QUANTUM AND ADVANCED TECHNOLOGIES TALENT BUILDING PROGRAM

About the University of Southern Queensland (UniSQ)
UniSQ aims to foster Queensland's quantum and advanced technologies industry development and technology start-ups, through relevant workforce education training and career pathway guidance as part of a "Team Queensland" approach coordinated with other universities in the state.

Research capabilities
UniSQ's key strengths in Agriculture and Environment, Health, Space & Defence, and Regional Development provide multiple opportunities for PhD research projects in quantum and advanced technologies that complement those of Queensland's other universities, and as a regional university is well placed to benefit regional Queensland. I also note the inclusion of four UniSQ female researchers in our proposed supervisory teams to help foster PhD studies by female and non-binary people.

Justification for the requested UniSQ scholarship package
UniSQ requests support for the PhD projects detailed in succeeding pages of this document to demonstrate a strategic approach with evidence of multiple lines of research benefiting from support. Our request aligns with the stated program objectives as follows:

- With four different demonstrably female researchers in multiple research fields, the inclusion of two regional university campuses, and a focus on PhD studies by female or non-binary people we *"contribute to and strengthen participation of students in quantum and advanced technologies, particularly those who identify as women, are non-binary, are of Aboriginal and Torres Strait Islander descent, or are from regional areas"*. Our female staff supervisors include: Dr Lei Chen, a postdoctoral Research Fellow and expert in thermoelectric materials, phonons and neutron scattering, and working with Associate Professor Min Hong in the UniSQ Centre for Future Materials; Dr Carole Haeusler, a Chief Investigator on a recently awarded ARC grant in science education; Dr Louise Puslednik, who along with Dr Carole Haeusler, included in a recent successful $18M bid for a new *Australian Centre for Quantum Growth*; and Dr Belinda Nicholson, UniSQ PhD graduate, former Oxford university postdoc and current Women in STEMM postdoctoral Research Fellow in the Centre for Astrophysics, and one of the UniSQ team about to start work on a new iLAuNCH funded $6M+ industry collaboration project to translate astronomical science and technology into novel space camera technology for remote sensing and space-based astronomy applications.

- The list of supervisors presented in this request included multiple UniSQ researchers whose research track record demonstrates both high-level success and relevance to the objective to *"train a new generation of PhD students into excellent quantum researchers capable of being pioneers in this emerging discipline".* In addition to our female researchers, we thus note the inclusion of young and upcoming researchers – Associate Professor Toan Dinh (and his team), Associate Professor Min Hong (and his collaborators), newly arrived quantum researcher Professor Robert Sang (ex-Griffith University and the new Head of the UniSQ School, Maths, Physics and Computing). We have also formed a new industry collaboration with Analog Quantum Circuits (Prof Tom Stace and Assoc Prof Arkady Fedorov). It is also noted that Associate Professor Duncan Wright (whose technical skills delivered Australia's leading exoplanet survey work at Mt Kent Observatory, and who now leads UniSQ's space camera project) is included, alongside Prof Brad Carter, UniSQ's Dean of Research Infrastructure.

- The proposed supervisory teams and their current laboratory facilities and research success (notably Toan Dinh, Min Hong, Duncan Wright, and now Robert Sang) are

evidence that PhD support will help *“build technology capability and skills across a range of fields”*.

- The PhD projects will all emphasise industry or academic collaboration to *“improve translation and commercialisation skills”* and *“foster collaboration across academia and industry.”*

PhD Project #1

Developing high-performance compound semiconductor nanosensors at low temperatures

Supervisors: Toan Dinh, John Bell UniSQ Centre for Future Materials (plus collaborators Dzung Dao, Nam-Trung Nguyen from Griffith University)

Research area: ***Compound semi-conductors*** *Award sought: Quantum and advanced technologies global talent attraction PhD stipend for international students that identify as women or non-binary.*

Abstract: Compound semiconductor nanosensors represent a significant advancement in quantum and advanced technologies, offering various advanced features over traditional sensors based on metals and silicon. However, development of these sensors faces great challenges such as low sensitivity and poor stability which do not meet the practical requirements. This project will develop a new compound silicon-carbon nanoheterojunction technology that offers ultrahigh sensitivity and stability using low temperature conditions (mK). The control of low temperature will result in electric transport enhancement owing to the reduction of scattering effect, lower thermal noise, and enhanced mobility. The outcome of the project will enhance understanding of underlying physics of charge transport through the silicon carbide heterojunction at low temperatures, opening up new pathways for developing new compound semiconductor nanosensors at low temperatures.

