINKAGE INFRASTRUCTURE, EQUIPMENT AND FACILITIES

Raman Spectroscopic System for In-Operando Electrochemical Studies

Total Funding: $240,000

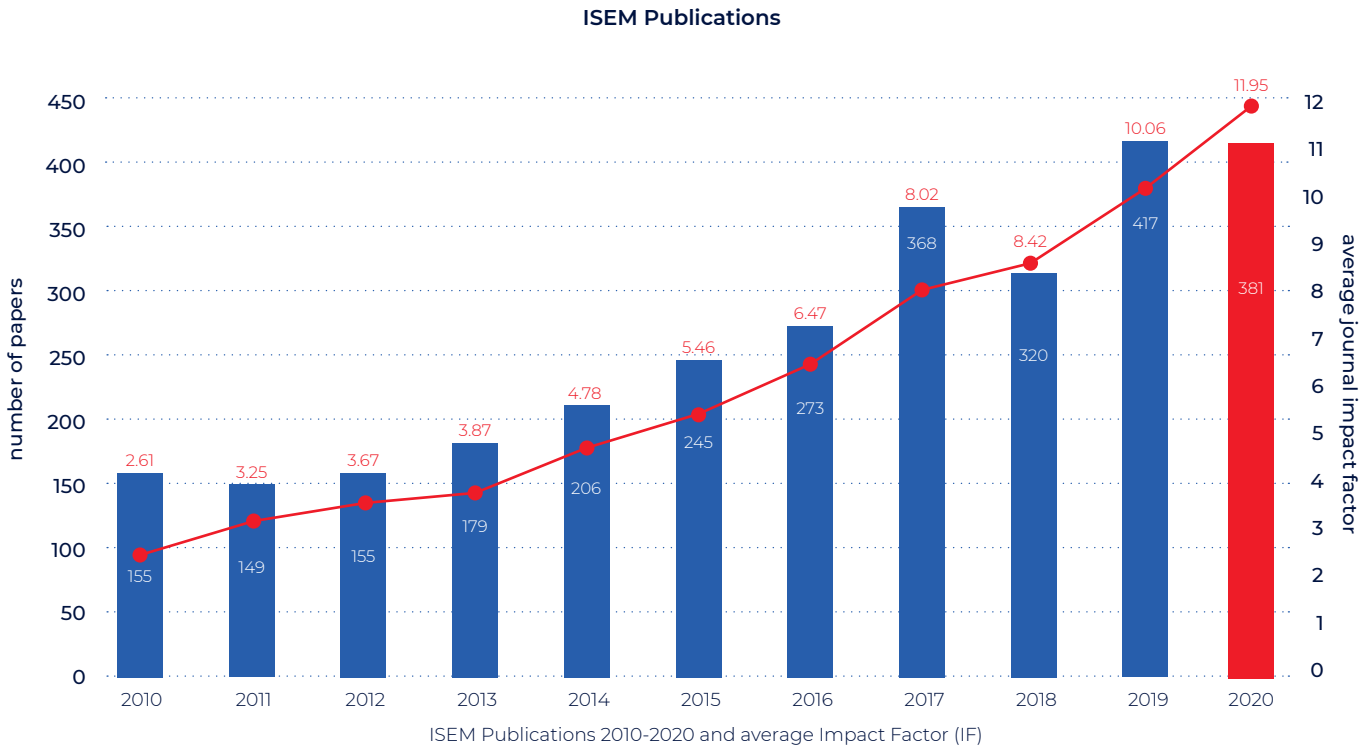
Project ID: LE210100109

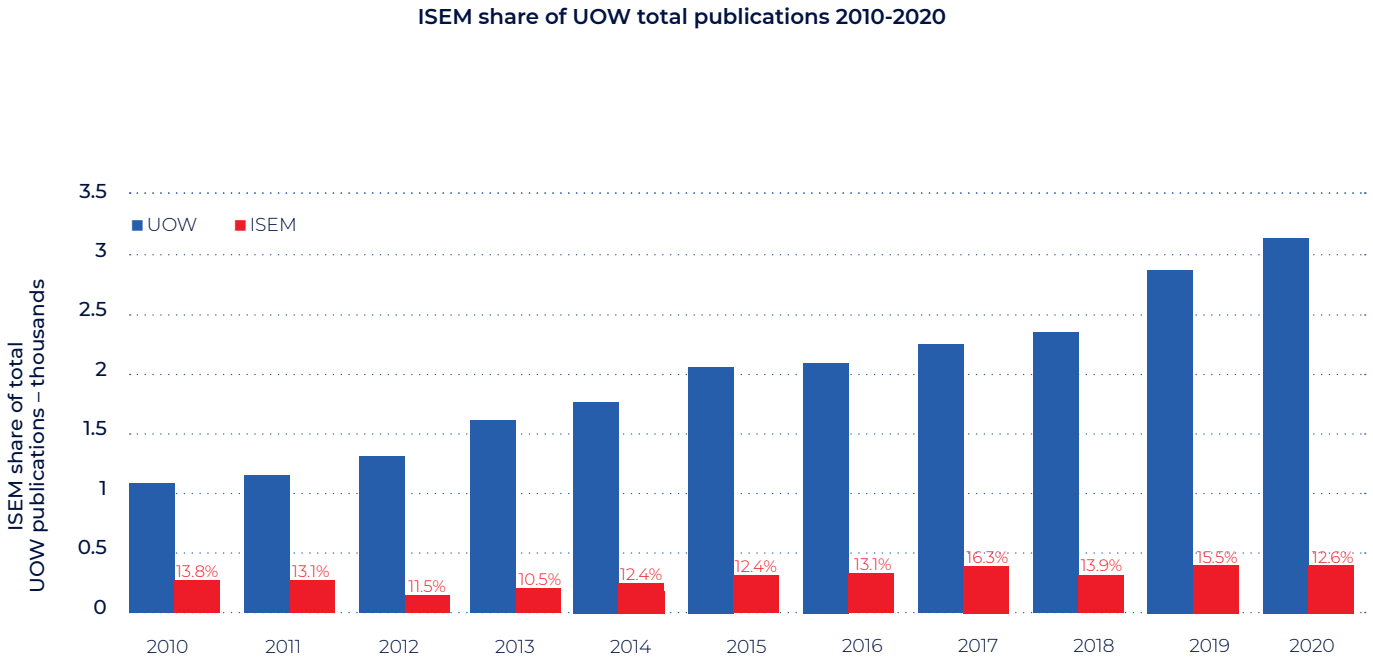
Lead CI: Z. P. Guo

UOW CIs: W. K. Pang, R. A. Lewis

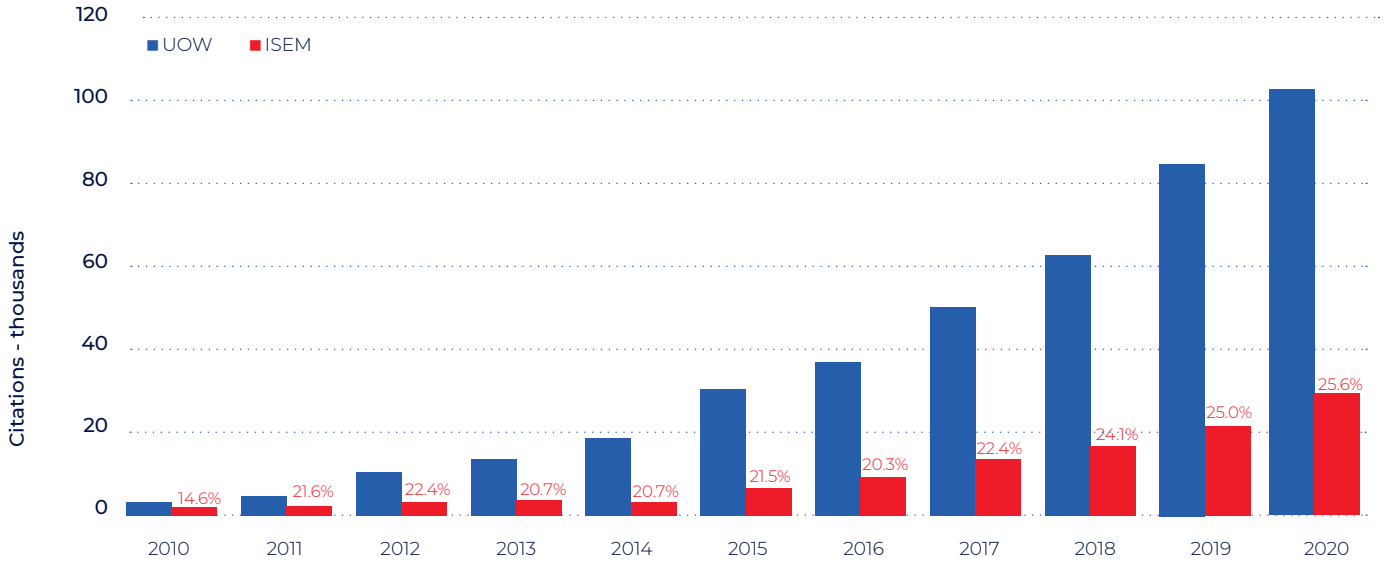
Project Summary: This proposal aims to establish a Raman microscopic system with real-time tracking capability, which will allow investigation of the activities of battery components during charging. An instrument that allows this level of interrogation is currently not available in Australia. Expected outcomes include advanced knowledge for improved battery technology, which will meet the increasing demand of electronic applications and provide commercial opportunities in Australia. This system will be highly versatile and extendable to other fields of energy and materials-related research, providing high-quality training of researchers, as well as a platform from which to enhance materials research capabilities in Australia.

Facts and Figures

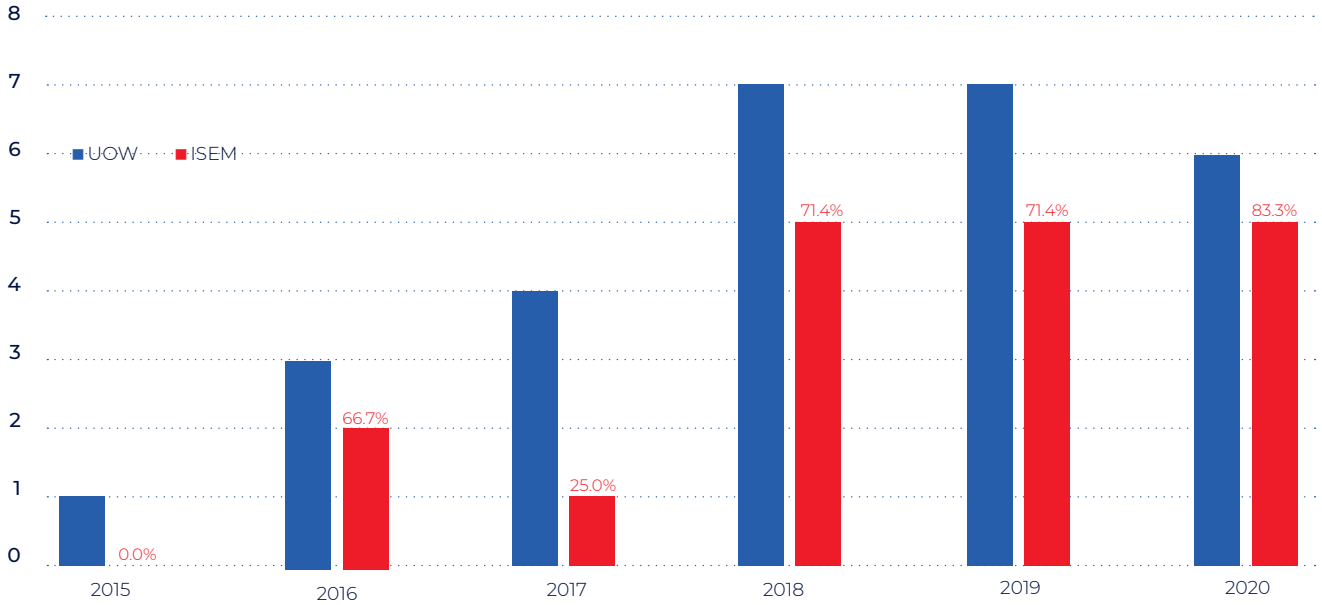


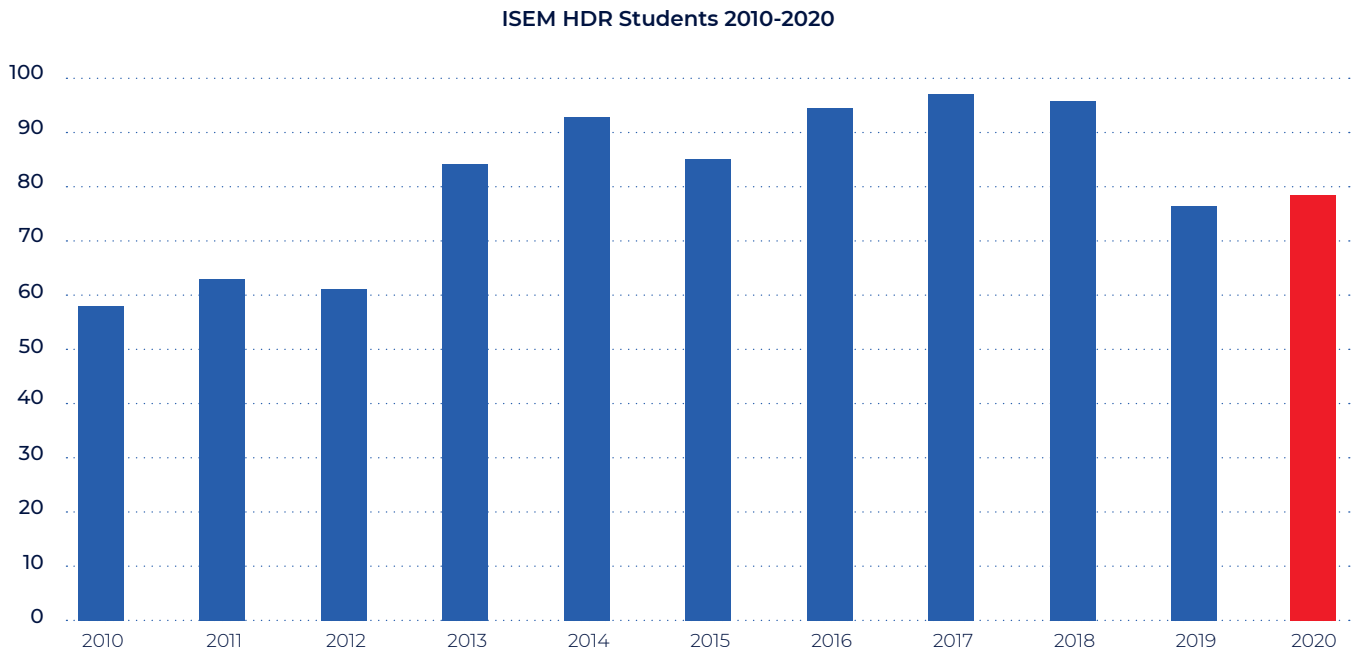


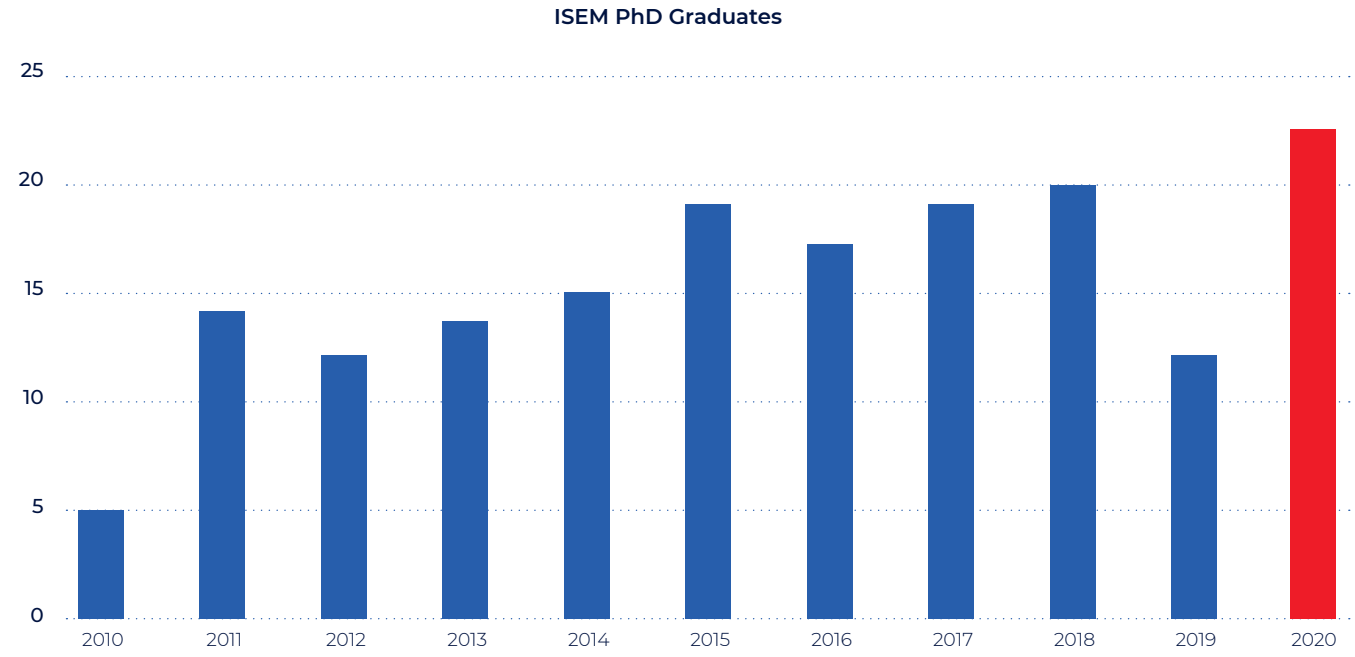
ISEM share of total UOW citations 2010-2020



ISEM share of UOW ISI Highly Cited Researchers 2015-2020




ISEM HDR Students 2010-2020
100
90
80
70
60
50
40
30
20
10
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020


