Annual Report

QinetiQ Ltd
The University of Exeter
EP/R004781/1: The Tailored Electromagnetic and Acoustic Materials Accelerator (TEAM-A)

Summary: This five-year Prosperity Partnership programme continues to build upon the successful relationship that exists between the University of Exeter and QinetiQ. TEAM-A is developing advanced materials that can be used to control and manipulate the propagation of electromagnetic and acoustic energy in a highly tailored, bespoke fashion, and focuses to develop innovative techniques for their cost-effective manufacture, thereby working to bolster academia and the technology sector within the South-West of England. The outcome of TEAM-A is a sustainable, long term partnership, underpinned by revenue created through the licensing of intellectual property, the development of products and the advancement of academic understanding.

Introduction and Background: Materials that have the ability to fully control and manipulate the flow of electromagnetic (e.g. radiated heat, light, radiowaves) and acoustic (e.g. sound, vibration, shock) energy have the potential to transform, and enable, a large and diverse range of technologies. Exeter and QinetiQ have long been at the forefront of the science and engineering of such materials. However, there are still significant challenges prohibiting the widespread take up of these new materials in applications. In particular, concepts developed in the laboratory are often incompatible with commercial manufacture, due to their complexity and the nature of the constituent parts. Instead, the basic science that describes the behaviour of these new materials needs to be combined with a detailed understanding of how such materials could be manufactured, so that new materials can be designed and engineered to tackle specific technological challenges, using commercially viable approaches. The objectives of this Partnership are to bring together leading advanced materials and manufacturing research at Exeter and QinetiQ to address real technology and innovation challenges, to share and disseminate new knowledge and to inspire the next generation of future research and industry leaders. Through the exchange of expert academic and industry leading staff, the shared use of facilities, QinetiQ's unique knowledge of industry challenges and an emphasis on the training of a new generation of entrepreneurial researchers, we work across conventional discipline and institutional boundaries to accelerate the impact of academic research.

Programme achievements: Over this past year (2018/19), all Post-doctoral Research Fellows (PDRFs) have been recruited, and work in all research projects is now underway. Some highlights from this year include:

Advancement of academic understanding and technology development:

Tunable Radio-Frequency Devices: We have developed new photomodulators that are orders of magnitude more efficient than those currently described in the literature, enabling the transmission of electromagnetic radiation to be modulated by >90%, via photoexcitation intensities 500 times less than strong daylight. This was achieved by fabricating silicon wafers with surface treatments that prevent recombination of any photoexcited charge carriers at the surface, resulting in a much higher change in the conductivity of the silicon for a given optical illumination intensity, with corresponding reductions in the transmission of millimetre waves (mmW) through the wafers. This approach will allow us to realise fast modulators, patterned at or below wavelength-scale - we will have produced amplitude spatial light modulators (SLMs) for RF and millimetre waves. These can modify beam patterns (e.g. for dynamic beam steering) on fast timescales. ***This could have profound implications in communications and imaging technologies*** and these efficient SLMs for manipulating RF and mmW radiation will represent ***a new class of tools for manipulating radiation in these technologically important frequency bands***. This work also underpinned a successful grant application to EPSRC (EP/S036466/1), between the Universities of Exeter and Warwick, with QinetiQ as a project partner.

THz Technology: A working prototype of a near-field imaging system suitable for cancer margin detection and improved security screening is being created and trialed. ***Presently a subject of a patent application***, the near-field imaging system is hoped to ***reduce the need for multiple surgeries to remove breast tumours***, as it will allow for fast and precise measurement of healthy tissue margins around tumours. In addition, were it to be implemented in general public areas, it could speed up the process of checking for concealed dangerous objects, and ***improve the UK's ability to detect non-metal hazardous objects*** (ceramic blades, plastic explosives, etc.), thus increasing the safety of the general public. Designing more efficient photomodulators has allowed the use of much lower optical powers for the photomodulation, which in turn leads to the ability to design imaging systems that are cheaper, more compact, more portable, and easier to use than those with lasers.

Multispectral imaging using phase-change metasurfaces: A new approach to multispectral imaging is under development, combining the extraordinary optical transmission (EOT) effect and chalcogenide phase-change materials to deliver dynamically tuneable image capture in the mid and long-wave infrared. Long-term, new IR camera systems could be developed to produce multiple images almost simultaneously over the 3-5 or

8-12 micron wavebands. TEAM-A's goal is to demonstrate the basic science/technical developments needed to underpin such a long-term impact. The basic fixed-wavelength EOT filters mentioned above are not a specified deliverable per se, but reliable and repeatable lithographic production processes have been a significant milestone achievement for the first year. Multispectral imaging finds applications in a host of important fields, from security and defense to environmental monitoring, agriculture, remote sensing, medical diagnostics and more. Current systems are limited in speed and resolution – the approach being followed by us (TEAM-A) has the potential to sidestep these limitations, ***making multispectral imaging faster, cheaper and more effective***.