Justification for the requested scholarship and at UniSQ

Research capabilities: UniSQ has state-of-the-art engineering laboratories and research facilities dedicated to microelectromechanical system (MEMS) and semiconductor sensor technologies, including Semiconductor Device Parameter Analyser, precise temperature controller, precise pressure controllers, etc. We have ongoing research projects funded by Australian Research Council (e.g. ARC DP 22 CI Toan Dinh, ARC DP 24 CI Toan Dinh and CI John Bell) focusing on the development and application of MEMS and compound semiconductor sensors in various industries, including healthcare, environmental monitoring, and space exploration. We also have ongoing collaboration with leading institutions such as NASA JPL on development of sensors.

Experts in compound semiconductors and MEMS: UniSQ comprises leading experts in the fields of MEMS and semiconductor sensors, including Prof John Bell (material expert) and A/Prof Toan Dinh who have been recognised with various national awards such as Top 40 Rising Star researcher in Condense Matter Physics and Semiconductors, 2020 by the Australian. We have a robust publication record, with over 100 of peer-reviewed journal articles from Prof John Bell and A/Prof Toan Dinh's group and conference papers. We have published many papers in high-impact journals related to MEMS and compound semiconductor sensor technologies.

Talent attraction and success: UniSQ consistently attracts high-caliber students to our engineering programs. For example, A/Prof Toan Dinh's group include 5 PhD researchers working in compound semiconductors and MEMS sensors with two talented female PhD students. These students have have been well trained with MEMS technologies. We trained a postdoc researcher who drives impactful research outcomes and joint industry work forces.

PhD Project #2

Advanced Quantum Thermal Technology

Supervisors: Min Hong, Lei Chen, UniSQ Centre for Future Materials

Research area: ***Quantum*** *Award sought: Quantum and advanced technologies global talent attraction PhD stipend for international students that identify as women or non-binary.*

Abstract. The quantum electronic states have been intensively investigated by groups from worldwide and have made significant contributions to high-efficiency low-energy electronic techniques. Meanwhile, novel topological quasi particles related quantum thermal transport measurement in various physical environments have gained increasing attention recently. However, measuring high-accuracy (mK level) thermal transport of the topological fermions under extreme physical conditions is much more challenging than detecting electric signals. In this context, this PhD project aims finding new topological quasiparticles in quantum materials with strong correlation such as $La_3Ni_2O_7$, $TbTi_6Sn_6$, YbOCl etc, and demonstrate their contributions to thermal transport properties. In this project, 1) high-quality quantum material single crystals will be fabricated for thermal transport study; 2) topological quasiparticle states in these single crystals will be mapped using inelastic neutron scattering technique; 3) the thermal Hall effect related to these topological quasiparticles will be studied, to present a comprehensive picture of quantum thermal effect. The outcome of this project will facilitate the new quantum states, e.g., Majorana modes, from laboratory research to real applications like fault-tolerant quantum computation, as well as contributing to the development of quantum technology in Queensland.

Justification for the requested scholarship and at UniSQ

Research capabilities. The UniSQ Strategic Research Fund recently allocated $5M to extend advanced materials research, which is strongly aligned with this project. Facilities related to the proposed project are available at UniSQ, e.g. thermoelectric materials synthesis, characterization and properties measurement equipment. Calculation resources of high-performance computing clusters, including Gadi at NCI, Fawkes at UniSQ, and Bunya at UQ, for high throughput calculations and simulations will be available for our PhD students. Besides, the research group, led by A/Prof Min Hong has on-going research grants to support the research activities, including Australian Research Council (ARC) Future Fellowship, ARC Discovery Project, ARC Research Hub and Trailblazer Universities Program. Close collaborations have been built with FLEET (Centre for Future Low Energy Electronic Technology), Monash University and Australian Nuclear Science and Technology Organization (ANSTO), which will introduce nanofabrication and neutron scattering resources to this PhD project. This PhD student will be well trained in physical principles of phonon quantum technology, high-accuracy thermal and electronic transport experimental skills as well as micro-sized quantum devices fabrications, making them impactful in both research fields and industrial applications.

Expertise of the supervisors. The group leader A/Prof. Min Hong is an ARC Future Fellow (level 2) at UniSQ. His research focuses on thermoelectric technology and physical principles of transport properties. He is awarded the 2024 Queensland Yong Tall Poppy Science Awards. He has been the Top 2% of Highly Cited Researchers worldwide since 2019 by Elsevier. His research has led to over 100 high-impact journal articles and three book chapters. His publications have attracted > 7100 citations with an H-index of 42 (Google Scholar). His research outcomes are predominantly published in top-tier international journals (over 85% in top 10% journals and over 70 papers in journals with IF > 10), including one in Joule (2023 IF = 38.6), two in Energy & Environmental Science (IF = 32.4), six in Advanced Materials (IF = 27.4), two in Journal of the American Chemical Society (IF = 14.4), one in Accounts of Chemical Research (IF = 16.4), three in ACS Nano (IF = 15.8), etc.