ISEM PhD Graduates
25
20
15
10
5
0
2010
2011
2012
2013
2014
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2017
2018
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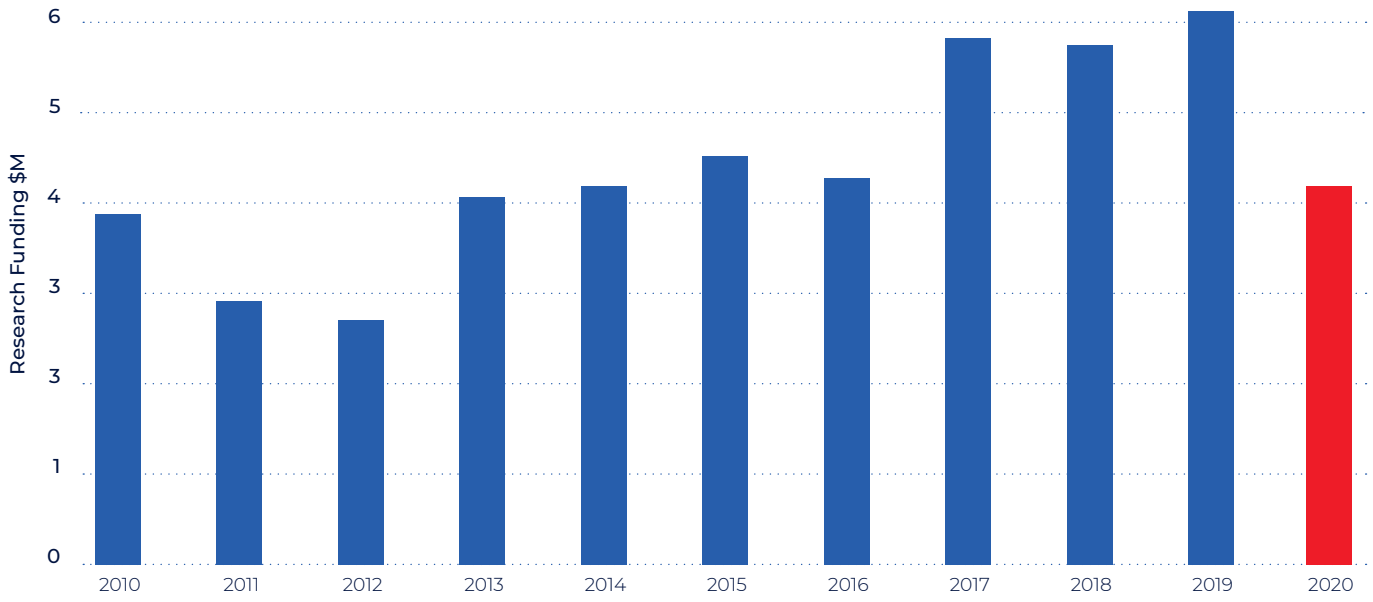
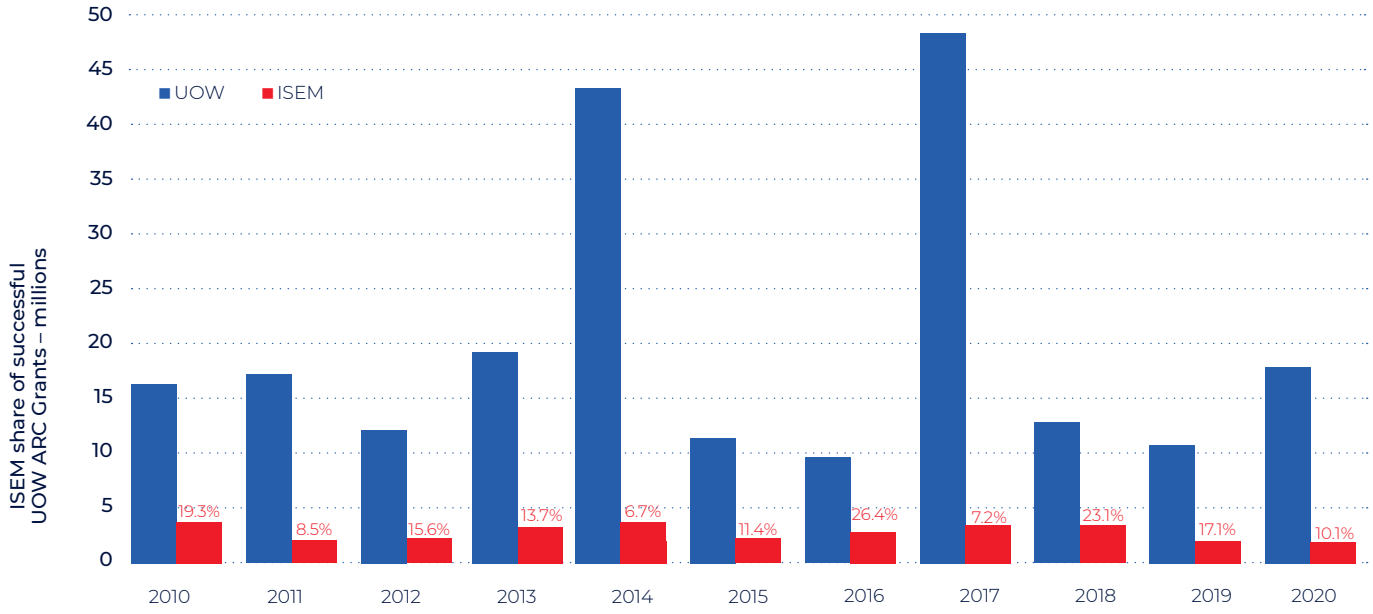
2020

ISEM Research Funding, 2010-2020



ISEM share of successful UOW ARC Grants, 2010-2020



Our Research Programs

SUPERCONDUCTORS AND LOW ENERGY MATERIALS

Prof. Xiaolin Wang
Coordinator

Superconductors and low energy materials for use in electrical and electronic devices such as motors, fault current limiters, transformers and magnetic resonance imaging (MRI) and future low-energy electronics.

BATTERY MATERIALS

Prof. Zaiping Guo
Coordinator

Developing advanced materials for fuel cells and solar cells, and advancing rechargeable batteries for electric cars.

PIEZOELECTRIC AND DIELECTRIC MATERIALS

Prof. Shujun Zhang
Coordinator

For electromechanical applications including the ultrasound transducers and piezoelectric sensors, and energy related applications such as mechanical energy harvesting and electrostatic energy storage.

ENERGY CONVERSION MATERIALS

Prof. Jung-Ho Kim
Coordinator

Developing solar cell technology to improve energy generation and help reduce carbon dioxide emissions.

BATTERY MANAGEMENT SYSTEMS

Dr. Khay Wai See
Coordinator

Integrated electronic and software system to intelligently manage every single battery cell in a battery pack for the purpose to extend battery life while protecting the cells from any abnormal operations.

MULTIFERROIC MATERIALS

Prof. Zhenxiang Cheng
Coordinator

Focusing on materials with independent/ coexisting ferroic properties, such as ferroelectric, magnetic and ferroelastic properties, which have applications in energy storage, harvesting and conversion, information storage and processing.

THIN FILM TECHNOLOGY

Prof. Alexey Pan
Coordinator

Innovations and development of thin films structures for applications in superconducting sensing, advanced electronics, and electronic transport.

THz PHOTONICS AND SOLID-STATE PHYSICS

Prof. Chao Zhang
Coordinator

Developing advanced materials and structures for terahertz science and technology for applications including medicine and biology.

BIOMATERIALS FOR HEALTH

A/Prof. Kosta Konstantinov
Coordinator

Design, fabrication and study of advanced biocompatible multifunctional materials and composites for various health applications including therapeutic and diagnostic medical applications, melanoma prevention and treatment of oxidative stress.

SCANNING TUNNELLING MICROSCOPY

A/Prof. Yi Du
Coordinator

Probing the fundamental properties of low-dimensional quantum matters and energy conversion/storage materials. Describing exotic behaviours in low-dimensional materials at the surface and interfaces.

United Nations Sustainable Development Goals

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests.

In 2019, UOW became a signatory to the University Commitment to the SDGs and embedded the goals in our 2020 - 2025 Strategic Plan and KPIs. Throughout a global network, UOW works together with industry, research partners, governments, communities and other universities to provide solutions to society's critical economic, environmental, social and health challenges.

In 2020, the University of Wollongong ranked 6th in the world in the Times Higher Education global Impact Rankings.

The ISEM has committed to support the UOW focus on UN SDGs, and has made sustained contributions in progress towards these goals through our research, governance, community engagement and development activities.

Some of ISEM's research is targeted towards innovations and technologies to support good health and well-being within our communities. Multi-disciplinary projects on **Next-Generation Sunscreens**, **Nanomaterials for theranostics**, **Innovative low-cost MgB_2-based MRI machines**, and **Liquid metal sensors** are helping to push boundaries and facilitate new solutions for health and well-being.

Within the ISEM, a strong focus on personal health and well-being - particularly mental health - has ensured our staff and students are healthy, safe, engaged and feel valued.

A core component of ISEM activities is training the next generation of research and innovation leaders. High-quality education and training, including a strong focus on tackling 'wicked problems', encourages our students and 240+ alumni to be active participants in their education - setting them up for a culture of lifelong learning.

Through our linkages and collaborations within and beyond UOW, ISEM participates in open days, seminars, and activities with schools to inspire and engage with the community.

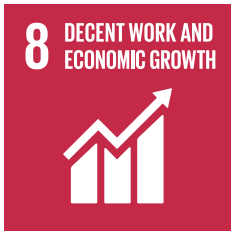
ISEM has a commitment to ensuring all members of the community are given the opportunity and support to pursue their research and career development aspirations.

Our unwavering support for ISEM community, through targeted nomination to faculty- and university-level committees and roles, has resulted in a 30% female cohort in ARC-supported ISEM researchers, and more than 40% female cohort in HDR students.

In 2020 40% of authors on ISEM publications were female, underscoring the progress made towards gender equality in our research activities.

As the world looks to consider the value of research not only in terms of numbers and citations, but also in impact on big challenges, a survey of ISEM publications showed that for the period 2011-2020, ISEM was the source of more than 45% of UOW's publications on Goal 7. This outcome underscores the societal value of the research being undertaken at the ISEM.

A strong focus of ISEM research is in energy materials, where outcomes will lead to cheap, sustainable and accessible energy for people and communities around the world.



ISEM's commitment to high-quality, relevant training - coupled with our extensive collaborative networks - has resulted in our 200+ graduates and alumni being highly sought-after the world over. These international ambassadors are taking the culture of decent, fulfilling and inclusive work instilled at the ISEM to their roles in academia, industry and government.

ISEM focus on industry-relevant research helps translate lab-based successes into economic growth and opportunity in our local and national community.

ISEM research focuses on innovation through collaboration - building partnerships with industry, academia and the community to translate research into meaningful impact. Our successes in industry research funding and projects - such as the **Smart Sodium Storage System (S^4) Project** and projects on **electrification of underground mining vehicles** - highlights our support of innovation and industry in the community.

Our Research Programs bridge the gaps between breakthroughs, prototypes and commercialisation - ensuring lab successes today become the innovations of tomorrow.

Researchers at the ISEM understand the unique position we have in being able to make a meaningful impact on climate. Our Research Programs are targeted towards novel materials and solutions that will facilitate sustainable energy practices - a core requirement for lasting climate action.

Multidisciplinary projects on **Low-energy electronics**, **Waste heat-to-electricity, Photocatalysis, Triboelectricity, Novel battery architectures** and others highlight our focus on leading the way in translating research outcomes into climate action.

Current and Ongoing Research Projects

ARC CENTRE OF EXCELLENCE

ARC Centre of Excellence in Future Low Energy Electronics Technologies

Years Funded:	2017 $224,105	2018 $216,211	2019 $218,842	2020 $218,842	2021 $218,842	2022 $221,474	2023 $221,474

Total Funding: $1,539,788

Project ID: CE170100039

Lead CI: M. Fuhrer (University of Melbourne)

UOW CI: X. L. Wang

Project Summary: This Centre aims to develop the scientific foundation and intellectual property for new electronics technologies. Decreasing energy use is a major societal challenge, and this Centre aims to meet that challenge by realising fundamentally new types of electronic conduction without resistance in solid-state systems at room temperature. Novel resistance-free electronic phenomena at room temperature are expected to form the basis of integrated electronics technology with ultra-low energy consumption. This Centre's development of innovative electronics could put Australia at the forefront of the international electronics industry.

ARC DISCOVERY PROJECTS

Development of ambient air operation rechargeable sodium-air batteries

Years Funded:	2018 $124,388	2019 $124,000	2020 $124,000

Total Funding: $372,388

Project ID: DP180101453

Chief Investigators: J. Z. Wang, K. Konstantinov

Partner Investigator: W. S. Yang, Q. F. Gu

Project Summary: This project aims to develop Sodium (Na)-air batteries for large-scale renewable energy storage. The expected outcomes include development of new air cathode materials, gel polymer electrolytes and oxygen selective membranes, establishing novel Na-air battery systems for ambient air operation using advanced electrode materials, gel polymer electrolytes, and oxygen selective membranes, and exploring the electrochemical reaction mechanisms and degradation Na-air battery systems by the operando study method and other advanced techniques. The success of this project will contribute to the Australia Science and Research Priority area of energy.

Magnetic skyrmion materials for next generation spintronic-based devices

Years Funded:	2019 $137,000	2020 $137,000	2021 $136,000

Total Funding: $410,000

Project ID: DP190100150

Chief Investigators: Z. X. Cheng, X. L. Wang

Partner Investigator: W. H. Wang, H. X. Yang, E. Gilbert

Project Summary: Magnetic skyrmions are a novel class of materials with unique spin arrangement, making them suitable for the next generation of information processing and storage with ultrahigh density and extremely low energy consumption. This project aims to establish Australia as a world authority in the field of magnetic skyrmions and their applications, by developing ground-breaking materials and advanced technologies. The expected outcomes of this project include the creation of new functional materials, leading to a better understanding of the skyrmions and producing a foundation for the future development of novel information storage devices.

Low cost aqueous rechargeable zinc batteries for grid-scale energy storage

Years Funded:	2020	2021	2022
	$170,000	**$170,000**	$170,000
Total Funding:	$510,000		
Project ID:	DP200101862		
Chief Investigators:	Z. P. Guo, J. F. Mao		
Partner Investigator:	C. S. Wang		
Project Summary:	This project aims to advance energy storage technology by developing high energy aqueous rechargeable zinc batteries, which are the most promising choice for large-scale electrical energy storage, in particular for smart electric grids, owing to their low cost, high safety, and eco-friendly features. The success of this project will advance our fundamental understanding of aqueous rechargeable batteries, provide techniques for the development of a low-cost, high energy, and long life system for renewable energy storage, and benefit Australia's environment, economy, and sustainability.		

Controlling and understanding interface chemistry for energy conversions

Years Funded:	2020	2021	2022
	$160,000	**$160,000**	$160,000
Total Funding:	$4800,000		
Project ID:	DP200101862		
Chief Investigators:	S. X. Dou, W. P. Sun, J. Liang		
Partner Investigator:	Y. Y. Liu, C. Z. Wu, J. B. Baek		
Project Summary:	This project aims to develop a promising electrocatalyst technology platform, based on novel 2D material architectures that have applications ranging from hydrogen generation via water splitting through to carbon dioxide reduction. The project is expected to generate advanced knowledge for the rational design of electrocatalysts and to promote the development of renewable energy technologies. Expected outcomes include a clear understanding of the relevant fundamental science and mechanisms, a framework for designing and optimising for specific applications, and a demonstration of prototype devices. This project is of great benefit for addressing Australia's energy and environmental concerns and boosting national economic growth as well.		

FUTURE FELLOWSHIPS

High-voltage electrode materials for lithium-ion batteries

Years Funded:	2016	2017	2018	2019	2020
	$82,000	**$163,000**	$163,000	$163,000	$82,000
Total Funding:	$653,000				
Project ID:	FT160100251				
Chief Investigator:	W. K. Pang				
Project Summary:	This project aims to establish a complete battery research system and develop high-voltage electrode materials for lithium-ion batteries through mechanistic understanding obtained in operando studies. Lithium-ion batteries are the most promising choice for portable electronic devices, including electric vehicles, due to their high power and energy performance compared with other battery technologies. The success of this project is expected to advance fundamental understanding of lithium-ion batteries, and provide techniques to develop a promising high-energy and high-power battery system.				

Functional two-dimensional materials for photocatalysis

Years Funded:	2018 $110,500	2019 $219,000	2020 $219,000	2021 $219,000	2022 $110,500
Total Funding:	$878,000				
Project ID:	FT180100585				
Chief Investigator:	Y. Du				
Project Summary:	This project aims to explore and tailor two-dimensional materials and heterostructures by new synthetic strategies, and to develop a comprehensive understanding of the effects of crystalline and electronic structures on photocatalysis at the atomic level. The project expects to provide deep insight into catalytic mechanisms by bridging the current gap between realistic systems and theoretical calculations. By simply using solar energy, the project aims to provide an efficient and durable method for clean energy generation/conversion, and carbon sequestration. This project will build national research capacity in an emerging field and put Australia at the forefront of research on photocatalysis to address energy and environmental issues.				

DECRA FELLOWSHIPS

Engineering magnetism at the atomic scale in topological insulators

Years Funded:	2018 $118,000	2019 $118,000	2020 $118,000
Total Funding:	$354,000		
Project ID:	DE180100314		
Chief Investigators:	D. Cortie		
Project Summary:	This project aims to explore strategies to optimise the magnetisation and Curie temperature by incorporating dopants via ion implantation, and exploiting proximity effects in heterostructures with magnetic thin films. The recently discovered magnetism in topological insulators opens up a new class of materials with potential applications in energy-efficient electronics, data storage and information processing. The central challenges are to control the underlying magnetic structure and stabilise magnetic order at desirable temperatures. The project expects to discover new composite materials and advance our knowledge for designing magnetic components in the next generation of electronics with ultra-low power dissipation.		

High performance lead-free piezoelectrics based on polar nanoregions

Years Funded:	2018 $120,000	2019 $120,000	2020 $120,000
Total Funding:	$360,000		
Project ID:	DE180101454		
Chief Investigators:	F. Li		
Project Summary:	This project aims to enhance the electro-mechanical couplings of lead free piezoelectrics via introducing polar nanoregions for medical transducers applications. This is expected to impact on the design and development of high-performance lead free piezoelectrics, and have environmental benefits through replacing lead based counterparts.		

Long life sodium ion batteries by optimising initial coulombic efficiency

Years Funded:	2018	2019	2020
	$118,000	$118,000	$118,000

Total Funding: $354,000

Project ID: DE180101478

Chief Investigators: W. J. Li

Project Summary: The project aims to develop novel structured phosphorus (Sn/P)-based composites as anode electrodes for sodium ion storage, which have high initial coulombic efficiency (charge capacity), high capacity and stable cycle life. Approaches of modifying surface structure will improve initial coulombic efficiency of Sn/P-based composites, and strategies to stabilise solid electrolyte interphase (SEI) film will obtain long-cycle stability. The success of this project will greatly accelerate the commercialisation of sodium ion batteries and support the utilisation of renewable energy in Australia.

Interphases and interfaces of nanomaterials in potassium-ion batteries

Years Funded:	2019	2020	2021
	$128,000	$128,000	$128,000

Total Funding: $384,000

Project ID: DE190100504

Chief Investigators: T. F. Zhou

Project Summary: This project aims to improve the fundamental understanding of interfacial interactions in multicomponent materials, which is a critical precursor to successfully designing and experimentally validating novel layered sulphide systems for potassium-ion batteries. A new layered structure construction technique will be employed to enhance the intrinsic electronic and ionic conductivities in the anode by controllable interphase and interface engineering. The expected outcomes of this project are to generate potassiumion batteries with high energy density, high safety, and long cycle life for next generation energy storage. This project should give Australia a competitive edge in the globally emerging sustainable manufacturing and energy-storage technologies.

Engineering of exotic electronic properties in atomically thin antimony

Years Funded:	2019	2020	2021
	$120,000	$120,000	$120,000

Total Funding: $360,000

Project ID: DE190100219

Chief Investigators: Z. Li

Project Summary: This project aims to introduce a new method of engineering electronic resistance properties of materials to reduce energy consumption in computation. Next-generation electronic devices require materials hosting current at near-zero resistance to reduce energy consumption and heat dissipation in computation. Using a novel air-stable topological material, the project will use band engineering techniques to enable the production of near-zero resistance electronic material. This project will advance the knowledge required for exploring and designing materials with novel electronic properties. The advanced materials engineering techniques and exotic phase of matter identified in this project will support the development of next-generation electronic device technologies.

Nanostructures derived from metal-organic frameworks for sodium-ion batteries

Years Funded:	2019	2020	2021
	$136,000	$136,000	$136,000
Total Funding:	$408,000		
Project ID:	DE190100082		
Chief Investigators:	Y. Lu		

Project Summary: This project aims to overcome poor reaction kinetics and the lack of effective anode materials owing to the large size of sodium-ions in high performance sodium-ion batteries. The project will explore a series of functional nanomaterials with unique nanostructures and complex compositions, enabled by metal-organic framework assisted synthetic methods. High performance sodium ion batteries are demonstrating great potential to meet the future demand for large-scale and low-cost stationary energy storage. However, their practical implementation is still hindered by their poor reaction kinetics and the lack of effective anode materials owing to the large size of sodium-ions. The project outcomes will promote the commercialisation of sodium ion batteries and power Australia's sustainable economy in the long run.

Stable lithium-sodium metal anodes for rechargeable alkali metal batteries

Years Funded:	2020	2021	2022
	$133,000	$132,000	$132,000
Total Funding:	$497,000		
Project ID:	DE200101103		
Chief Investigators:	H. Ye		

Project Summary: The project aims to address the safety issues derived from the dendritic growth and volume variation of alkali metal anodes, which are a challenge for the practical application of rechargeable alkali metal batteries. This project seeks to design a novel 3D lithium/sodium host featuring a lithiophilic-lithiophobic gradient interfacial layer to achieve uniform deposition and structural stability. The expected outcome of this project is to successfully develop alkali metal batteries that are stable, safe and have high energy density. This project should have significant benefits such as the advancement of knowledge in alkali metal batteries and strengthen Australia's competitiveness in the area of next-generation energy storage technologies.

Economical electrode materials for safe sodium ion batteries

Years Funded:	2020	2021	2022
	$138,000	$137,000	$137,000
Total Funding:	$412,000		
Project ID:	DE200101384		
Chief Investigators:	N. N. Wang		

Project Summary: The project aims to address the lack of effective anode materials for high performance sodium-ion batteries, through the development of functional titanium-based materials, realizing high energy/power density, long cycle life, low cost and high safety sodium ion batteries. Expected outcomes of this project will address the limitation of current energy storage technologies and be beneficial for the development of large-scale energy storage systems that are efficient, cost-effective and reliable in Australia. This project will explore titanium-based materials with advantageous architectures and deeply doped heteroatoms by novel synthetic strategies and will be assessed as electrode materials for high performance batteries.