Entrepreneurial Researcher Development:

In addition to TEAM-A's technology and research progress outputs, outcomes and anticipated long term impacts, this past annum our PDRFs, PhD students and first summer internship have benefitted from a range of career-development activities, enhancing their talent and longer-term employment prospects. This is part of our aim to create a new generation of entrepreneurial researchers who will help to drive innovation in academia and industry. For example, our postdoctoral researchers have received training on QinetiQ's UK unique equipment facilities, intellectual property, the multiphysics software COMSOL, article writing, and communication and media skills courses. They have also participated in QinetiQ-led ideas workshops.

New Collaborations:

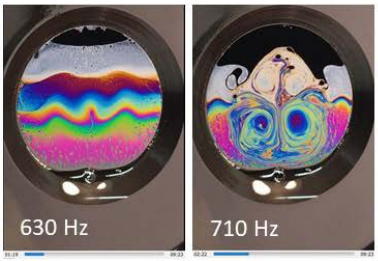
PepsiCo (John Bows): In a new fully-funded project, we are helping PepsiCo to solve technical challenges related to food manufacturing. Through collaboration, we are getting clear insight into their technical and business aims, enabling us to develop collaborative strategies and solutions. Further, by combining equipment and expertise held by both the University and QinetiQ – some of which is unique in the UK - we are developing and testing concepts that could give PepsiCo real advantages in their marketplace. For example, novel measurements of dielectric foodstuffs could improve the microwave radiation methods used for par-drying and food heating. John Bows has extensive experience in food manufacturing, allowing our collaborative work to reach a wider range of potential collaborators. Scientific publications are in preparation.

University of Warwick (John Murphy & Nicholas Grant): Prof. Murphy and Dr. Grant have undertaken specialized surface treatments for us, leading to further publications and supporting the successful EPSRC grant

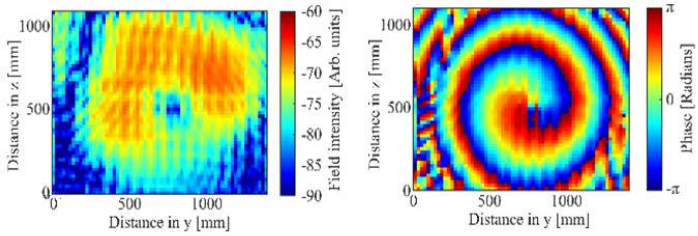
proposal mentioned above. This collaboration will continue to develop the next generation of photomodulators, using their knowledge of semiconductor charge carrier dynamics (as per solar cells) in all our THz imaging systems. More efficient modulators are allowing us to overcome the need for high intensity laser sources so that we can create smaller, cheaper, faster THz imaging systems that can be easily implemented outside the lab.

University of Exeter (Nick Stone): Professor of biomedical imaging at the University of Exeter, Prof. Stone is involved in a biomedical THz imaging project which has spun out of TEAM-A. Prof. Stone is lending his expertise on imaging cancer margins and his contacts at the Royal Devon and Exeter Hospital. With his guidance and a joint spin-out PhD studentship we are building a THz imaging system to determine the thickness of a layer of healthy fat tissue around a surgically removed breast tumour – a parameter of great importance in reducing the local recurrence of cancer.

Technical Composite Systems Ltd (Mike Sloan): We have engaged with TCS Ltd, a South-West-based SME that specializes in the design and manufacture bespoke composite components. We are now supporting TCS in the development of two new concepts, one that will lead to a new project in April 2020, and the other, the exploration of a TEAM-A concept for a metamaterial-based radome.



Soap films driven by an acoustic source at different frequencies. Part of research into novel acoustic absorbers.



The magnitude (left) and phase (right) of radio-frequency orbital angular momentum studies, in collaboration with Prof Tim Drysdale of the University of Edinburgh.

Staff Highlights:

There have been a number of staff successes, including:

1. Two new externally funded postdoctoral research fellow positions have been created, and will be filled in the coming weeks. One new position for a PhD student in collaboration with Prof. Nick Stone (Exeter) has been filled, with the student starting work in the New Year.
2. TEAM-A PDRF, Dr Alexander May was elected a full member of the Institute of Mathematics and Its Applications (IMA) during the period 2018/2019, as well as working with a mentor from the Institute of Engineering and Technology (IET) to obtain Chartered Engineer status.