Dr Lei Chen is a research fellow in Min's group. Her research focused on thermoelectric materials, phonon transports and topological materials. Lei is experienced in high-quality quantum single crystals growth, electronic and thermal quantum states measurements under extreme conditions such as low temperature and high magnetic fields. She has close collaboration with ANSTO by using their neutron scattering facilities investigating phonon dynamics of thermoelectric materials. Lei has published a series of high-impact peer-review papers, covering research fields of Physics and materials science, e.g. Nanoscale, Physical Review B, Physical Review Materials, ACS Applied Materials & Interfaces, etc.

Success in HDR Education. At UniSQ, A/Prof. Min Hong has co-supervised two PhD students to completion. Their research has led to many Q1 publications. One PhD student won the Award for Excellence in Doctoral Research. Currently, the research group has one PhD student (co-supervised by Dr. Lei Chen) and three international PhD students are confirmed to enrol in the late 2024. A/Prof. Hong is also co-supervising one PhD student and two master students at UQ. In addition, his research was extended into seven PhD projects. He was actively involved in these PhD projects by providing advice to conceive projects, designing experiments, collecting data, and drafting manuscripts. Specifically, he obtained preliminary results in SnSe and SnTe thermoelectric materials, which were then developed into four PhD projects. His research on GeTe-based materials became another two PhD projects. Meanwhile, he has led one PhD student to conduct new research related to flexible thermoelectric materials.

PhD Project #3

Advanced Cryogenic Measurement for Quantum Device Development

Supervisory team: Tom Stace, Arkady Fedorov (Analog Quantum Circuits and to be appointed as UniSQ Springfield adjunct staff), Robert Sang (UniSQ School of Maths, Physics and Computing) and Brad Carter (UniSQ Institute for Advanced Engineering and Space Sciences.

Research area: ***Quantum*** *Award sought: Quantum and advanced technologies global talent attraction PhD stipend for international students that identify as women or non-binary. It is noted that this project is dependent on success with a forthcoming QCIP grant application and if the QCIP application is unsuccessful the project will be reframed accordingly.*

Abstract: Subject to a companion Quantum and Advanced Technologies Commercialisation Infrastructure Program **(**QCIP) funding student will work on collaborative research between UniSQ and Analog Quantum Circuits on commissioning and use of a dedicated new cryogenic laboratory that provides capability for cryogenic characterisation and measurement of an extensive range of solid-state quantum devices, including microwave components and superconducting qubits. The facility will initially consist of two dilution refrigerators and several measurement racks, which can be shared between the refrigerators and used for specific types of measurements.

Justification for the requested scholarship and at UniSQ

Research capabilities: UniSQ will appoint one PhD student to work with Professors Brad Carter and Robert Sang to work with Analog Quantum Circuits (AQC), Queensland's first quantum technology startup, and utilise UniSQ's modern laboratory laboratory facilities and infrastructure to host the new equipment and provide access to others seeking to use the new facilities. AQC develops microwave control hardware for superconducting quantum computing platforms, and, subject to mutually agreeable IP management, this student will work with AQC personnel on industry-relevant problems.

PhD Project #4

Developing an educational model to engage diverse high school students in authentic research mentor projects within the field of quantum technologies and with quantum scientists

Supervisors: Dr Louise Puslednik, Dr Carole Haeusler (UniSQ School of Education), Prof. Tom Stace (Analog Quantum Circuits), Prof. Robert Sang (UniSQ School of Maths, Physics and Computing)

Research area: ***Quantum + education*** *Award sought: Quantum and advanced technologies global talent attraction PhD stipend for international students that identify as women or non-binary. Note: This project also fits within the category of "Cross-disciplinary PhD collaboration incentive award supports PhD students studying in a non-quantum field whose project could benefit from collaboration with research or industry partners in quantum or advanced technologies". However, a full scholarship is sought to provide certainty of PhD scholarship support.*

Abstract: STEM skills play a crucial role in supporting innovation and the Australian economy, and the recent rapid growth of the quantum industries in Queensland requires a STEM-skilled workforce. However, Queensland has shown a continual decline in science performance at the high school level over the last 15 years, with regional students showing significant gaps in disciplines fundamental to quantum science. Therefore, there is a need to develop educational STEM and quantum programs to address this decline to as well as bridge the regional STEM gap. Any STEM programme aimed at providing authentic intellectual and academic growth for students' needs to ensure students have access to experts within the field to maximise student engagement. Role modelling and mentoring has been identified as crucial factors in developing STEM students' academic sense of belonging as well as their social and emotional skills needed to work in the quantum industry. This research project will draw on the needs of diverse learners and academic literature to develop an educational model whereby diverse high school students engage in an authentic research science program with the support of quantum scientists as mentors. This educational model will then be implemented in three diverse Queensland schools over two years. This multi-method study will utilise both quantitative and qualitative data to determine the impact of the program on students learning in STEM and quantum fields, as well as provide an assessment of students' growth in their social and emotional skills that are critical to the quantum industry.