ARC LINKAGE PROJECTS

Liquid metal for quench detection sensors and low resistance joints

Years Funded:	2019	2020	2021	2022
	$47,000	$90,000	$83,000	$42,000
Industry Fund:	$50,000	$50,000	$50,000	
Total Funding:	$412,000			
Project ID:	LP180100722			
Chief Investigators:	S. X. Dou, X. Xu, Y. Du, W. P. Sun, K. W. See, J. Zheng			
Industry Partner:	Ningbo Jansen NMR Technology Co., Ltd.			

Project Summary: This project aims to develop next-generation liquid metal-based superconducting joints and quench detection sensors to enable superconducting magnets to operate in "persistent mode". This would make a significant contribution to improving the safety and performance of superconducting coil systems at a reduced cost. Furthermore, intelligent features will be formulated to prevent hazardous and inefficient operating conditions. The expected outcome is that an advanced superconducting coil system with improved stability and safety is delivered with newly developed liquid metal-based materials and relevant fabrication techniques.

OTHER GRANTS

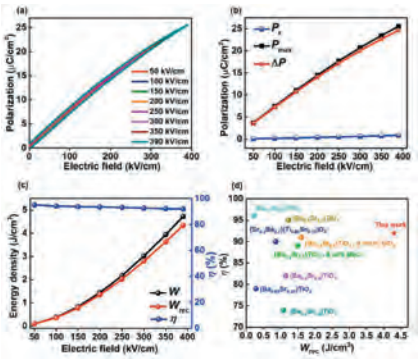
Australian Renewable Energy Agency
The Smart Sodium Storage Solution (S4)

Years Funded:	2016	2017	2018	2019	2020
	$579,500	$869,500	$1,328,000	$1,181,500	$558,500
Total Funding:	$4,517,000				
Chief Investigators:	S. X. Dou, H. K. Liu, S. L. Chou, K. W. See, D. Soetanto, K. Muttaqi, S. Ville				

Project Summary: This project will develop and integrate a new type of sodium-ion battery in a low-cost, modular and expandable energy storage system to be demonstrated at the Illawarra Flame House and Sydney Water's Bondi Sewage Pumping Station. This project will develop a new sodium-ion battery architecture, optimised for use in renewables storage applications, by building on the world-class energy materials research and deep industry ties of the Institute for Superconducting and Electronic Materials (ISEM). Facilities at the ISEM used to prototype and characterise the sodium-ion batteries for ISEM's industry-leading researchers will be upgraded and expanded to support the rapid development of the battery architecture. A modular, expandable packaging system with integrated battery and thermal management systems will be developed, produced and validated through two applications: a 5 kWh battery at Illawarra Flame House, an award-winning net-zero energy home, and a 30 kWh integrated battery and energy management system at Sydney Water's Bondi Sewage Pumping Station. The Sydney Water site will also have an energy management system developed as part of this project, which will integrate and manage renewable energy generation, storage and consumption in an efficient manner by utilising intelligent algorithms and control strategies. The Sydney Water site will demonstrate the turn-key nature of the system and highlight the suitability of sodium-ion batteries for use in utility applications.

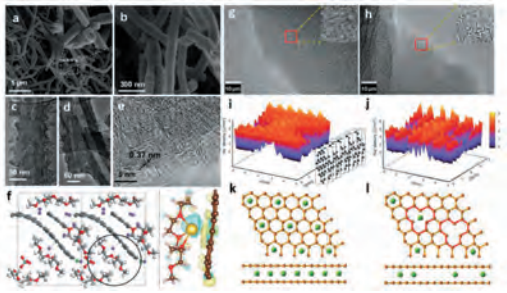
Selected Abstracts

$(Ba,Sr)TiO_3$–$Bi(Mg,Hf)O_3$ lead-free ceramic capacitors with high energy density and energy efficiency



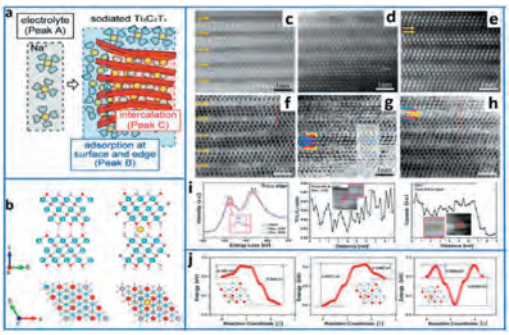
Dielectric capacitors with high energy storage performance have been actively studied for emerging applications. In this work, a series of environmental friendly lead-free relaxor ferroelectric ceramics, $(1 - x)(Ba_{0.75}Sr_{0.25})TiO_3 - xBi(Mg_{0.5}Hf_{0.5})O_3$ with $0 \le x \le 0.5$ [abbreviated as $(1 - x)$BST $-$ xBMH], were synthesized by a high-temperature solid-state reaction method. The perovskite structure without any secondary phase can be obtained in samples with $x \le 0.4$. As the BMH content increases, the polarization–electric field (P–E) loop becomes slim and slanted. A large recoverable energy storage density of 4.3 J/cm³ and high energy efficiency of 92% were achieved simultaneously in 0.6BST–0.4BMH at 390 kV/cm. The fine grain morphology with minimal porosity and the high conductivity activation energy were responsible for the enhanced breakdown strength. Of particular importance is that the 0.6BST–0.4BMH ceramic shows excellent temperature stability and cycling reliability with energy density variations below 3 and 4%, respectively. In addition, the 0.6BST–0.4BMH ceramic possesses fast discharge time (~0.59 μs) with a high power density of 3.5 MW/cm³. All these merits reveal that the lead-free 0.6BST–0.4BMH relaxor ceramic is a promising candidate for high-temperature and high-power energy storage capacitor applications. (X. Kong et al., ***ACS Applied Energy Materials*** 3, 12254 (2020))

Synthesis strategies and structural design of porous carbon-incorporated anodes for sodium-ion batteries



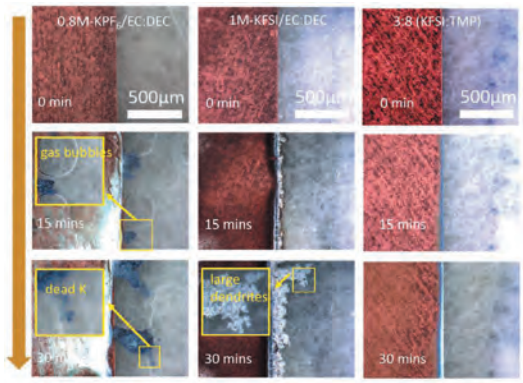
Over the past decades, porous carbonaceous and carbon-incorporated composites have aroused tremendous attention owing to their unique properties such as high surface area, excellent accessibility to active sites, tunable morphologies and structures, and superior mass transport and diffusion. They have been widely investigated and applied in various fields, such as energy storage, absorption, water filtration, drug delivery, catalysis, and sensing. In the energy storage area, rechargeable sodium-ion batteries (SIBs) have attracted tremendous attention as the next-generation power plants for large-scale energy storage systems (EESs). However, their low energy density and power density, as well as their poor cyclability, are still the main challenges for SIBs, especially for the anode, which acts as a bottleneck. With the incorporation of appropriate porous carbonaceous materials, the disadvantages of large volume shrinkage and low electron conductivity of alloying- and conversion-based anode materials have been significantly alleviated. This review points out and summarizes the most recent developments in synthesis strategies and morphology control of porous carbonaceous materials and the corresponding carbonaceousmaterial-incorporated high performance anodes for SIBs. Furthermore, the remaining challenges associated with these composites and effective routes to enhance their performance are discussed. (E. H. Wang et al., ***Small Methods*** 4, 1900163 (2020))

Tailoring MXene-based materials for sodium-ion storage: synthesis, mechanisms, and applications



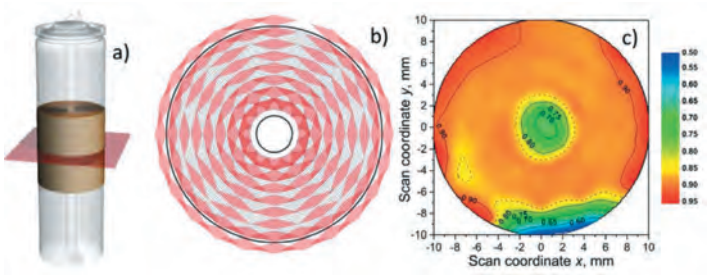
Advanced electrodes with excellent rate performance and cycling stability are in demand for the fast development of sodium storage. Two-dimensional (2D) materials have emerged as one of the most investigated subcategories of sodium storage related anodes due to their superior electron transfer capability, mechanical flexibility, and large specific surface areas. Recently, 2D metal carbides and nitrides (MXenes), one type of the new 2D materials, are known to have competitive advantages in terms of high electroconductivity, terminal functional groups, large specific surface areas, tunable interlayer spacing, and remarkable safety. These advances endow MXenes and MXene-based materials with superior electrochemical performance when they are used as electrodes for sodium-ion storage. MXenes, however, share similar defects with other 2D materials, such as serious restacking and aggregation, which need to be improved in consideration of their further applications. In this review, we present the big family of MXenes and their synthetic methods. Furthermore, recent research reports related to progress on MXene-based materials for sodium storage are compiled, including materials design and reaction mechanisms in sodium-ion batteries and sodium metal batteries. Significantly, we discuss the challenges for existing MXene-based structures with respect to their future use as electrodes, such as low capacitance, aggregation, untenable termination groups, and unclear mechanisms, thereby providing guidance for future research on MXene-based materials for sodium-ion storage. (Y. J. Lei et al., ***Electrochemical Energy Reviews*** 3, 766 (2020))

Manipulating the solvation structure of nonflammable electrolyte and interface to enable unprecedented stability of graphite anodes beyond 2 years for safe potassium-ion batteries



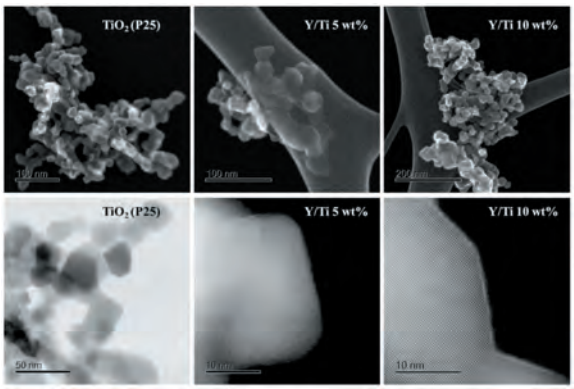
Potassium-ion batteries (PIBs) are attractive for low-cost and large-scale energy storage applications, in which graphite is one of the most promising anodes. However, the large size and the high activity of K+ ions and the highly catalytic surface of graphite largely prevent the development of safe and compatible electrolytes. Here, a nonflammable, moderate-concentration electrolyte is reported that is highly compatible with graphite anodes and that consists of fire-retardant trimethyl phosphate (TMP) and potassium bis(fluorosulfonyl)imide (KFSI) in a salt/solvent molar ratio of 3:8. It shows unprecedented stability, as evidenced by its 74% capacity retention over 24 months of cycling (over 2000 cycles) at the 0.2 C current rate. Electrolyte structure and surface analyses show that this excellent cycling stability is due to the nearly 100% solvation of TMP molecules with K+ cations and the formation of FSI−-derived F-rich solid electrolyte interphase (SEI), which effectively suppresses the decomposition of the solvent molecules toward the graphite anode. Furthermore, excellent performance on high-mass loaded graphite electrodes and in a full cell with perylenetetracarboxylic dianhydride cathode is demonstrated. This study highlights the importance of the compatibility of both electrolyte and the interface, and offers new opportunities to design the electrolyte–SEI nexus for safe and practical PIBs. (S. L. Liu et al., ***Advanced Materials*** 33, 2006313 (2020))

Understanding rechargeable battery function using in operando neutron powder diffraction



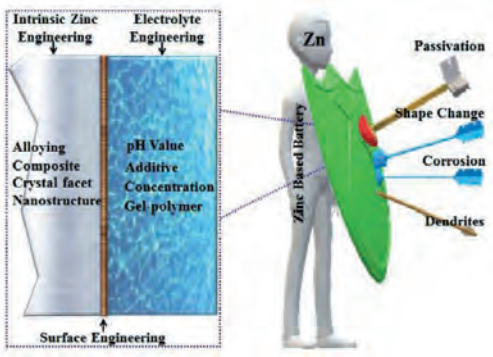
The performance of rechargeable batteries is influenced by the structural and phase changes of components during cycling. Neutron powder diffraction (NPD) provides unique and useful information concerning the structure–function relation of battery components and can be used to study the changes to component phase and structure during battery cycling, known as in operando measurement studies. The development and use of NPD for in operando measurements of batteries is summarized along with detailed experimental approaches that impact the insights gained by these. A summary of the information gained concerning battery function using in operando NPD measurements is provided, including the structural and phase evolution of electrode materials and charge-carrying ion diffusion pathways through these, which are critical to the development of battery technology. (G. M. Liang et al., ***Advanced Materials*** 32, 1904528 (2020))

Y_2O_3 decorated TiO_2 nanoparticles: Enhanced UV attenuation and suppressed photocatalytic activity with promise for cosmetic and sunscreen applications



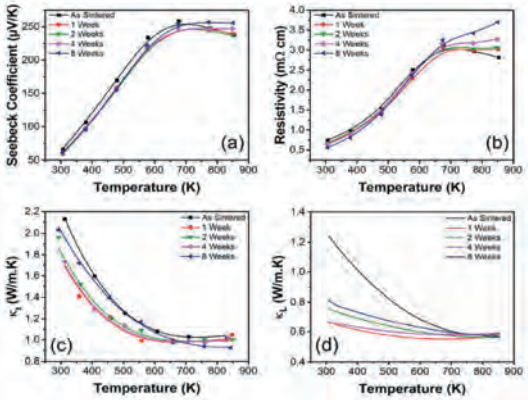
Nanoparticulate titanium dioxide (TiO_2) is widely used in cosmetic products and sunscreens. However, primarily due to their photocatalytic activity, some TiO_2 products have been shown to be cytotoxic. Thus, the aim of this study was to reduce the photoactivity and consequent cytotoxicity of TiO_2 nanoparticles. As such, in this work, yttrium oxide (Y_2O_3) was deposited onto TiO2, at 5% and 10% Y/Ti weight ratio, via a hydrothermal method. The nanocomposites produced, TiO_2@Y_2O_3 5 and 10 wt%, were characterised to assess their physical, photochemical and toxicological properties. These materials exhibit a uniform yttria coating, enhanced UV attenuation in the 280–350 nm range and significantly reduced photoactivity compared with a pristine commercial TiO_2 sample (Degussa Aeroxide P25). Furthermore, the comparative cytotoxicity and photo-cytotoxicity of these materials to a human keratinocyte cell line (HaCaT), was assessed using a colorimetric tetrazolium salt (MTS) assay. Following 24-hour incubation with cells, both Y_2O_3 loadings exhibited improved biocompatibility with HaCaT cells, compared to the pristine TiO_2 sample, under all subsequent test conditions. In conclusion, the results highlight the potential of these materials for use in products, applied topically, with sun protection in mind. (M. C. Borras et al., ***Journal of Photochemistry & Photobiology, B: Biology*** 207, 111883 (2020))

Principals and strategies for constructing a highly reversible zinc metal anode in aqueous batteries



Among all the electrochemical energy storage systems, zinc-based batteries, such as zinc-air, zinc-metal, zinc-ion batteries, etc., have been recognized as an important group of candidates that could be potential alternatives to the currently dominant lead-acid and lithium-ion battery systems, because they have many unbeatable merits, including direct use of zinc metal as electrode; compatible with low cost, non-flammable, and environement-friendly aqueous electrolyte; assembly in ambient conditions; environmental benignity; and high safety. Currently, however, the capacitance, cycle life, and safety of zinc-based batteries were significantly degraded by zinc-water interaction problems that took place on the zinc metal electrode, including corrosion, passivation, shape change, and dendrite formation. This review gives a specific, comprehensive and in-depth summary of the mechanisms behind these problems; as well as state-of-the-art progress in the protection of the zinc electrode via intrinsic zinc alloy, zinc surface coating and electrolyte engineering in full pH range aqueous electrolyte. Future development trends, perspective and outlooks on the further blossom of these strategies are also presented. (C. Han et al., ***Nano Energy*** 74, 104880 (2020))

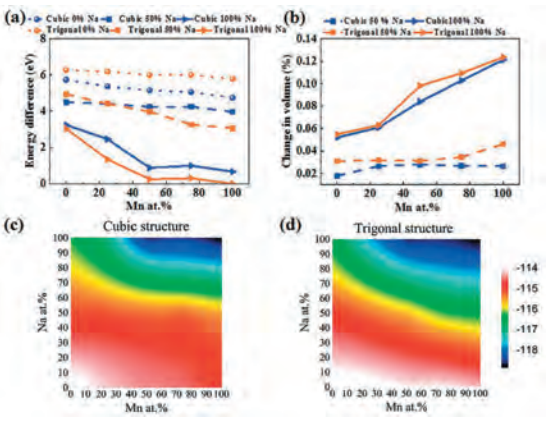
Thermoelectric performance of thermally aged nanostructured bulk materials - a case study of lead chalcogenides



The performance of nanostructured bulk thermoelectric material is shown to be enhanced because of phonon scattering. However, it is well-known that microstructures evolve by thermal aging, and their stability at the operating temperature is of vital importance to the success of the device. Here, we investigate the effect of long-term annealing (up to 8 weeks) on thermoelectric performance and microstructure of a high-efficiency Na-doped multiphase quaternary Pb chalcogenides.

