PhD PROJECT PROPOSAL

PhD Project Title

Terahertz near-field polarimetry and imaging

PhD Supervisory Team

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Project Abstract

With the aim of realising fast polarisation-resolved subdiffraction imaging for material science (incl. topological insulator nanoparticles), this PhD research programme will look at combining spintronic THz emitters and single-pixel imaging. The PhD student will carry out specifically the following tasks: design, modelling, implementation, and calibration of the THz near-field imaging system along with developing the suitable image-processing algorithm. The last phase of the project will involve automation of the image acquisition (hardware and software).

How does the project utilise topology or topological design?

The physical mechanism of the THz radiation of spintronic emitters is based on the inverse spin Hall effect that originates from the topology of the Bloch bands in momentum space. This effect appears in THz spintronic emitters because of the multilayer heterostructure that consist of ferromagnetic and nonmagnetic layers. Interesting, using topological insulators with large spin Hall angle like BiSe can promote large spin injection efficiency, and therefore, higher THz signal. The microscopy system will enable characterisation of topological insulator nanoparticles.

Detailed Project Description

Research background, intended outcomes and methodology;

Topology is now seen as enabling framework for understanding exotic forms of matter, some of which could be used for quantum computation. In recognition of this, the Nobel Prize for physics in 2016 was awarded for the theory of topological matter that was developed at the University of Birmingham in the 1970s.

Topological insulators are materials with very unusual electrical conductivity behaviour. These materials are poor conductors of electricity in their interior but support the flow of electrons on their surface due to quantum effects. In general, electrons spin in random directions because of external effects such as collisions, but in topological insulators, the quantum spin of surface electrons is aligned with their direction of motion. In addition, the flow of electrons is robust even to surface defects. All these features make the surface electrons ideal for carrying and encoding information securely. However, what if the topological insulator is a nanoparticle? A theoretical work (Nature Communications 7, 12375

(2016)) showed that in this nanoparticle scenario, not only do the topologically protected properties hold, but there is also the emergence of a new state coined surface topological particle mode that could be observed in the terahertz frequency range (i.e. 0.1 to 10 THz) even at room temperature. In fact, we reported evidences of such new state in 2020 using FTIR spectroscopy (Nanoscale 12, 22817 (2020)), but the results were not completely conclusive.

To probe the unique features of topological insulators and 2D semiconductor materials, a THz microscopy system would be ideal. Unfortunately, THz microscopy is not nearly as developed as optical microscopy or even the neighbouring microwave and infrared microscopies (Adv. Opt. Photon. 10, 843 (2018)), let alone if selective probing of electric and magnetic properties is required. THz microscopy has been hampered by the traditional lack of compact efficient room-temperature sources and detectors (both single and in array form). Although these obstacles have been largely resolved in recent times, challenges in terms of cameras – array of detectors – spatial resolution, image acquisition speed and signal-to-noise ratio remain.

This project aims to demonstrate unequivocally the so-called surface topological particle mode and build a new THz microscopy system to be used in the overarching realm of material science, particularly to underpin research and development in topological insulator nanoparticles and 2D semiconductor materials. To this end, a new THz microscope based on a combination of a spintronic emitter (whose polarisation is controlled via magnetic bias) and computational imaging techniques will be implemented.

In order to achieve this aim, the research objectives are:

O1. Implement a THz time-domain spectrometer based on a spintronic emitter.

O2. Convert the THz time-domain spectrometer into a single-pixel compressive imaging system.

O3. Synthesize topological insulator nanoparticles with narrow nanoparticle size distribution.

O4. Demonstrate experimentally with preliminary data the existence of the surface topological particle mode.

Training and skills to be developed over the PhD;

This PhD project offers training in diverse areas of research in experimental physics and computational and applied electromagnetics. The student will develop critical thinking and analysis capability through strong linkage between the computational/theory and experimental outcomes. S/he will be supported in developing project management and leadership skills, and be active in the direction of the research. S/he will develop her/his communication skills through reporting, and disseminating the research outputs through publication and conferences.

Explanation of why the project is suitable for the CDT in Topological Design;

At heart of the microscopy system is a spintronic emitter whose underlying physics is based on topology. The ability of modifying the topology of the THz interrogating field using magnetic bias is another evidence of the project’s relevance to the CDT in Topological design.

The relevance of the topological insulator nanoparticles to the CDT is self-explanatory.

Links with research in the research groups of the supervising team;
This project will benefit from close synergy with EPSRC New Investigator Awards THEIA: fast super-resolution TeraHErtz mIcroscopy for nAtural sciences (EP/S018395/1; PI: Dr Navarro-Cía) and Terahertz Lab-on-a-Chip for Bio-liquid Analysis (EP/V001655/1; PI: Dr Hanham). Also, the Metamaterials Research Group (Dr Navarro-Cia) is a partner in the EU funded H2020 Rise "Non-Conventional Wave Propagation for Future Sensing & Actuating Technologies" project and is involved in the EPSRC UK Metamaterials network led by the University of Exeter - the proposed PhD project falls within the remit of both of them.
Links with research strategies, possibly including UoB, EPSRC, partner organisations;
The project falls within two of the UoB strategic priority areas within the overarching themes 'Science Frontiers' and 'Advanced Manufacturing Research'.

The project will make full use of a recent investment in the School of Engineering in a new anechoic chamber and associated facilities for antenna characterisation (£2.5M) and the THz testing equipment (£1.2M EPSRC investment).

The proposed research is a foundational topic situated at the intersection of the ICT and Physical Sciences EPSRC thematic portfolio areas, specifically the RF & Microwave Communications area. This in turn, underpins much of the strategic priority themes of Digital Economy, Healthcare Technologies, Engineering (e.g. Sensors and Instrumentation) and Living with Environmental Change (e.g. Information Infrastructure).

Links with research strategies, possibly including UoB, EPSRC, partner organisations;
The project falls within the UoB strategic priority area metamaterials within the overarching theme 'Science Frontiers'.

The project will make full use of the THz and Optics lab of the Metamaterials Research Group equipped over the last 10 years through UoB investment and grants including ERC, EPSRC and the Royal Society.

An ideal/acceptable undergraduate background and interests.
First degree in Physics, Electronic Engineering or closely related subject, with background in basic electromagnetics and preferably some experience or interest in experimental optics.