PhD Project #5

Creating atom sensors to date ground water

Supervisory team: Prof. Robert Sang (UniSQ School of Maths, Physics and Computing) and collaborators

Research area: ***Photonics*** *Award sought: Quantum and advanced technologies global talent attraction PhD stipend for international students that identify as women or non-binary.*

Abstract: The proposed research is based around a state-of-the-art laser system, the Australian Attosecond Science Facility (AASF). This laser system is unique in Australia and one of only a few around the world. The light pulses generated by this laser are highly amplified and are only a few cycles of the optical field. The laser also has the capability of controlling of the waveform of the electric field of the light pulses. The research in this PhD project is concerned with the study of the interaction of such engineered light pulses with atomic systems. Such interactions with atoms can induce a great variety of process such as the generation of soft x-rays bursts in a process called high harmonic generation (HHG). These bursts of light can be further isolated to generate light pulses of approximately 100 attoseconds (10-18 sec) duration. The attosecond light pulses can be utilised to investigate electronic dynamics in atoms and molecules on a timescale that has only become available since the application of lasers such as the AASF. Other interactions are also possible such as the

ionisation of the target (atom, molecule or solid target). These processes are investigated at the AASF.

The proposed research project is funded through a recently funded Australian Research Council Discovery Project Grant to extend an investigation to create excited atoms in metastable states (atoms in long-lived excited quantum states) through the interaction of these ultra-short and highly intense light pulses using a process call frustrated tunnel ionisation. CI Sang is a world expert in the experimental investigation of this fundamental quantum process. The interest in the optical excitation of atoms in metastable states is their application to radiometric dating of ground water using isotopes of argon and krypton. The concentration of the isotopes of these species of atoms facilitates a broad range of dating of the water from 50 years to 300,000 years. Due to the small fraction of these atoms being present in water, the only way that this dating can be achieved is through optical trapping techniques called Atom Trap Trace Analysis. There are only 4 such devices in the world that can undertake this analysis one of which is at the University of Adelaide. This project facilitates a collaboration between, UniSQ, Griffith University, University of Adelaide and the CSIRO with the goal of this PhD project to establish new high throughput excitation techniques using lasers for the application of ATTA.

PhD Project #6

A systematic approach to investing in commercial universal gate-based quantum computing

Supervisory team: Francis Gacenga, Brad Carter (UniSQ Springfield) and collaborators

Research area: ***Quantum computing + information systems*** *Award sought: Quantum and advanced technologies global talent attraction PhD stipend for international students that identify as women or non-binary.*

Abstract: This multidisciplinary research project will design a framework for guiding systematic investment in commercial universal gate-based quantum computing use cases. The project will identify investment approaches used by investors, technology providers and end-users of quantum computing information systems. Australia's National Quantum Strategy identifies investment, development, and use of quantum computing as a national priority contributing to future economics, jobs, business, industry, and national security. This project addresses the current gap in the commercialisation of quantum computing by systematically studying the strategies for successful investment in current term quantum computing information systems.

Expected Research Contribution

This project focuses on the commercialisation of quantum computing information systems which is one of three categories of technologies on Australia's National Quantum Strategy published in May 2023. The project is situated in the theme on thriving research and development, investment in and use of quantum technologies and the strategic approach of creating the environment for businesses to harness emerging technologies. This project aligns with Queensland's quantum strategy whose vision is to harness Queensland's expertise in quantum technologies for accelerated economic growth and transformative solutions and contributing to the strategy pillar of growing the quantum and advanced technologies commercialisation pipeline and the related pillar of attracting external investment into the Queensland quantum ecosystem.

PhD Project #7

Quantum meets Space

Supervisory team: Belinda Nicholson, Brad Carter, Duncan Wright (UniSQ) and collaborators

Research area: ***Photonics + space*** *Award sought: Quantum and advanced technologies global talent attraction PhD stipend for international students that identify as women or non-binary.*

Abstract: This multidisciplinary research project will explore the translation of developments in astronomical light collection technology (astrophotonics) based on quantum physics into space photonics technology for high optical performance, compact, lightweight space photonics with strong commercial potential as well as scientific applications.