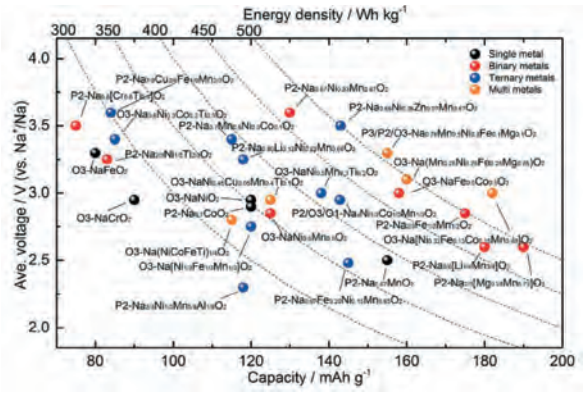
A zT of ~1.7e1.9 in the 700e850 K temperature range is achieved at all stages of thermal aging. A redistribution of Na-dopant between phases above ~630 K is believed to explain an increasing electrical resistivity in aged samples. This is balanced by a reduced total thermal conductivity as thermal aging time increases, possibly because of an increased concentration of nanoscale precipitates in samples aged for 8 weeks. Intermediate annealing of nanostructured lead chalcogenides has been shown to be an effective means of preparing thermally stable, high-performance thermoelectric materials. We have also determined the precipitates coarsening rate constant, k, to be 0.0206 mm/h$^{1/3}$. (J. Byrnes et al., ***Materials Today Physics*** 13, 100190 (2020))

Stress distortion restraint to boost the sodium ion storage performance of a novel binary hexacyanoferrate



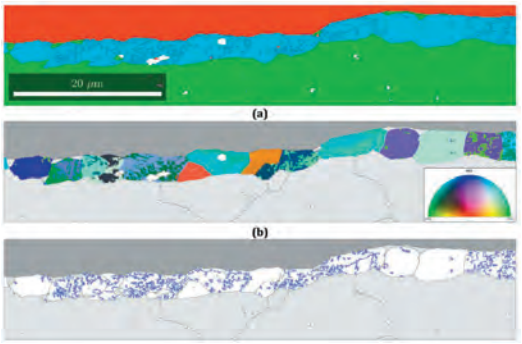
Mn-based hexacyanoferrate NaxMnFe(CN)$_6$ (NMHFC) has been attracting more attention as a promising cathode material for sodium ion storage owing to its low cost, environmental friendliness, and its high voltage plateau of 3.6 V, which comes from the Mn^{2+}/Mn^{3+} redox couple. In particular, the Na-rich NMHFC (x > 1.40) with trigonal phase is considered an attractive candidate due to its large capacity of ≈130 mAh g^{-1}, delivering high energy density. Its unstable cycle life, however, is holding back its practical application due to the dissolution of Mn^{2+} and the trigonal-cubic phase transition during the charge–discharge process. Here, a novel hexacyanoferrate ($Na_{1.60}Mn_{0.833}Fe_{0.167}[Fe(CN)_6]$, NMFHFC-1) with Na-rich cubic structure and dual-metal active redox couples is developed for the first time. Through multiple structural modulation, the stress distortion is minimized by restraining Mn^{2+} dissolution and the trigonal-cubic phase transition, which are common issues in manganese-based hexacyanoferrate. Moreover, NMFHFC-1 simultaneously retains an abundance of Na ions in the framework. As a result, $Na_{1.60}Mn_{0.833}Fe_{0.167}[Fe(CN)_6]$ electrode delivers high energy density (436 Wh kg^{-1}) and excellent cycle life (80.2% capacity retention over 300 cycles), paving the way for the development of novel commercial cathode materials for sodium ion storage. (W. J. Li et al., ***Advanced Energy Materials*** 10, 1903006 (2020))

The cathode choice for commercialization of sodium-ion batteries: layered transition metal oxides versus Prussian blue analogs



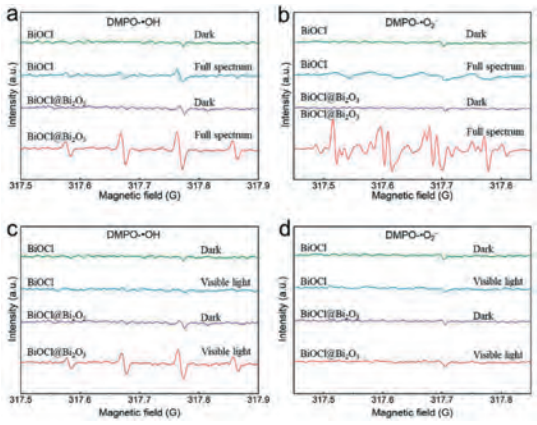
With the unprecedentedly increasing demand for renewable and clean energy sources, the sodium-ion battery (SIB) is emerging as an alternative or complementary energy storage candidate to the present commercial lithium-ion battery due to the abundance and low cost of sodium resources. Layered transition metal oxides and Prussian blue analogs are reviewed in terms of their commercial potential as cathode materials for SIBs. The recent progress in research on their half cells and full cells for the ultimate application in SIBs are summarized. In addition, their electrochemical performance, suitability for scaling up, cost, and environmental concerns are compared in detail with a brief outlook on future prospects. It is anticipated that this review will inspire further development of layered transition metal oxides and Prussian blue analogs for SIBs, especially for their emerging commercialization. (Q. N. Liu et al., ***Advanced Functional Materials*** 30, 1909530 (2020))

Multiphase identification in NiePbTe contacts by EBSD and aberration-corrected STEM



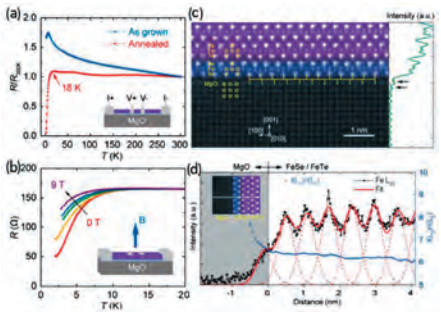
EBSD in combination with aberration-corrected STEM is used to study the interfacial layer forming at Ni electrode - PbTe thermoelectric material interfaces. Contrary to previous studies, both orthorhombic and monoclinic phases are identified within the interfacial layer. EBSD and STEM data at interphase boundaries demonstrate an approximately smooth transition from orthorhombic to monoclinic phase with almost no crystal defects due to the small differences in lattice parameters and the prevalence of one of two previously unknown orientation relationships between the phases. Moreover, the presence of special boundaries resulting in orientation domains within both phases throughout the interfacial nickel telluride layer needs to be considered when fabricating future thermoelectric devices. (X. R. Ferreres et al., ***Materials & Design*** 185, 108252 (2020))

Promoted photocharge separation in 2D lateral epitaxial heterostructure for visible-light-driven CO_2 photoreduction



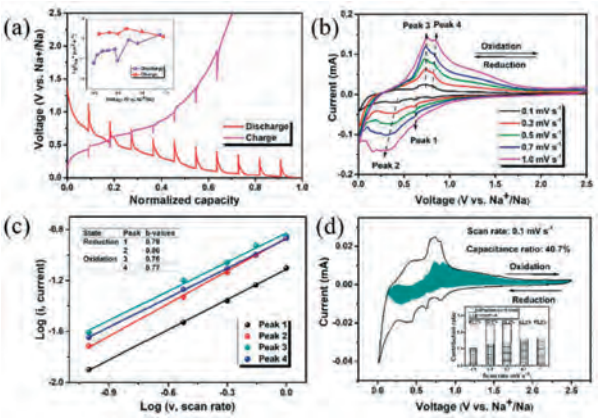
Photocarrier recombination remains a big barrier for the improvement of solar energy conversion efficiency. For 2D materials, construction of heterostructures represents an efficient strategy to promote photoexcited carrier separation via an internal electric field at the heterointerface. However, due to the difficulty in seeking two components with suitable crystal lattice mismatch, most of the current 2D heterostructures are vertical heterostructures and the exploration of 2D lateral heterostructures is scarce and limited. Here, lateral epitaxial heterostructures of BiOCl @ Bi_2O_3 at the atomic level are fabricated via sonicating-assisted etching of Cl in BiOCl. This unique lateral heterostructure expedites photoexcited charge separation and transportation through the internal electric field induced by chemical bonding at the lateral interface. As a result, the lateral BiOCl @ Bi_2O_3 heterostructure demonstrates superior CO_2 photoreduction properties with a CO yield rate of about 30 μmol g^{-1} h^{-1} under visible light illumination. The strategy to fabricate lateral epitaxial heterostructures in this work is expected to provide inspiration for preparing other 2D lateral heterostructures used in optoelectronic devices, energy conversion, and storage fields. (L. Wang et al., ***Advanced Materials*** 32, 2004311 (2020))

Atomically thin superconductors



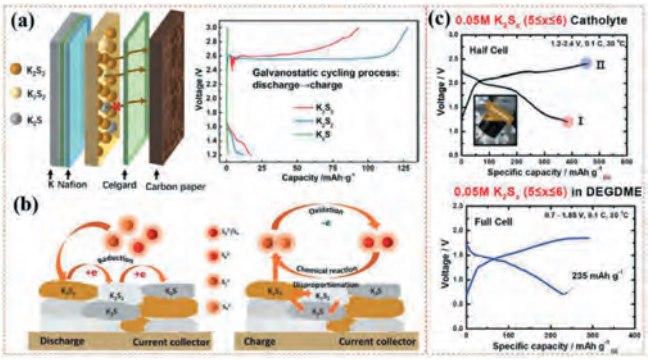
In recent years, atomically thin superconductors, including atomically thin elemental superconductors, single layer FeSe films, and few-layer cuprate superconductors, have been studied extensively. This hot research field is mainly driven by the discovery of significant superconductivity enhancement and high-temperature interface superconductivity in single-layer FeSe films epitaxially grown on $SrTiO_3$ substrates in 2012. This study has attracted tremendous research interest and generated more studies focusing on further enhancing superconductivity and finding the origin of the superconductivity. A few years later, research on atomically thin superconductors has extended to cuprate superconductors, unveiling many intriguing properties that have neither been proposed or observed previously. These new discoveries challenge the current theory regarding the superconducting mechanism of unconventional superconductors and indicate new directions on how to achieve high-transition-temperature superconductors. Herein, this exciting recent progress is briefly discussed, with a focus on the recent progress in identifying new atomically thin superconductors. (Z. Li et al., ***Small*** 17, 1904788 (2020))

Ultrathin few-layer GeP nanosheets via lithiation-assisted chemical exfoliation and their application in sodium storage



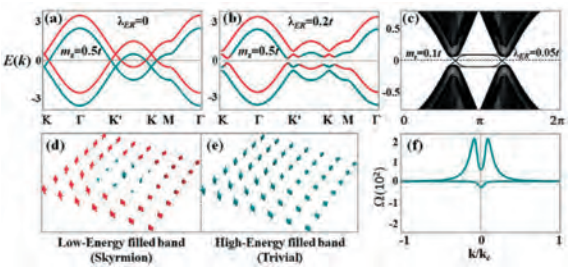
Ultrathin few-layer materials have attracted intensive research attention because of their distinctive and unique properties. Few-layer GeP (FL-GP) is potentially interesting for application in electronics and optoelectronics because of its appropriate band gap and good stability under ambient conditions. Nevertheless, it is a challenge to achieve ultrathin few-layer or single layer GeP from exfoliation of bulk crystals. Here, a lithiation-assisted chemical exfoliation technique is employed to achieve FL-GP, in which the interlayer\ spacing can be efficiently enlarged after a preliminary lithium ion intercalation,allowing the bulk crystal to be readily exfoliated in a following ultrasonication. As a result, ultrathin FL-GP is obtained. In a demonstration, the FL-GP/ reduced graphene oxide (rGO) demonstrates remarkable sodium storage performance. The FL-GP with a two-dimensional structure shortens the ion transport pathways and alleviates the volume variation during sodiation. Meanwhile, the rGO in the composite improves the conductivity of the whole electrode. The as-prepared FL-GP/rGO electrode exhibits a high capacity of 504.2 mAh g^{-1} at 100 mA g^{-1}, remarkable rate performance, and superior cycling stability in the half cells. FL-GP/rGO//$Na_3V_2(PO_4)_3$ full cells are also assembled and demonstrated satisfactory electrochemical performance, indicating potential application of the as-prepared anode materials. (F. H. Yang et al., ***Advanced Energy Materials*** 10, 1903826 (2020))

Alkali-metal sulfide as cathodes toward safe and high-capacity metal (M = Li, Na, K) sulfur batteries



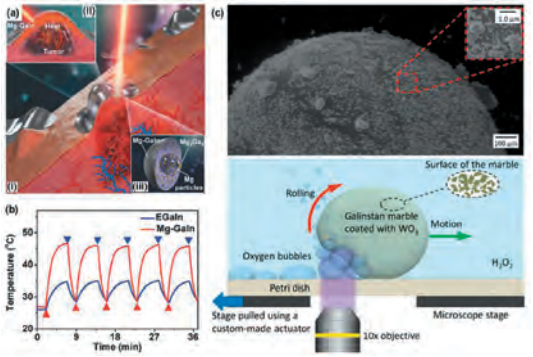
Rechargeable alkali-metal–sulfur (M–S) batteries, because of their high energy density and low cost, have been recognized as one of the most promising next-generation energy storage technologies. Nevertheless, the dissolution of metal polysulfides in organic liquid electrolytes and safety issues related to the metal anodes are greatly hindering the development of the M–S batteries. Alkali-metal sulfides (M_2Sx) are emerging as cathode materials, which can pair with various safe nonalkali-metal anodes, such as silicon and tin. As a result, the combined M_2Sx cathode-based M–S batteries can achieve high capacity as well as safety, thereby providing a more feasible battery technology for practical applications. In this review, recent progress in developing M_2Sx cathode-based M–S batteries is systematically summarized, including the activation methods for M_2Sx cathodes, M_2Sx cathode optimization, and the improvement of electrolytes and anode materials. Furthermore, perspectives and future research directions of M_2Sx cathodebased M–S batteries are proposed. (H. L. Yang et al., ***Advanced Energy Materials*** 10, 2001764 (2020))

Quantum anomalous Hall effect in magnetic doped topological insulators and ferromagnetic spin-gapless semiconductors—A perspective review



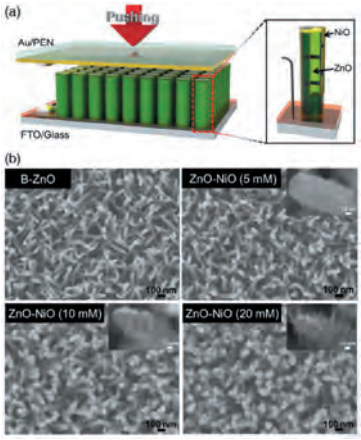
Quantum anomalous Hall effect, with a trademark of dissipationless chiral edge states for electronics/spintronics transport applications, can be realized in materials with large spin–orbit coupling and strong intrinsic magnetization. After Haldane's seminal proposal, several models have been presented to control/enhance the spin–orbit coupling and intrinsic magnetic exchange interaction. After brief introduction of Haldane model for spineless fermions, following three fundamental quantum anomalous Hall models are discussed in this perspective review: i) low-energy effective four band model for magnetic-doped topological insulator $(Bi,Sb)_2Te_3$ thin films, ii) four band tight-binding model for graphene with magnetic adatoms, and iii) two (three) band spinful tight-binding model for ferromagnetic spin-gapless semiconductors with honeycomb (kagome) lattice where ground state is intrinsically ferromagnetic. These models cover 2D Dirac materials hosting spinless, spinful, and spin-degenerate Dirac points where various mass terms open bandgap and lead to quantum anomalous Hall effect. With emphasis on the topological phase transition driven by ferromagnetic exchange interaction and its interplay with spin–orbit-coupling, various symmetry constraints on the nature of mass term and the materialization of these models are discussed. This study will shed light on the fundamental theoretical perspectives of quantum anomalous Hall materials. (M. Nadeem et al., ***Small*** 16, 1904322 (2020))

Liquid metals and their hybrids as stimulus–responsive smart materials



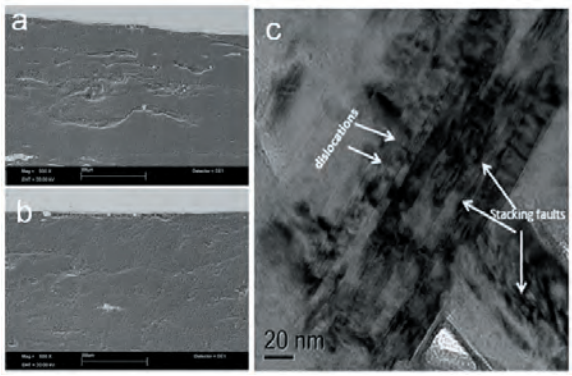
The re-emergence of room temperature liquid metals presents an exciting paradigm for an ideal combination of metallic and fluidic properties. The unique fluid metal features of non-hazardous Gabased liquid metals, including high surface energy, low viscosity, electrical and thermal conductivity, a wide temperature range of the liquid state, and desirable chemical activity for many applications, have led to remarkable possibilities for harnessing their properties and achieving unique functionalities. The realization of their stimulus-responsivity and multi-functionality make Ga-based liquid metals an attractive family of 'smart materials' that could act as the basis of countless applications in new frontiers, covering a wide range from materials science and engineering to medicine. Constructing hybrids of Ga-based liquid metals with other functional materials can further extend the fieldresponsive capacity of liquid metals to incredible levels. An increasing number of reports have revealed Ga-based liquid metals and their hybrids as remarkable soft smart-response materials. Nevertheless, the mechanisms underlying their stimulus–response activities, their interactions with other functional entities, and efficient tuning in their intimate integration, still require further exploration. Considering the applications of Ga-based liquid metals and their hybrids, this review focuses on their fieldresponsive physical and chemical properties. The recent field-responsive reports are comprehensively presented. The analysis of their responsive properties and the types of field applied in each case are discussed, so that a critical outlook on this field can be established. (L. Ren et al., ***Materials Today*** 34, 92 (2020))

n-ZnO/p-NiO Core/shell-structured nanorods for piezoelectric nanogenerators



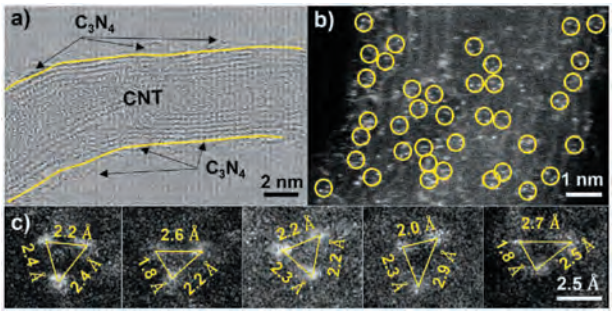
Energy-harvesting technologies, which can generate electrical energy from various energy sources, such as solar, thermal, and mechanical movement that are commonly found in the local environment, supply permanent and environmentally friendly energy. In addition, related research has been in the spotlight because it provides power by harvesting and converting a naturally occurring energy source without a charging process through external power. Piezoelectric nanogenerators (PENGs) based on piezoelectric materials have attracted much attention due to their high energy-conversion efficiency, capability for miniaturization, and light weight. Zinc oxide (ZnO), which has a wurtzite crystal structure, is a representative piezoelectric material. The defects that are inevitably present in ZnO nanorods (NRs), however, generate excessive free electrons, which reduce the piezoelectric potential and thus reduce the output characteristics. Herein, ZnO–NiO core–shell structure–based PENGs are designed to enhance their piezoelectric output performance by reducing excess electrons in the ZnO NRs using a p-type semiconducting NiO layer. The thickness and structure of the NiO coated on the ZnO NRs are observed and analyzed by adjusting the molar concentration of solution for the NiO layer coating, and the effects of these on the piezoelectric output are discussed. (S. A. Han et al., ***Energy Technology*** 8, 2000462 (2020))

Interplay between cold densification and malic acid addition ($C_4H_6O_5$) for the fabrication of near-isotropic MgB_2 conductors for magnet application



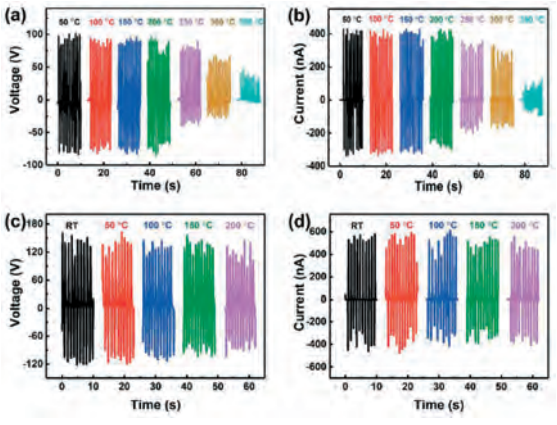
The effect of cold high pressure densification (CHPD) on anisotropy of the critical current density (J_c) in « *in situ* » single core binary and alloyed MgB_2 tapes has been determined as a function of temperatures at 4.2 K, 20 K and 25 K as well as at applied magnetic fields up to 19 T. The study includes binary and $C_4H_6O_5$ (malic acid) doped MgB_2 tapes before and after CHPD. It is remarkable that the CHPD process not only improved the J_c values, in particular at the higher magnetic fields, but also decreased the anisotropy ratio, = $J_c^{//}/J_c^{\perp}$. In binary MgB_2 tapes, the anisotropy factor _ increases with higher aspect ratios, even after applying CHPD. In malic acid ($C_4H_6O_5$) doped tapes, however, the application of CHPD leads only to small enhancements of _, even for higher aspect ratios. This is attributed to the higher carbon content in the MgB_2 filaments, which in turn is a consequence of the reduced chemical reaction path in the densified filaments. At all applied field values, it was found that CHPD processed $C_4H_6O_5$ doped tapes exhibit an almost isotropic behavior. This constitutes an advantage in view of industrial magnet applications using wires with square or slightly rectangular configuration. (M. S. A. Hossain et al., ***Journal of Magnesium and Alloys*** 8, 493 (2020))

Confined Fe–Cu clusters as sub-nanometer reactors for efficiently regulating the electrochemical nitrogen reduction reaction



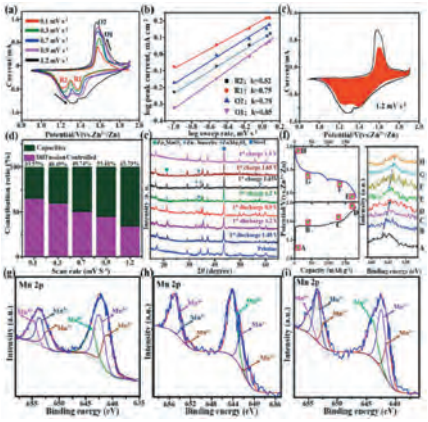
Electrochemical nitrogen reduction reaction (NRR) over nonprecious-metal and single-atom catalysts has received increasing attention as a sustainable strategy to synthesize ammonia. However, the atomic-scale regulation of such active sites for NRR catalysis remains challenging because of the large distance between them, which significantly weakens their cooperation. Herein, the utilization of regular surface cavities with unique microenvironment on graphitic carbon nitride as “subnano reactors” to precisely confine multiple Fe and Cu atoms for NRR electrocatalysis is reported. The synergy of Fe and Cu atoms in such confined subnano space provides significantly enhanced NRR performance, with nearly doubles ammonia yield and 54%-increased Faradic efficiency up to 34%, comparing with the single-metal counterparts. First principle simulation reveals this synergistic effect originates from the unique Fe–Cu coordination, which effectively modifies the N2 absorption, improves electron transfer, and offers extra redox couples for NRR. This work thus provides new strategies of manipulating catalysts active centers at the sub-nanometer scale. (X. W. Wang et al., ***Advanced Materials*** 32, 2004382 (2020))

Flexible hybrid piezo/triboelectric energy harvester with high power density workable at elevated temperatures



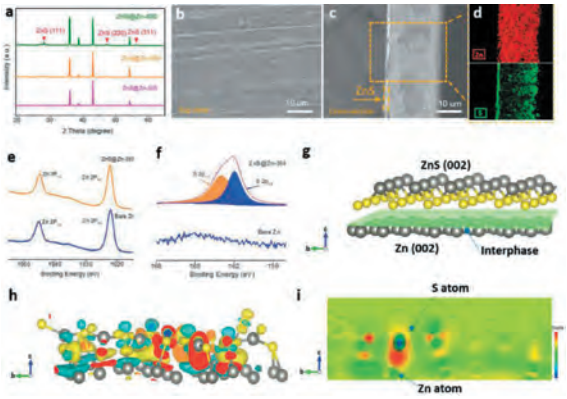
Eco-friendly energy harvesters with high output for effectively harvesting mechanical energy over a broad temperature range are highly desirable. Here, a lead-free, flexible, and efficient hybrid energy harvester was demonstrated by the combination of a single electrode triboelectric energy harvester (TEH) and an interdigital electrode piezoelectric energy harvester (PEH), which are based on a 0–3 composite of high temperature $BiFeO_3$–$BaTiO_3$ (BF–BT) piezoelectric ceramic particles and polyimide (PI) matrix. With an appropriate external connection, the hybrid piezo–triboelectric energy harvester (P–TEH) generates an open-circuit voltage and a short-circuit current of 175 V and 600 nA, respectively, together with high power density of 4.1 mW cm^3. This work demonstrates that the combination of the interdigital electrode PEH with TEH can enable high electrical output due to minimum internal interference between the two energy harvesting parts. Of particular significance is that the flexible P–TEH shows great high temperature stability up to 200 °C with an open-circuit voltage of 150 V and a short-circuit current of 560 nA, exhibiting excellent potential for using at high temperature. (Y. H. Sun et al., ***Journal of Materials Chemistry A*** 8, 12003 (2020))

Boosted charge transfer in twinborn α-(Mn_2O_3–MnO_2) heterostructures: Toward high-rate and ultralong-life zinc-ion batteries



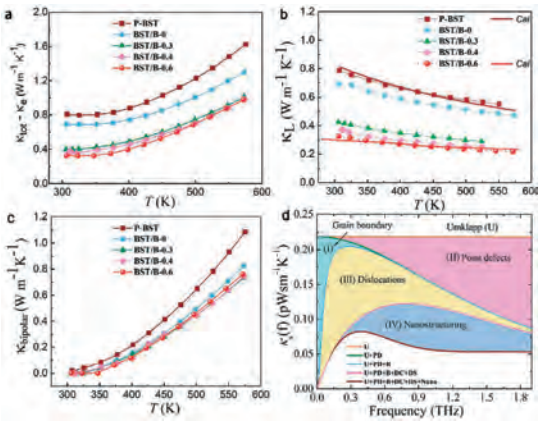
Aqueous ZIBs are one of the most promising nextgeneration rechargeable batteries because of the high capacity, high hydrogen evolution overpotential, and chemically stable reversible plating/stripping of the zinc electrode in the mild aqueous electrolyte. However, there are limited cathode materials that can store Zn^{2+} reversibly with superior cycling and rate capability. Herein, hierarchically porous nanorods composed of twinborn α-(Mn_2O_3–MnO_2) heterostructures are proposed as a robust cathode for Zn storage. Thanks to the hierarchically porous nanorod morphology and the abundant interface of the heterostructures involving a built-in electric field, the as-obtained twinborn α-(Mn_2O_3–MnO_2) electrode delivers a high capacity of 170 mA h g^{-1} for 2000 cycles at 500 mA g^{-1} and shows an excellent rate capability of up to 1.5 A g^{-1} with a capacity of 124 mA h g^{-1}. The inspiring results achieved exhibit the enormous potential of the high performance heterostructure cathode for fast and stable ZIBs. (J. Long et al., ***ACS Applied Materials & Interfaces*** 12, 32526 (2020))

An In-depth study of Zn metal surface chemistry for advanced aqueous Zn-ion batteries



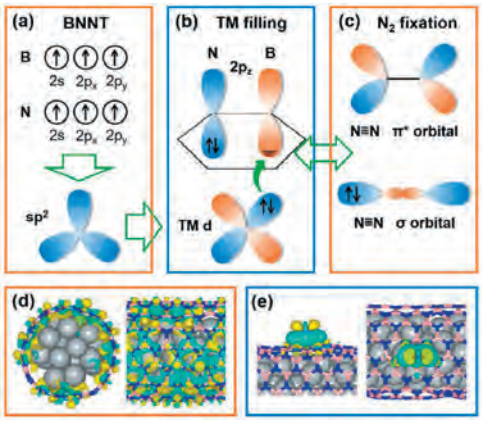
Although Zn metal has been regarded as the most promising anode for aqueous batteries, it persistently suffers from serious side reactions and dendrite growth in mild electrolyte. Spontaneous Zn corrosion and hydrogen evolution damage the shelf life and calendar life of Zn-based batteries, severely affecting their industrial applications. Herein, a robust and homogeneous ZnS interphase is built in situ on the Zn surface by a vapor–solid strategy to enhance Zn reversibility. The thickness of the ZnS film is controlled via the treatment temperature, and the performance of the protected Zn electrode is optimized. The dense ZnS artificial layer obtained at 350 °C not only suppresses Zn corrosion by forming a physical barrier on the Zn surface, but also inhibits dendrite growth via guiding the Zn plating/stripping underneath the artificial layer. Accordingly, a side reaction-free and dendrite-free Zn electrode is developed, the effectiveness of which is also convincing in a MnO_2/ZnS@Zn full-cell with 87.6% capacity retention after 2500 cycles. (J. N. Hao et al., ***Advanced Materials*** 32, 2003021 (2020))

Ultra-high thermoelectric performance in bulk BiSbTe/amorphous boron composites with nano-defect architectures



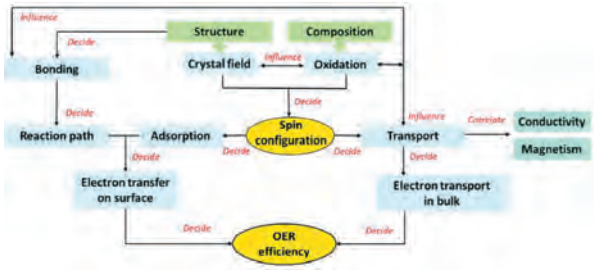
Based on the Seebeck and Peltier effects, state-of-the-art bismuth telluridebased thermoelectric materials, which are capable of direct and reversible conversion of thermal to electrical energy, have great potential in energy harvesting and solid-state refrigerators. However, their widespread use is limited by their low conversion efficiency, which is determined by the dimensionless figure-of-merit (ZT). Significant enhancement of ZT is a great challenge owing to the common interdependence of electrical and thermal conductivity. Here, it is demonstrated that by incorporating nanoamorphous boron into the p-type $Bi_{0.5}Sb_{1.5}Te_3$, a record high ZT of 1.6 at 375 K is achieved. It is shown that a high density of nanostructures and dislocations due to the incorporation of the boron inclusions, leads to a significant reduction of thermal conductivity and improved charge transport. The findings represent an important step to further promote the development of thermoelectric technology and its widespread application in solid-state refrigeration and power generation from waste heat. (G. S. Yang et al., ***Advanced Energy Materials*** 10, 2000757 (2020))

Boron nitride nanotubes for ammonia synthesis: activation by filling transition metals



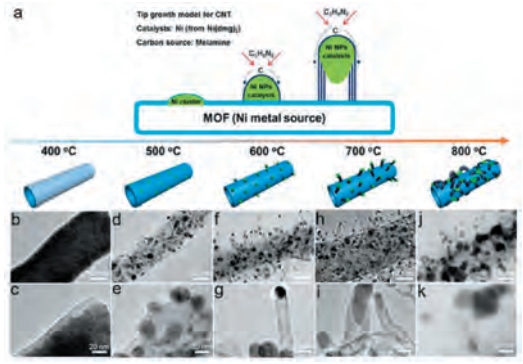
Boron nitride (BN), with outstanding stability and robustness in diverse polymorphs, possesses many advantageous properties for industrial applications. Activation of BN materials for nonmetal catalysts is among the most revolutionary and challenging tasks. Taking advantage of quantum size effect and synergistic effect, here we exploit boron nitride nanotubes (BNNTs) encapsulating early transition metal nanowires, which is experimentally feasible, for nitrogen fixation and ammonia synthesis. Using first principles calculations and microkinetic modeling, we show that the coexisting occupied and unoccupied p states of B atoms in filled BNNTs can effectively mimic the d states of transition metal. They act as electron reservoirs with tunable orbital energies and occupancy, which are beneficial for associative N_2 adsorption and hydrogenation. Due to the competition between thermodynamics of gas adsorption and kinetics of hydrogenation reaction, the activity can be optimized by controlling the type of metal filler and size of BN nanotube, achieving a turnover frequency competitive to that of benchmark Fe catalyst. These results manifest a universal strategy for activating BN nanomaterials as a promising family of robust and efficient catalysts and provide vital insights into the activity–band structure relationship for p-block nonmetal catalysts. (S. Zhou et al., ***Journal of the American Chemical Society*** 142, 308 (2020))

Understanding the mechanism of the oxygen evolution reaction with consideration of spin



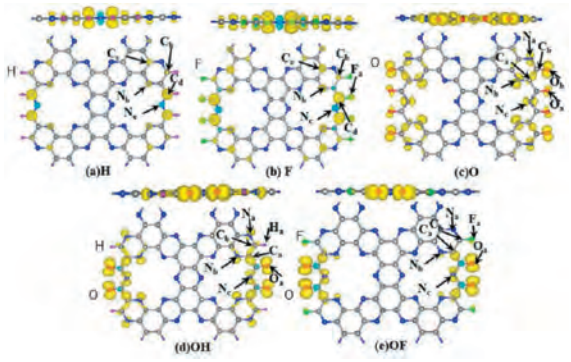
The oxygen evolution reaction (OER) with its intractably high overpotentials is the rate-limiting step in many devices, including rechargeable metal–air batteries, water electrolysis systems and solar fuel devices. Correspondingly, spin state transitions from spin singlet OH–/H2O reactants to spin triplet O2 product have not yet received enough attention. In view of this, this article will discuss electron behaviours during OER by taking into consideration of spin attribute. The main conclusion is that, regardless of the possible adopted mechanisms (the adsorbate evolution mechanism or the lattice oxygen mechanism), the underlying rationale of OER is that three in four electrons being extracted from adsorbates should be in the same spin direction before O=O formation, superimposing high requirements on the spin structure of electrocatalysts. Therefore, upon fully understanding of the OER mechanism with considerations of spin, the awareness of the coupling between spin, charge, orbital and lattice parameters is necessary in the optimization of geometric and electronic structures in transition metal systems. Based on this, this article will discuss the possible dependency of OER efficiency on the electrocatalyst spin configuration, and the relevance of well-recognized factors with spin, including the crystal field, coordination, oxidation, bonding, the eg electron number, conductivity and magnetism. It is hoped that this article will clarify the underlying physics of OER to provide rational guidance for more effective design of energy conversion electrocatalysts. (X. N. Li et al., ***Electrochemical Energy Reviews*** 4, 136 (2020))

In-situ grafting of N-doped carbon nanotubes with Ni encapsulation onto MOF-derived hierarchical hybrids for efficient electrocatalytic hydrogen evolution



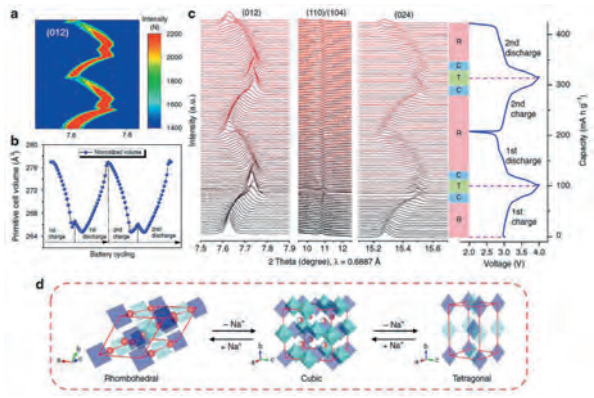
Developing highly efficient and cost-effective catalysts for the hydrogen evolution reaction (HER) is of paramount importance to solve the problems arising from the depletion of non-renewable fossil fuels and increasing air pollution issues. Herein, an in-situ heterogeneous catalytic synthesis approach is developed for constructing hierarchical Ni/carbon hybrids via grafting nitrogen-doped-carbon (NC) nanotubes with Ni encapsulation onto the metal-organic framework (MOF)-derived carbon matrix. Following the "nanotube tip-growth model" involved in the in-situ catalytic synthesis process, the morphology and size of the nanotubes and encapsulated particles of the as-prepared hierarchical Ni based carbon hybrids can be controlled by regulating the conditions during the thermal decomposition of the Ni-MOF in the presence of melamine. The grafting and decoration of the Ni-encapsulated carbon nanotubes on the MOF-derived architecture rapidly enhance the HER electrocatalytic performance of the bare thermally decomposed Ni/N-doped carbon composite. Due to the synergistic effects of the stable metallic Ni active sites and the N-doped carbon support, the optimized Ni@NC_6-600 sample exhibits stable and high catalytic activity, only requiring an overpotential of 181 mV to drive 10 mA/cm^2 towards the HER in alkaline media. (N. Y. Cheng et al., ***Carbon*** 163, 178 (2020))

Spin-gapless semiconductors for future spintronics and electronics



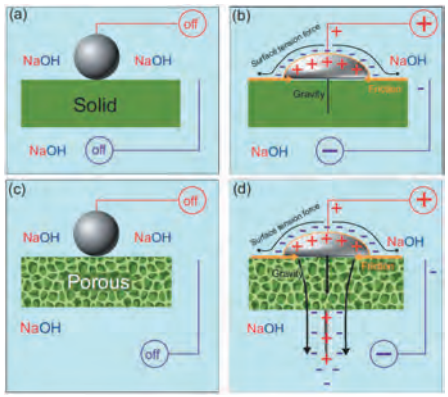
In recent years, spin-gapless semiconductors (SGSs) with parabolic and linear band dispersions have aroused great interest worldwide in the field of materials science due to their various attractive properties. In this review, the theoretical and experimental progress from 2008 to 2020 on the structure, electronic, and magnetic properties of almost all the SGSs with one-, two-, and three-dimensional structures are summarized. The potential applications in spintronic devices based on SGSs are introduced. Compared to the SGSs with parabolic band dispersions (PSGSs), the linear Dirac-type SGSs (DSGSs), which belong to the type I linear-type SGSs, host real massless fermions and dissipationless transport properties, and thus are regarded as promising material candidates for applications in ultra-fast and ultra-low-power spintronic devices. The predicted DSGSs are good platforms to achieve the quantum anomalous Hall (QAH) states and to study the entanglement between the DSGS and QAH states. In this work, we introduce the DSGS state and the possible QAH state for the DSGSs predicted in the past six years. Interestingly, nodal-line spin-gapless semiconductors (NLSGSs), which enable fully spin polarized fermionic states, are currently receiving considerable interest and are highly desirable for promising spintronics applications. In this review, we also summarize four sub-types of NLSGSs with different shapes of nodal lines in momentum space, including the nodal ring, nodal link, nodal chain, and nodal knot. The recent advances in nodal-ring spin-gapless semiconductors and nodal-chain spin-gapless semiconductors are reviewed. Possible new physics and potential applications for the NLSGSs are also discussed.. (X. T. Wang et al., ***Physics Reports*** 888, 1 (2020))

Reversible structural evolution of sodium-rich rhombohedral Prussian blue for sodium-ion batteries



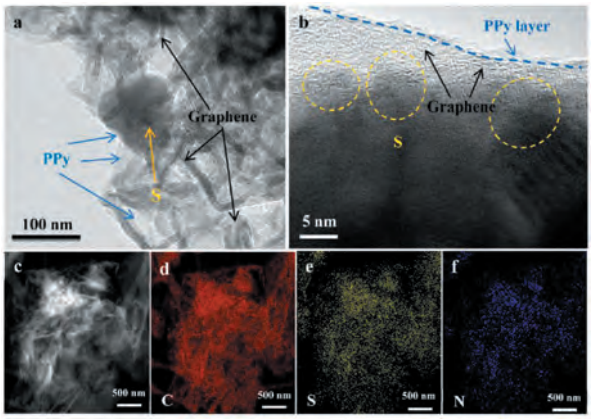
Iron-based Prussian blue analogs are promising low-cost and easily prepared cathode materials for sodium-ion batteries. Their materials quality and electrochemical performance are heavily reliant on the precipitation process. Here we report a controllable precipitation method to synthesize high-performance Prussian blue for sodium-ion storage. Characterization of the nucleation and evolution processes of the highly crystalline Prussian blue microcubes reveals a rhombohedral structure that exhibits high initial Coulombic efficiency, excellent rate performance, and cycling properties. The phase transitions in the as-obtained material are investigated by synchrotron in situ powder X-ray diffraction, which shows highly reversible structural transformations between rhombohedral, cubic, and tetragonal structures upon sodium-ion (de)intercalations. Moreover, the Prussian blue material from a large-scale synthesis process shows stable cycling performance in a pouch full cell over 1000 times. We believe that this work could pave the way for the real application of Prussian blue materials in sodium-ion batteries. (W. L .Wang et al., ***Nature Communications*** 11, 980 (2020))

Voltage-induced penetration effect in liquid metals at room temperature



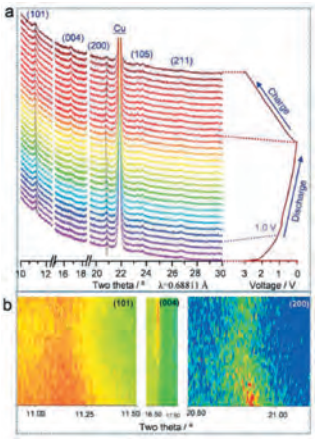
Room-temperature liquid metal is discovered to be capable of penetrating through macro- and microporous materials by applying a voltage. The liquid metal penetration effects are demonstrated in various porous materials such as tissue paper, thick and fine sponges, fabrics, and meshes. The underlying mechanism is that the high surface tension of liquid metal can be significantly reduced to near-zero due to the voltage-induced oxidation of the liquid metal surface in a solution. It is the extremely low surface tension and gravity that cause the liquid metal to superwet the solid surface, leading to the penetration phenomena. These findings offer new opportunities for novel microfluidic applications and could promote further discovery of more exotic fluid states of liquid metals. (F. F. Yun et al., ***National Science Review*** 7, 366 (2020))

Uniform polypyrrole layer-coated sulfur/graphene aerogel via the vapor-phase deposition technique as the cathode material for Li–S batteries



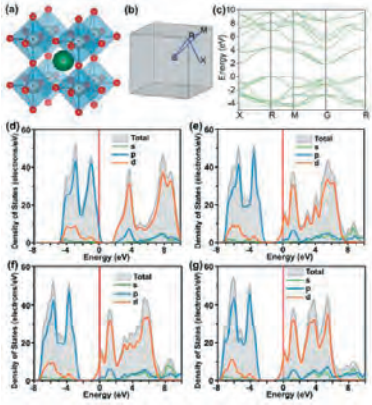
The practical application of Li–S batteries is hampered because of their poor cycling stability caused by electrolyte-dissolved lithium polysulfides. Dual functionalities such as strong chemical adsorption stability and high conductivity are highly desired for an ideal host material for the sulfur-based cathode. Herein, a uniform polypyrrole layer-coated sulfur/graphene aerogel composite is designed and synthesized using a novel vapor phase deposition method. The polypyrrole layer simultaneously acts as a host and an adsorbent for efficient suppression of polysulfide dissolution through strong chemical interaction. The density functional theory calculations reveal that the polypyrrole could trap lithium polysulfides through stronger bonding energy. In addition, the deflation of sulfur/graphene hydrogel during the vapor-phase deposition process enhances the contact of sulfur with matrices, resulting in high sulfur utilization and good rate capability. As a result, the synthesized polypyrrole-coated sulfur/graphene aerogel composite delivers specific discharge capacities of 1167 and 409.1 mA h g^{-1} at 0.2 and 5 C, respectively. Moreover, the composite can maintain a capacity of 698 mA h g^{-1} at 0.5 C after 500 cycles, showing an ultraslow decay rate of 0.03% per cycle. (F. Li et al., ***ACS Applied Materials & Interfaces*** 12, 5958 (2020))

Confining ultrathin 2D superlattices in mesoporous hollow spheres renders ultrafast and high-capacity Na-Ion storage



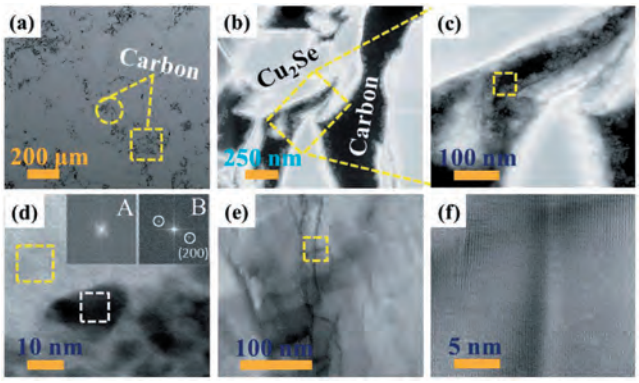
Sodium-ion batteries have attracted ever-increasing attention in view of the natural abundance of sodium resources. Sluggish sodiation kinetics, nevertheless, remain a tough challenge, in terms of achieving high rate capability and high energy density. Herein, a sheet-in-sphere nanoconfiguration of 2D titania–carbon superlattices vertically aligned inside of mesoporous TiO_2@C hollow nanospheres is constructed. In such a design, the ultrathin 2D superlattices consist of ordered alternating monolayers of titania and carbon, enabling interpenetrating pathways for rapid transport of electrons and Na+ ions as well as a 2D heterointerface for Na^+ storage. Kinetics analysis discloses that the combination of 2D heterointerface and mesoporosity results an intercalation pseudocapacitive charge storage mechanism, which triggers ultrafast sodiation kinetics. In situ transmission electron microscope imaging and in situ synchrotron X-ray diffraction techniques elucidate that the sheet-in-sphere architecture can maintain robust mechanical and crystallographic structural stability, resulting an extraordinary high rate capability, remarkable stable cycling with a low capacity fading ratio of 0.04% per cycle over 500 cycles at 0.2 C, and exceptionally long-term cyclability up to 20 000 cycles at 50 C. This study offers a method for the realization of a high power density and longterm cyclability battery by designing of a hierarchical nanoarchitecture. (Q. B. Xia et al., ***Advanced Energy Materials*** 10, 2001033 (2020))

Significant improvement in electrical conductivity and Figure of Merit of nanoarchitectured porous $SrTiO_3$ by La doping optimization



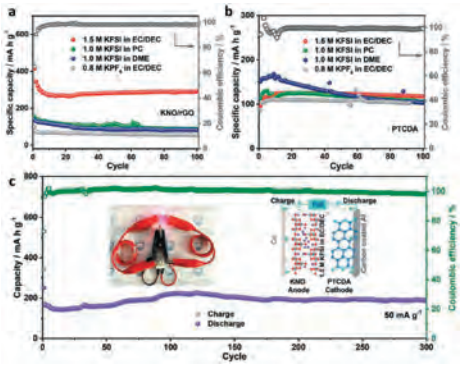
$SrTiO_3$ is a well-studied n-type metal oxide based thermoelectric (TE) material. In this work, the first-principles calculation of La-doped $SrTiO_3$ has been performed using the density functional theory. In addition, high TE properties of bulk $SrTiO_3$ material have been achieved by introducing nanoscale porosity and optimizing carrier concentration by La doping. The X-ray diffraction, atomic resolution scanning transmission electron microscopy imaging, and energy-dispersive X-ray spectrometry results show that La has been doped successfully into the lattice. The scanning electron microscopy images confirm that all the samples have nearly similar nanoscale porosities. The significant enhancement of electrical conductivity over the broad temperature range has been observed through optimization of La doping. Additionally, the samples possess very low thermal conductivity, which is speculated because of the nanoscale porosity of the samples. Because of this dual mechanism of doping optimization and nanoscale porosity, there is a remarkable improvement in power factor, 1 mW/m2K from 650 to 800 K, and figure of merit, zT of 0.26 at 850 K, of the sample, 22 at. % La-doped $SrTiO_3$. (A. J. Ahmed et al., ***ACS Applied Materials & Interfaces*** 12, 28057 (2020))

Grape juice: an effective liquid additive for significant enhancement of thermoelectric performance of Cu_2Se



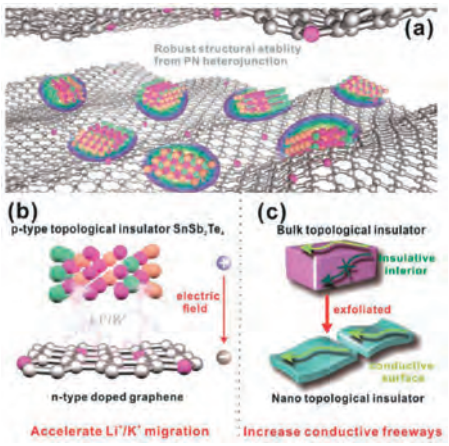
The reduction of thermal conductivity and enhancement of electrical properties is the ultimate goal for achieving high performance thermoelectric materials. In this paper, a high thermoelectric performance is demonstrated when grape juice is used as an additive to Cu_2Se. High temperature processing of the mixture pyrolyzes the sugars in the grape juice and provides a fine scale and well-mixed dispersion of elemental carbon in the Cu2Se matrix. These materials show a significant enhancement of electrical conductivity due to a high hole concentration with little change of the Seebeck coefficient, leading to an ultra-high power factor of 1.3 mW m^{-1} K^{-2} at 984 K. Microstructural studies reveal that the carbon phase is embedded on the Cu_2Se grain boundaries and that Cu_2O nanoparticles are located at the interface between carbon and Cu_2Se. This results in phonon scattering at the interface which leads to a reduction of thermal conductivity of up to ~38%. It is proposed that the formation of Cu_2O also induces Cu deficiencies in Cu_2Se resulting in greater enhancement of electrical conductivity. As a result, the zT is significantly enhanced up to ~2.5 at 984 K. This study opens up a new avenue for enhancing the properties of thermoelectric materials. (S. M. K. N. Islam et al., ***Journal of Materials Chemistry A*** 8, 16913 (2020))

Dehydration-triggered ionic channel engineering in potassium niobate for Li/K-ion storage



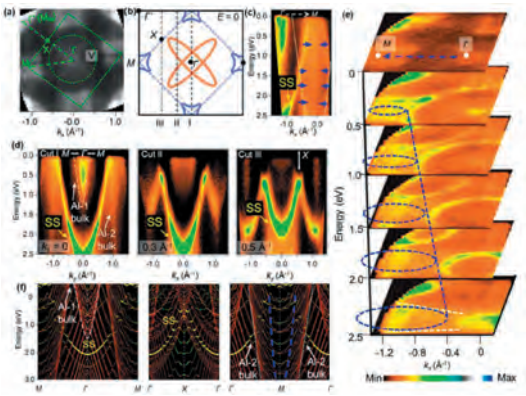
Boosting charge transfer in materials is critical for applications involving charge carriers. Engineering ionic channels in electrode materials can create a skeleton to manipulate their ion and electron behaviors with favorable parameters to promote their capacity and stability. Here, tailoring of the atomic structure in layered potassium niobate ($K_4Nb_6O_{17}$) nanosheets and facilitating their application in lithium and potassium storage by dehydration-triggered lattice rearrangement is reported. The spectroscopy results reveal that the interatomic distances of the Nb-O coordination in the engineered $K_4Nb_6O_{17}$ are slightly elongated with increased degrees of disorder. Specifically, the engineered $K_4Nb_6O_{17}$ shows enhanced electrical and ionic conductivity, which can be attributed to the enlarged interlamellar spacing and subtle distortions in the fine atomic arrangements. Moreover, subsequent experimental results and calculations demonstrate that the energy barrier for Li^+/K^+ diffusion is significantly lower than that in pristine $K_4Nb_6O_{17}$. Interestingly, the diffusion coefficient of K^+ is one order of magnitude higher than that of Li^+, and the engineered $K_4Nb_6O_{17}$ presents superior electrochemical performance for K^+ to Li^+. This work offers an ionic engineering strategy to enable fast and durable charge transfer in materials, holding great promise for providing guidance for the material design of related energy storage systems. (S. Zhang et al., ***Advanced Materials*** 32, 2000380 (2020))

Coupling topological insulator $SnSb_2Te_4$ nanodots with highly doped graphene for high-rate energy storage



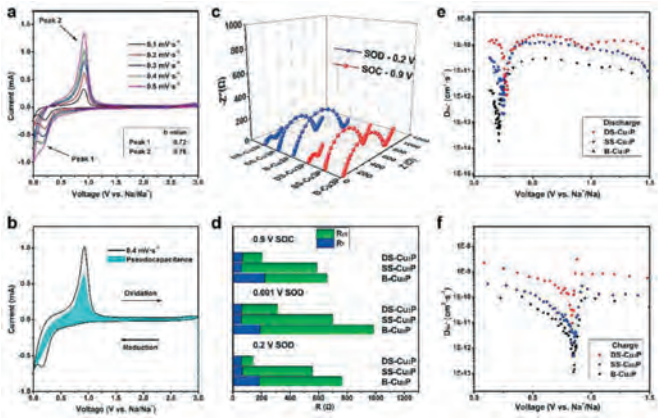
Topological insulators have spurred worldwide interest, but their advantageous properties have scarcely been explored in terms of electrochemical energy storage, and their high-rate capability and long-term cycling stability still remain a significant challenge to harvest. p-Type topological insulator $SnSb_2Te_4$ nanodots anchoring on few-layered graphene ($SnSb_2Te_4$/G) are synthesized as a stable anode for high-rate lithium-ion batteries and potassium-ion batteries through a ball-milling method. These $SnSb_2Te_4$/G composite electrodes show ultralong cycle lifespan (478 mAh g^{-1} at 1 A g^{-1} after 1000 cycles) and excellent rate capability (remaining 373 mAh g^{-1} even\ at 10 A g^{-1}) in Li-ion storage owing to the rapid ion transport accelerated by the PN heterojunction, virtual electron highways provided by the conductive topological surface state, and extraordinary pseudocapacitive contribution, whose excellent phase reversibility is confirmed by synchrotron in situ X-ray powder diffraction. Surprisingly, durable lifespan even at practical levels of mass loading (>10 mg cm^{-2}) for Li-ion storage and excellent K-ion storage performance are also observed. This work provides new insights for designing high-rate electrode materials by boosting conductive topological surfaces, atomic doping, and the interface interaction. (Z. B. Wu et al., ***Advanced Materials*** 32, 1905632 (2020))

Experimental realization of two-dimensional buckled Lieb lattice



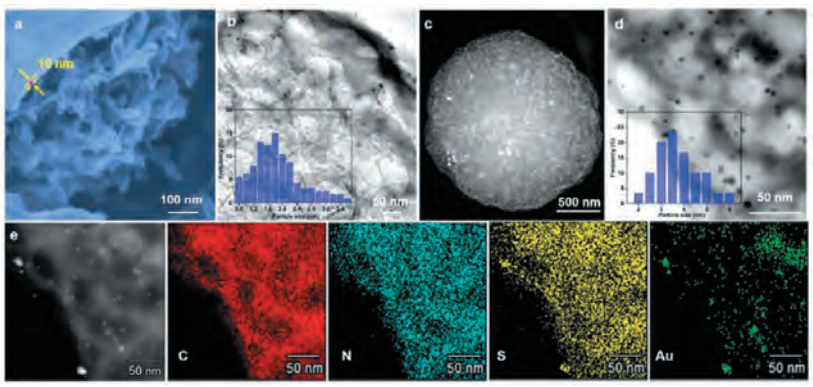
Two-dimensional (2D) materials with a Lieb lattice host exotic electronic band structures. Such a system does not exist in nature, and it is also difficult to obtain in the laboratory due to its structural instability. Here, we experimentally realized a 2D system composed of a tin overlayer on an aluminum substrate by molecular beam epitaxy. The specific arrangement of Sn atoms on the Al(100) surface, which benefits from favorable interface interactions, forms a stabilized buckled Lieb lattice. Theoretical calculations indicate a partially broken nodal line loop and a topologically nontrivial insulating state with a spin–orbital coupling effect in the band structure of this Lieb lattice. The electronic structure of this system is experimentally characterized by angle-resolved photoemission spectroscopy, in which the hybridized states between topmost Al atoms and Sn atoms are revealed. Our work provides an appealing method for constructing 2D quantum materials based on the Lieb lattice. (H. F. Feng et al., ***Nano Letters*** 20, 2537 (2020))

Manipulating molecular structure and morphology to invoke high-performance sodium storage of copper phosphide



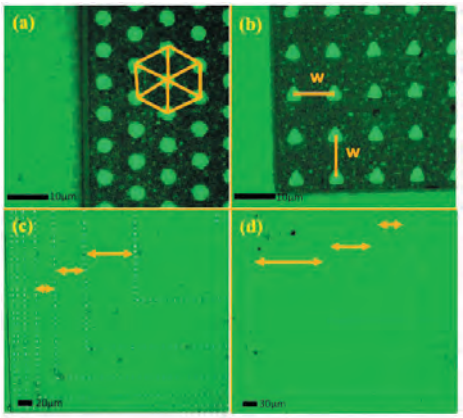
Copper is used as current collector in rechargeable ion batteries due to its outstanding electronic conductivity and low cost. The intrinsic inactivity of copper, however, makes it a poor candidate for an electrode material without further structural modification. To fully utilize its high electronic conductivity, herein, the incorporation of heterogeneous phosphorus combined with building a unique 3D hollow structure is proposed. The as-prepared copper phosphide hollow nanocubes deliver a stable capacity of 325 mAh g^{-1} at 50 mA g^{-1} and fast charging and discharging via pseudo capacitance behavior. The outstanding electrochemical performance is attributed to the synergetic effects of high electronic conductivity of copper and the high sodium storage capability of phosphorus. In addition, this facile synthesis method is also easily scaled up for practical applications. Thus, copper phosphide is a promising anode material for sodium ion batteries. (Z. Hu et al., ***Advanced Energy Materials*** 10, 1903542 (2020))

High-performance room-temperature sodium–sulfur battery enabled by electrocatalytic sodium polysulfides full conversion



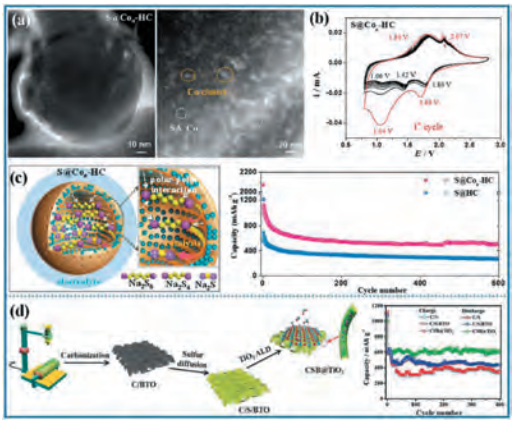
Room-temperature sodium–sulfur (RT-Na–S) batteries are highly desirable for grid-scale stationary energy storage due to their low cost; however, short cycling stability caused by the incomplete conversion of sodium polysulfides is a major issue for their application. Herein, we introduce an effective sulfiphilic host, gold nanodots decorated on hierarchical N-doped carbon microspheres (CN/Au/S), to achieve completely reversible conversion reactions in the S cathode by electrocatalyzing the lowkinetics conversion of Na_2S_4 into NaS_2 (discharge process) or S (charge process). Besides, gold nanodots and N-doped carbon can increase the conductivity of the S cathode and provide strong polar–polar adsorption of sodium polysulfides to alleviate the shuttling effects. When serving as the cathode, the CN/Au/S composite can realize enhanced sulfur utilization, excellent cycling stability, and outstanding rate capability. This work deepens our understanding of the catalytic effect of gold atoms on sulfur molecules, opening a new avenue for cathode design and development of advanced RT-Na–S batteries. (N. N. Wang et al., ***Energy & Environmental Science*** 13, 562 (2020))

Large artificial ferromagnetic dot arrays for the critical current enhancement in superconducting $YBa_2Cu_3O_{7-\square}$ thin films



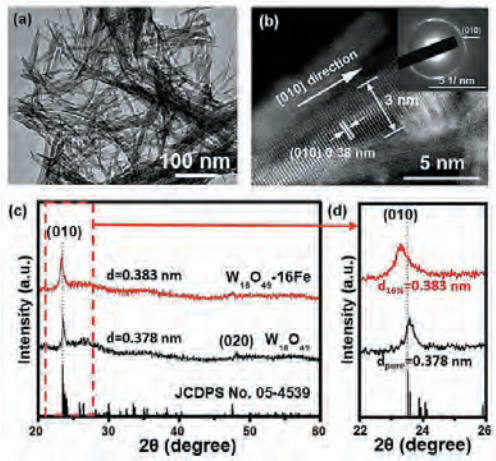
In order to enhance and/or control critical current density (Jc) in superconducting $YBa_2Cu_3O_{7-\square}$ (YBCO) thin films, different arrays of 3 μm large ferromagnetic (iron) dots with differing configurations and shapes have been deposited on top of high-quality YBCO thin films post-buffered with a layer of CeO_2. Some tremendous Jc enhancement of up to nearly 100% have been obtained at high temperatures and low fields. However, the Jc performance is strongly dependent on the array configurations, shape and amount of ferromagnetic iron involved. We show that it is possible to enhance Jc at high or low magnetic field ranges. The results are clearly different to similar non magnetic array structures used to previously manipulate Jc in YBCO films, which proves the magnetic origin of the changes in Jc we observed. The enhancement is likely due to the flux localization and magnetic pinning effects, rather than magnetic shielding alone, which is effective at relatively low fields only. The results also suggest that the observed Jc changes depend on rather minor variations in initial pinning and corresponding Jc levels of the films. At the same time a common trend for all of the various investigated magnetic arrays could not be established due to explained factors. (M. M. Al-Qurainy et al., ***Superconductor Science & Technology*** 33, 105006 (2020))

Remedies for polysulfide dissolution in room-temperature sodium–sulfur batteries



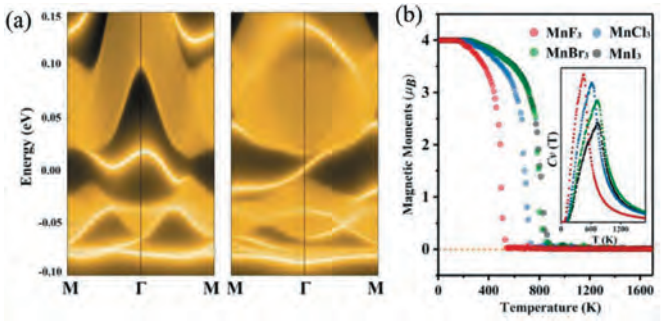
Rechargeable room-temperature sodium–sulfur (RT-NaS) batteries represent one of the most attractive technologies for future stationary energy storage due to their high energy density and low cost. The S cathodes can react with Na ions via two-electron conversion reactions, thus achieving ultrahigh theoretical capacity (1672 mAh g−1) and specific energy (1273 Wh kg−1). Unfortunately, the sluggish reaction kinetics of the nonconductive S, severe polysulfide dissolution, and the use of metallic Na are causing enormous challenges for the development of RT-NaS batteries. Fatal polysulfide dissolution is highlighted, important studies toward polysulfide immobilization and conversion are presented, and the reported remedies in terms of intact physical confinement, strong chemical interaction, blocking layers, and optimization of electrolytes are summarized. Future research directions toward practical RT-NaS batteries are summarized. (Y. X. Wang et al., ***Advanced Materials*** 32, 1903952 (2020))

Vacancy engineering of iron-doped $W_{18}O_{49}$ nanoreactors for low-barrier electrochemical nitrogen reduction



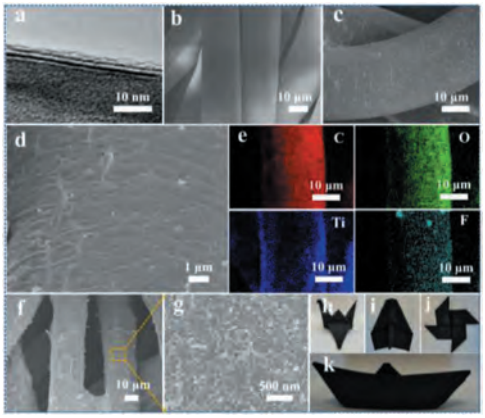
The electrochemical nitrogen reduction reaction (NRR) is a promising energy-efficient and low-emission alternative to the traditional Haber–Bosch process. Usually, the competing hydrogen evolution reaction (HER) and the reaction barrier of ambient electrochemical NRR are significant challenges, making a simultaneous high NH_3 formation rate and high Faradic efficiency (FE) difficult. To give effective NRR electrocatalysis and suppressed HER, the surface atomic structure of$W_{18}O_{49}$, which has exposed activeWsites and weak binding for H_2, is doped with Fe. A high NH_3 formation rate of 24.7 mgh^{-1} mg_{cat}^{-1} and a high FE of 20.0% are achieved at an overpotential of only -0.15 V versus the reversible hydrogen electrode. Ab initio calculations reveal an intercalation-type doping of Fe atoms in the tunnels of the $W_{18}O_{49}$ crystal structure, which increases the oxygen vacancies and exposes more W active sites, optimizes the nitrogen adsorption energy, and facilitates the electrocatalytic NRR. (Y. Y. Tong et al., ***Angewandte Chemie – International Edition*** 59, 7356 (2020))

Spin-gapless semiconductors



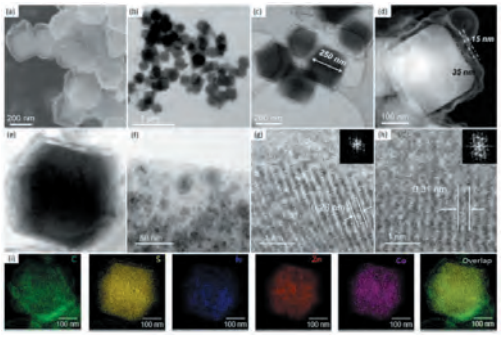
The spin-gapless semiconductors (SGSs) are a new class of zero-gap materials which have fully spin polarized electrons and holes. They bridge the zero-gap materials and the half-metals. The band structures of the SGSs can have two types of energy dispersion: Dirac linear dispersion and parabolic dispersion. The Dirac-type SGSs exhibit fully spin polarized Dirac cones, and offer a platform for massless and fully spin polarized spintronics as well as dissipationless edge states via the quantum anomalous Hall effect. With fascinating spin and charge states, they hold great potential for spintronics. There have been tremendous efforts worldwide to find suitable candidates for SGSs. In particular, there is an increasing interest in searching for Dirac type SGSs. In the past decade, a large number of Dirac or parabolic type SGSs have been predicted by density functional theory, and some parabolic SGSs have been experimentally demonstrated. The SGSs hold great potential for spintronics, electronics, and optoelectronics with high speed and low energy consumption. Here, both the Dirac and the parabolic types of SGSs in different material systems are reviewed and the concepts of the SGS, novel spin and charge states, and the potential applications of SGSs in next-generation spintronic devices are outlined. (Z. J. Yue et al., ***Small*** 16, 1905155 (2020))

Interfacing MXene flakes on fiber fabric as an ultrafast electron transport layer for high performance textile electrodes



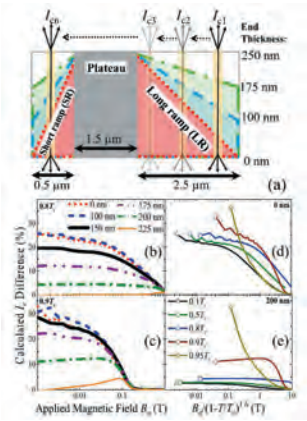
Highly flexible and compliant textile-based electrodes are of considerable interest for the next generation of wearable devices. Engineering interconnected electron transport channels in the insulating textile substrate without any detriment to its intrinsic porous structure, flexibility, and stability generally is a great challenge in developing the high-performance devices. Herein, a strategy to prepare a highly conductive textile by electrostatic self-assembly between positively charged polyester fabric modified with polyethyleneimine (PEI) and negatively charged titanium carbide MXene flakes is presented. The densified, horizontally aligned MXene flakes are painted on the fabric fibers with a low mass loading of 0.8 mg cm^{-2}. They not only form intergral layers of conductive skin, which can be easily charged/discharged at 10 V s^{-1}, but also create numerous active sites for further introducing functional electrochemical materials due to the surface chemistry of the MXene. As a proof-of-concept application, the conductive textile is combined with conformally coated polypyrrole (PPy) and used as a supercapacitor electrode, which has demonstrated large areal capacitance, high rate performance, and outstanding cycling stability without compromising its mechanical endurance. These features suggest the great potential of the as-prepared electrodes and open up a new avenue for the development of a new generation of textile electrode for the smart textile industry. (X. L. Li et al., ***Energy Storage Materials*** 33, 62 (2020))

Electrocatalyzing S cathodes via multisulfiphilic sites for superior room-temperature sodium–sulfur batteries



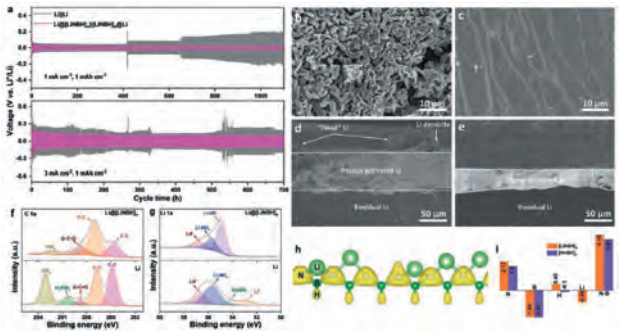
Room-temperature sodium–sulfur (RT-Na/S) batteries hold great promise for sustainable and cost-effective applications. Nevertheless, it remains a great challenge to achieve high capacity and cycling stability due to the low activity of sulfur and the sluggish conversion kinetics between polysulfide intermediates and sodium sulfide. Herein, an electrocatalyzing S cathode is fabricated, which consists of porous core–shell structure and multisulfiphilic sites. The flexible carbon structure effectively buffers volume changes during cycling and provides enclosed spaces to store S_8 with exceptional conductivity. Significantly, the multisulfiphilic sites (ZnS and CoS_2) enhance catalysis toward multistep S conversion, which effectively suppresses long-chain polysulfides dissolution and improves the kinetics of short-chain polysulfides. Thus, the obtained S cathodes achieve an enhanced cycling performance (570 mAh g^{-1} at 0.2 A g^{-1} over 1000 cycles), decent rate capability (250 mAh g^{-1} at 1.0 A g^{-1} over 2000 cycles), and high energy density of 384 Wh kg^{-1} toward practical applications. (H. W. Liu et al., ***ACS Nano*** 14, 7259 (2020))

Guided vortex motion control in superconducting thin films by sawtooth ion surface modification



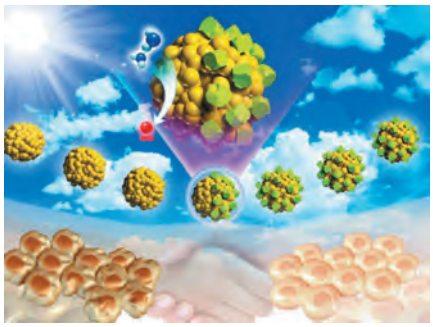
Design of flux profile and guided motion of magnetic flux quanta (also known as vortices) are central issues for functionality of superconducting devices. Anchoring vortex movement by trapping flux lines through the use of defects and preventing vortex entry by shielding magnetic field have been broadly explored, which can also enable reduction of noise for optimal device operation. Removing vortices entirely via the so called ratchet effect (employing an asymmetric energy potential) is another alternative. This ratcheting potential is also used in DNA splitting, particle separation, surface atom electromigration, and electrophoresis. Utilizing a superconductor with the ratchet vortex pinning potential induces a dominant motion direction, which can be used to pump flux out from device functional zones. In this work, a varying thickness superconductor with its tailored intrinsic pinning mechanism has been simulated and proven to provide this preferential vortex motion. We demonstrate both theoretically and experimentally that a varying thickness superconducting ratchet is indeed possible. Furthermore, the sawtooth shape of the bridge provides a tunability to the preferred vortex motion direction, dependent on the ramp gradient and intrinsic pinning strength. (A. Jones et al., ***ACS Applied Materials & Interfaces*** 12, 26170 (2020))

Building artificial solid-electrolyte interphase with uniform intermolecular ionic bonds toward dendrite-free lithium metal anodes



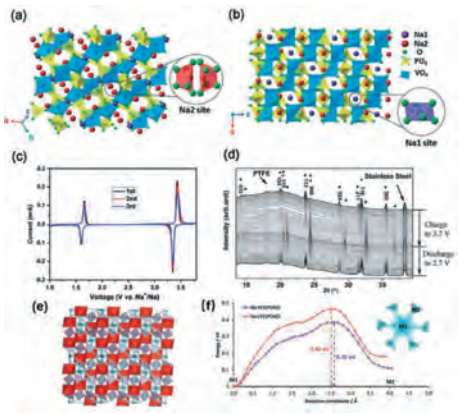
Li metal has been widely regarded as a promising anode for next-generation batteries due to its high theoretical capacity and low electrochemical potential. The unstable solid-electrolyte interphase (SEI) and uncontrollable dendrite growth, however, incur severe safety hazards and hamper the practical application of Li metal anodes. Herein, an advanced artificial SEI layer constructed by $[LiNBH]_n$ chains, which are crosslinked and self-reinforced by their intermolecular Li-N ionic bonds, is designed to comprehensively stabilize Li metal anodes on a molecular level. Benefiting from its polymer-like structure, the $[LiNBH]_n$ layer is flexible and effectively tolerates the volume change of Li metal anodes. In addition, this layer with high polarity in its structure, helps to regulate the homogeneous distribution of the Li+ flux on Li electrodes via the further formation of Li-N bonds. The designed $[LiNBH]_n$ layer is electrically nonconductive but highly ionically conductive, thus facilitating Li^+ diffusion and confining Li deposition beneath the layer. Therefore, under the protection of the $[LiNBH]_n$ layer, the Li metal anodes exhibit stable cycling at a 3 mA cm^{-2} for more than 700 h, and the full cells with high lithium iron phosphate and sulfur cathodes mass loading also present excellent cycling stability. (Z. J. Wang et al., ***Advanced Functional Materials*** 30, 2002414 (2020))

Development of CeO_2 nanodot encrusted TiO_2 nanoparticles with reduced photocatalytic activity and increased biocompatibility towards a human keratinocyte cell line



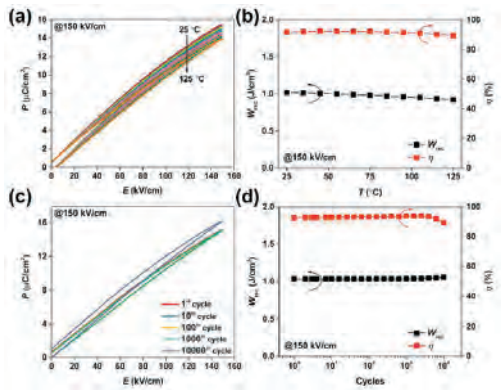
The cytotoxic and genotoxic effects of titanium dioxide (TiO_2) nanoparticles when exposed to ultraviolet (UV) radiation, particularly wavelengths between 320–400 nm, has raised concern over their safe use in health and cosmetic related products such as sunscreens. Cerium dioxide (CeO_2) nanoparticles have been demonstrated to display biocompatible properties and antioxidant activity due to redox cycling of the Ce^{3+}/Ce^{4+} oxidation states. In this work, CeO_2/TiO_2 nanocomposites were prepared through a standard precipitation method at atomic concentrations (at%) of Ce relative to Ti of 2.5, 5 and 10 at%, with the aim of reducing the photocatalytic activity of the core TiO_2 nanoparticles and improve biocompatibility. The UV absorptive properties of the nanocomposite samples revealed excellent absorbance across the UV region as compared to pristine TiO_2 and CeO_2. Furthermore, a drastic reduction in the photocatalysed decomposition of crystal violet, when in the presence of the nanocomposite samples, under both UV and solar simulated light was observed compared to the highly photoactive pristine TiO2. An optimal CeO_2 nanodot loading, displaying both high UV attenuation and low photocatalytic performance was determined at 5 at% and further in vitro biological testing revealed minimal impact on the cell viability of the human keratinocyte cell line (HaCaT) over a 24 h period with and without prior exposure to UV irradiation. In contrast, pristine TiO_2 nanoparticles induced toxicity to HaCaT cells with prior UV exposure before incubation, particularly at a dosage of 100 mg L^{-1}. Our findings demonstrate the effectiveness of CeO_2 nanodots in improving biocompatibility and its potential as a coating material for active inorganic UV filters. (A. Morlando et al., ***Journal of Materials Chemistry B*** 8, 4016 (2020))

Designing advanced vanadium-based materials to achieve electrochemically active multielectron reactions in sodium/potassium-ion batteries



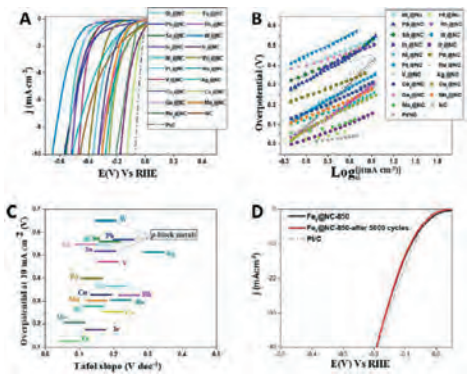
Next-generation sodium-ion batteries (SIBs) and potassium-ion batteries (PIBs) are considered to be promising alternatives to replace current lithium-ion batteries due to the high abundance of sodium and potassium resources. New energetic vanadium-based compounds that undergoes multielectron reactions and demonstrate good sodium/potassium storage capability, provide new solutions for high-performance SIBs/PIBs in terms of high energy/power density and long-time cyclability. So far, desirable rich redox centers (V^{2+}-V^{5+}), consolidated frameworks, and the high theoretical capacities of vanadium-based compounds have been widely explored for practical applications. Rational materials design utilizing vanadium multiredox centers and the fundamental understanding of their charge-transfer processes and mechanisms are critical in the development of high-performance battery systems. The scientific importance and basic design strategies for high performance V-based anode/cathode materials, structure-function properties and state-of-the-art understanding of V-based electrode materials are herein classified and highlighted alongside their design strategies. The important role of the valence electron layer of vanadium, and the scientific advances of vanadium partitions in other electrochemical behaviors are also summarized in detail. Finally, relevant strategies and perspectives discussed in this review provide practical guidance to explore the undiscovered potentials of multi-electron reaction relationships of not only V-based composites, but also other types of electrode materials. (M. Z. Chen et al., ***Advanced Energy Materials*** 10, 2002244 (2020))

Enhanced energy storage performance of sodium niobate-based relaxor dielectrics by a ramp-to-spike sintering profile



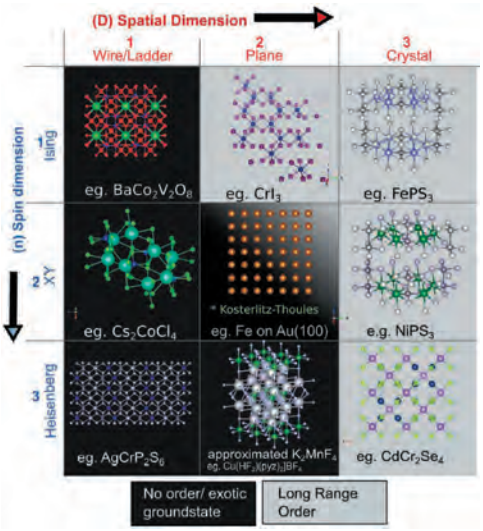
Sodium niobate ($NaNbO_3$)-based lead-free ceramics have been actively studied for energy storage applications because of their antiferroelectric and/or relaxor features achieved in modified systems. The P–E loops of $NaNbO_3$-based ceramics are usually hysteretic because of the existence of a metastable ferroelectric phase at room temperature. In this study, by introducing aliovalent cations and A-site vacancies, the relaxor characteristics are greatly enhanced in $(Na_{1-2x}Bi_x)(Nb_{1-x}Zr_x)O_3$ ceramics, leading to a high energy storage efficiency of above 90%. In addition, sintering aid CuO and a special ramp-to-spike sintering profile were employed to decrease the sintering temperature and reduce the grain size. The modified ceramic exhibits improved insulating properties and hence a higher breakdown strength, leading to a high recoverable energy density of 4.9 J/cm³ and a high energy efficiency of 88% at 430 kV/cm. The ceramic also exhibits satisfactory temperature stability over a wide temperature range from 25 to 125 °C and charge–discharge performance, making it a promising candidate for high-power dielectric energy storage applications. (L. T. Yang et al., ***ACS Applied Materials & Interfaces*** 12, 32834 (2020))

General synthesis of single-atom catalysts for hydrogen evolution reactions and room-temperature Na-S batteries



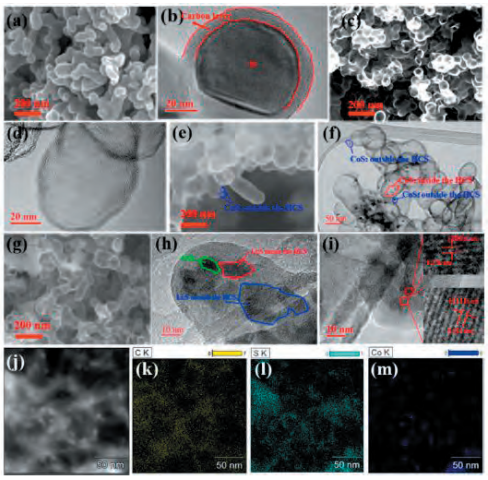
Herein, we report a comprehensive strategy to synthesize a full range of single-atom metals on carbon matrix, including V, Mn, Fe, Co, Ni, Cu, Ge, Mo, Ru, Rh, Pd, Ag, In, Sn, W, Ir, Pt, Pb, and Bi. The extensive applications of various SACs are manifested via their ability to electro-catalyze typical hydrogen evolution reactions (HER) and conversion reactions in novel room-temperature sodium sulfur batteries (RT-Na-S). The enhanced performances for these electrochemical reactions arisen from the ability of different single active atoms on local structures to tune their electronic configuration. Significantly, the electrocatalytic behaviors of diverse SACs, assisted by density functional theory calculations, are systematically revealed by in situ synchrotron X-ray diffraction and in situ transmission electronic microscopy, providing a strategic library for the general synthesis and extensive applications of SACs in energy conversion and storage. (W. H. Lai et al., ***Angewandte Chemie – International Edition*** 59, 22171 (2020))

Two-dimensional magnets: forgotten history and recent progress towards spintronic applications



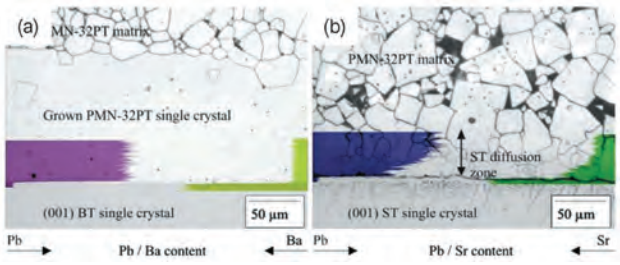
The recent discovery of 2D magnetic order in van der Waals materials has stimulated a renaissance in the field of atomically thin magnets. This has led to promising demonstrations of spintronic functionality such as tunneling magnetoresistance. The frantic pace of this emerging research, however, has also led to some confusion surrounding the underlying phenomena of phase transitions in 2D magnets. In fact, there is a rich history of experimental precedents beginning in the 1960s with quasi-2D bulk magnets and progressing to the 1980s using atomically thin sheets of elemental metals. This review provides a holistic discussion of the current state of knowledge on the three distinct families of low-dimensional magnets: quasi-2D, ultrathin films, and van der Waals crystals. It highlights the unique opportunities presented by the latest implementation in van der Waals materials. By revisiting the fundamental insights from the field of low-dimensional magnetism, this review highlights factors that can be used to enhance material performance. For example, the limits imposed on the critical temperature by the Mermin–Wagner theorem can be escaped in three separate ways: magnetocrystalline anisotropy, long-range interactions, and shape anisotropy. Several recent experimental reports of atomically thin magnets with Curie temperatures above room temperature are highlighted. (D. L. Cortie et al., ***Advanced Functional Materials*** 30, 1901414 (2020))

Nanostructured CoS_2-decorated hollow carbon spheres: A performance booster for Li-ion/sulfur batteries



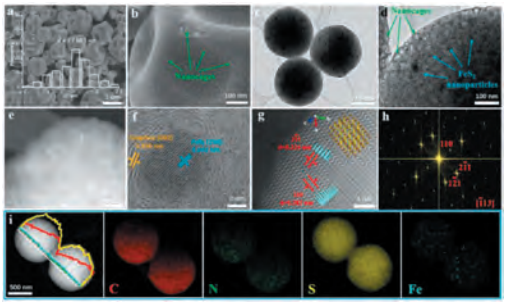
The practical application of Li–S batteries is being obstructed by severe safety concerns due to lithium dendrites. The Li-ion/sulfur batteries, which use Li_2S as the cathode and can be coupled with different anodes (e.g., Si or Sn), can eliminate the safety issues related to lithium metal. To improve the performance of Li_2S cathode for Li-ion/sulfur batteries, CoS_2-decorated hollow carbon spheres (HCS) are first explored as a conductive matrix for the Li_2S cathode. Hollow carbon spheres (HCS) possesses a strong tendency to physically absorb and trap high-order lithium polysulfides, while the CoS_2 can chemically bond with low-order lithium polysulfides. Moreover, CoS_2 has a catalytic effect that can reduce the energy barrier in the first charge. In situ synchrotron Xray diffraction has clarified the catalytic mechanism of CoS_2 toward barrier reduction. CoS_2 can boost the electrochemical reactions from Li_2S to polysulfide and act as a redox mediator, lowering the overpotential of Li_2S in the first charge process, resulting in less electrolyte decomposition, stable cycling performance, and higher capacity. The data show that CoS_2-decorated hollow carbon spheres have a higher initial specific capacity and better capacity retention, with specific capacity of 831 mA h g^{-1} and capacity retention of 79.5% after 100 cycles, which is much better than the performance of hollow carbon spheres (Li_2S–HCS) alone. The full cell core–shell Si@C||Li_2S–HCS/CoS_2 shows a specific capacity of 650 mA h g^{-1} and a capacity retention of 65% after 50 cycles at an average voltage of 1.6 V with low electrolyte to sulfur (E/S) and anode to cathode (A/C) ratio. (J. C. Jiang et al., ***ACS Applied Energy Materials*** 3, 6447 (2020))

Solid-state crystal growth of lead-free ferroelectrics



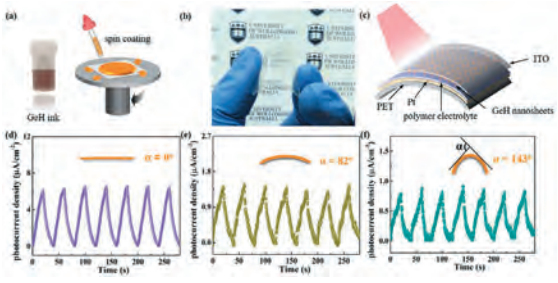
The forecasted restriction of lead containing materials in piezoelectric devices has created vast interest into the development of alternatives, i.e. lead-free systems. Since the discovery of improved properties, ferroelectric ceramics have dominated the commercial market for piezoelectric sensors, actuators and transducers. Relaxor ferroelectric single crystals are considered the premium piezoelectric materials, with high piezoelectric coefficients and low dielectric losses that enable them to be utilised in high-end applications, such as medical imaging ultrasounds. This review features the progress of lead-free single crystals that aim to replicate the remarkable piezoelectric properties that have been achieved in relaxor-$PbTiO_3$ ferroelectric systems. Solid-state crystal growth (SSCG) has become a critical technique in the development of high-quality single crystals for such systems. SSCG is advantaged by its lower growth temperatures than conventional melt and solution growth techniques by producing crystals through a solid phase transformation of a polycrystalline matrix into a single crystal. This allows for higher chemical homogeneity and volatility control, while remaining a cost-effective growth method. The proposed theories of abnormal grain growth, which is the underlying mechanism that facilitates SSCG, will initially be discussed, followed by the challenges that must be controlled for continual high-quality single crystal growth. Given the correct polycrystalline microstructure and other processing parameters, large single crystals can be produced of incongruently melting systems that are unachievable using other techniques. This review provides a comparison of the state of the art of SSCG versus melt and solution growth techniques and concludes with the authors' proposed focused points to inspire further improvements to both single crystal growth and piezoelectric properties. (P. Kabakov et al., ***Journal of Materials Chemistry C*** 8, 7606 (2020))

A High-kinetics sulfur cathode with a highly efficient mechanism for superior room-temperature Na–S batteries



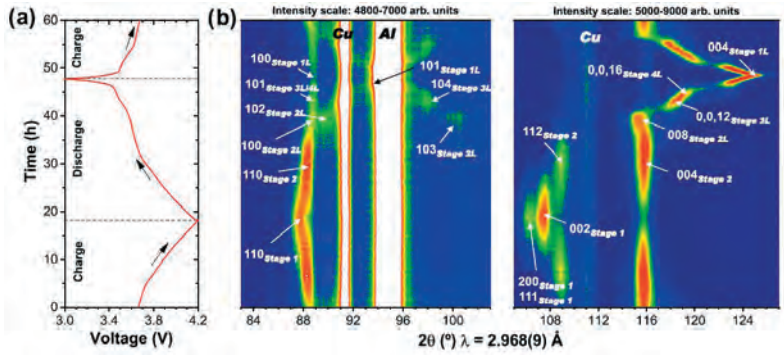
Applications of room-temperature–sodium sulfur (RT-Na/S) batteries are currently impeded by the insulating nature of sulfur, the slow redox kinetics of sulfur with sodium, and the dissolution and migration of sodium polysulfides. Herein, a novel micrometer-sized hierarchical S cathode supported by FeS_2 electrocatalyst, which is grown in situ in well-confined carbon nanocage assemblies, is presented. The hierarchical carbon matrix can provide multiple physical entrapment to polysulfides, and the FeS_2 nanograins exhibit a low Na-ion diffusion barrier, strong binding energy, and high affinity for sodium polysulfides. Their combination makes it an ideal sulfur host to immobilize the polysulfides and achieve reversible conversion of polysulfides toward Na_2S. Importantly, the hierarchical S cathode is suitable for large-scale production via the inexpensive and green spray-drying method. The porous hierarchical S cathode offers a high sulfur content of 65.5 wt%, and can deliver high reversible capacity (524 mAh g^{-1} over 300 cycles at 0.1 A g^{-1}) and outstanding rate capability (395 mAh g^{-1} at 1 A g^{-1} for 850 cycles), holding great promise for both scientific research and real application. (Z. C. Yan et al., ***Advanced Materials*** 32, 1906700 (2020))

Hydrogen terminated germanene for a robust self-powered flexible photoelectrochemical photodetector



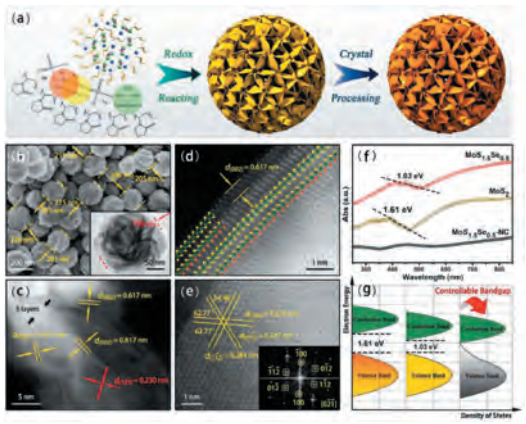
As a rising star in the family of graphene analogues, germanene shows great potential for electronic and optical device applications due to its unique structure and electronic properties. It is revealed that the hydrogen terminated germanene not only maintains a high carrier mobility similar to that of germanene, but also exhibits strong light–matter interaction with a direct band gap, exhibiting great potential for photoelectronics. In this work, few-layer germanane (GeH) nanosheets with controllable thickness are successfully synthesized by a solution-based exfoliation–centrifugation route. Instead of complicated microfabrication techniques, a robust photoelectrochemical (PEC)-type photodetector, which can be extended to flexible device, is developed by simply using the GeH nanosheet film as an active electrode. The device exhibits an outstanding photocurrent density of 2.9 μA cm^{-2} with zero bias potential, excellent responsivity at around 22 μA W^{-1} under illumination with intensity ranging from 60 to 140 mW cm^{-2}, as well as short response time (with rise and decay times, t_r = 0.24 s and t_d = 0.74 s). This efficient strategy for a constructing GeH-based PEC-type photodetector suggests a path to promising high performance, self-powered, flexible photodetectors, and it also paves the way to a practical application of germanene. (N. N. Liu et al., ***Small*** 16, 2000283 (2020))

Phase evolution and intermittent disorder in electrochemically lithiated graphite determined using in operando neutron diffraction



Since their commercialization in 1991, lithium-ion batteries (LIBs) have revolutionized our way of life, with LIB pioneers being awarded the 2019 Nobel Prize in Chemistry. Despite the widespread use of LIBs, many LIB applications are not realized due to performance limitations, determined largely by the ability of electrode materials to reversibly host lithium ions. Overcoming such limitations requires knowledge of the fundamental mechanism for reversible ion intercalation in electrode materials. In this work, the still-debated structure of the most common commercial electrode material, graphite, during electrochemical lithiation is revisited using in operando neutron powder diffraction of a commercial 18650 lithium-ion battery. We extract new structural information and present a comprehensive overview of the phase evolution for lithiated graphite. Charge–discharge asymmetry and structural disorder in the lithiation process are observed, particularly surrounding phase transitions, and the phase evolution is found to be kinetically influenced. Notably, we observe pronounced asymmetry over the composition range 0.5 > x > 0.2, in which the stage 2L phase forms on discharge (delithiation) but not charge (lithiation), likely as a result of the slow formation of the stage 2L phase and the closeness of the stage 2L and stage 2 phase potentials. We reconcile our measurements of this transition with a stage 2L stacking disorder model containing an intergrown stage 2 and 2L phase. We resolve debate surrounding the intercalation mechanism in the stage 3L and stage 4L phase region, observing stage-specific reflections that support a first-order phase transition over the 0.2 > x > 0.04 range, in agreement with minor changes in the slope of the stacking axis length, despite relatively unchanging 00l reflection broadening. Our data support the previously proposed /ABA/ACA/ stacking for the stage 3L phase and an /ABAB/BABA/ stacking sequence of the stage 4L phase alongside experimentally derived atomic parameters. Finally, at low lithium content 0 < x < 0.04, we find an apparently homogeneous modification of the structure during both charge and discharge. Understanding the phase evolution and mechanism of structural response of graphite to lithiation under battery working conditions through in operando measurements may provide the information needed for the development of alternative higher performance electrode materials. (C. Didier et al., ***Chemistry of Materials*** 32, 2518 (2020))

Enhanced potassium ion battery by inducing interlayer anionic ligands in $MoS_{1.5}Se_{0.5}$ nanosheets with exploration of the mechanism



The strategy of inducing interlayer anionic ligands in 2D $MoS_{1.5}Se_{0.5}$ nanosheets is employed to consolidate the interlayer band gap and optimize the electronic structure for the potassium ion battery. It combines complementary advantages from two kinds of anionic ligands with high conductivity and good affinity with potassium ions. The potassium ion diffusion rate is accelerated as well by an optimized lower energy barrier for ion diffusion pathways, with the formation of highly reversible KMo_3Se_3 crystal other than $K_{0.4}MoS_2/K_2MoS_4$, which encounters a much slower electro/ion diffusion rate upon discharging. These advances deliver enhanced potassium storage properties with excellent cycling stability, with retained specific capacity of 531.6 mAh g^{-1} at a current density of 200 mA g^{-1} even after 1000 cycles, and high rate capability with specific capacity of 270.1 mAh g^{-1} at 5 A g^{-1}. The insertion and conversion mechanism are also elucidated by a combination of density functional theory computations and in situ synchrotron measurements. (H. N. Fan et al., ***Advanced Energy Materials*** 10, 1904162 (2020))

Selected Publications

In 2020 ISEM published 9 in Nature group journals, 18 in Advanced Materials, 19 in Advanced Energy Materials, 3 in Energy & Environmental Science, 10 in Energy Storage Materials, and 15 in Angewandte Chemie International Edition. Overall ISEM published 180 articles in journals with impact factor above 10, which constitutes 47.24% of publications.

1. M. M. Al-Qurainy, A. Jones, S. Rubanov, S. A. Fedoseev, I. Rudnev, A. Hamood, and A. V. Pan, "Large artificial ferromagnetic dot arrays for the critical current enhancement in superconducting $YBa_2Cu_3O_{7-delta}$ thin films", ***Superconductor Science & Technology*** **33** (10), 105006 (2020). [IF: 3.219]
2. X. Bo, R. K. Hocking, S. Zhou, Y. B. Li, X. J. Chen, J. C. Zhuang, Y. Du, and C. Zhao, "Capturing the active sites of multimetallic (oxy)hydroxides for the oxygen evolution reaction", ***Energy & Environmental Science*** **13** (11), 4225 (2020). [IF: 38.532]
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10. C. Didier, W. K. Pang, Z. P. Guo, S. Schmid, and V. K. Peterson, "Phase evolution and intermittent disorder in electrochemically lithiated graphite determined using in operando neutron diffraction", ***Chemistry of Materials*** **32** (6), 2518 (2020). [IF: 9.811]
11. W. Y. Duan, Z. S. Ma, and C. Zhang, "Magneto-optical conductivity of a topological nodal ring semimetal in a tilted magnetic field", ***Physical Review B*** **102** (19), 195123 (2020). [IF: 4.306]
12. H. N. Fan, X. Y. Wang, H. B. Yu, Q. F. Gu, S. L. Chen, Z. Liu, X. H. Chen, W. B. Luo, and H. K. Liu, "Enhanced potassium ion battery by inducing interlayer anionic ligands in $MoS_{1.5}Se_{0.5}$ nanosheets with exploration of the mechanism", ***Advanced Energy Materials*** **10** (21), 1904162 (2020). [IF: 29.368]
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Funding 2020

AUSTRALIAN RESEARCH COUNCIL GRANTS

ARC CENTRE OF EXCELLENCE

Chief Investigators	Title	2020 Funding
X. L. Wang via M. Fuhrer et al.	ARC Centre of Excellence in Future Low Energy Electronics Technologies	$219,000
Total		$219,000

ARC DISCOVERY SCHEME GRANTS

Chief Investigators	Title	2020 Funding
J. Z. Wang, K. Konstantinov, W. S. Yang, Q. F. Gu	Development of ambient air operation rechargeable sodium-air batteries	$124,000
Z. X. Cheng, X. L. Wang, W. H. Wang, H. X. Yang, E. Gilbert	Magnetic skyrmion materials for next generation spintronic-based devices	$136,000
Z. P. Guo, J. F. Mao, C. S. Wang	Low cost aqueous rechargeable zinc batteries for grid-scale energy storage	$170,000
S. X. Dou, W. P. Sun, J. Liang, Y. Y. Liu, C. Z. Wu, J. B. Baek	Controlling and understanding interface chemistry for energy conversions	$160,000
Total		$590,000

ARC FUTURE FELLOWSHIPS

Chief Investigators	Title	2020 Funding
W. K. Pang	High-voltage electrode materials for lithium-ion batteries	$82,000
Y. Du	Functional two-dimensional materials for photocatalysis	$219,000
Total		$301,000

ARC DECRA FELLOWSHIPS

Chief Investigators	Title	2020 Funding
D. Cortie	Engineering magnetism at the atomic scale in topological insulators	$118,000
F. Li	High performance lead-free piezoelectrics based on polar nanoregions	$120,000
W. J. Li	Long life sodium ion batteries by optimising initial coulombic efficiency	$118,000
T. F. Zhou	Interphases and interfaces of nanomaterials in potassium-ion batteries	$128,000
Z. Li	Engineering of exotic electronic properties in atomically thin antimony	$120,000
Y. Lu	Nanostructures derived from metal-organic frameworks for sodium-ion batteries	$136,000
H. Ye	Stable lithium-sodium metal anodes for rechargeable alkali metal batteries	$133,000
N. N. Wang	Economical electrode materials for safe sodium ion batteries	$138,000
Total		$1,011,000

ARC LINKAGE PROJECTS		
Chief Investigators	Title	2020 Funding
S. X. Dou, X. Xu, Y. Du, W. P. Sun, K. W. See, J. Zheng	Liquid metal for quench detection sensors and low resistance joints	$140,000
Total		$140,000
2020 Australian Research Council Grants Total:		$2,261,000

ARENA PROJECT		
Chief Investigators	Title	2020 Funding
S. X. Dou, H. K. Liu, S. L. Chou, K. W. See	The Smart Sodium Storage Solution (S^4) Project	$584,000
2020 ARENA Project Total:		$584,000

OTHER GRANTS AND COMMERCIAL INCOME		
Chief Investigators	Title	2020 Funding
Yi Du et al., UGPN	2D Quantum materials for clean energy harvesting	$14,000
Other Grants		$788,000
Total		$802,000
UOW support	UOW support for baseline and student allocation funding	$357,000
Total Funding 2020		$4,004,000

ISEM Graduates 2020

Yaping Chen
"Design of two-dimensional material-based electrocatalysts via hetero-interface engineering"

Ningyan Cheng
"Application of organic-inorganic hybrids and their derivatives in energy conversion and storage"

Haining Fan
"Original 2D transition metal selenides/borides devoting to enhanced energy conversion and storage"

Nai-Sheng Hsu
"Application of In-based oxide nanoparticles for cancer therapy: towards the development of highly selective nano-ceramic theranostic agents"

Junnan Ha
"Developing high-performance aqueous Zn-based batteries with mild electrolyte"

Xi Kong
"High energy storage performances for bismuth-containing lead free dielectrics with relaxor characteristics"

Mengmeng Lao
"Manipulating interfacial chemistry of heterostructured electrocatalysts for alkaline hydrogen evolution reaction"

Jaewoo Lee
"Development of advanced anode materials for next generation lithium batteries"

Xiu Li
"Advanced anode materials for sodium ion batteries"

Yang Li
"Advanced atomic-level material for electrocatalysis"

Yun Lu
"Giant ME effect in the ME composite and its applications in sensing and energy harvesting"

Freddy Marpaung
"Synthesis of nanoporous carbon derived from hybrid metal organic frameworks for symmetric supercapacitor"

Alexander Morlando
"Next generation inorganic nanomaterials for sunscreening applications"

Rafid Mueen
"Advanced nano ceramic sunscreen UV filters for melanoma protection"

Nana Wang
"Exploring advanced electrode materials for sodium-ion batteries"

Wanlin Wang
"Investigation on iron-based Prussian blue cathode materials for sodium-ion batteries"

Liang Wang
"Development and exploration of novel photocatalysts by using STM"

Zichao Yan
"Investigations on novel cathode materials for sodium-based storage system"

Letao Yang
"Environmentally friendly bismuth-based relaxor and antiferroelectric ceramics for energy storage applications"

Xiaobo Zheng
"Ultrathin lithium cobalt oxide based electrocatalysts for water splitting"

Shilin Zhang
"Structural and defects engineering of the anode materials for enhanced lithium/potassium storage "

Qian Zhou
"Ultrathin two-dimensional nanomaterials as electrocatalysts for water splitting"

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