Bell Burnell Graduate Scholarship Scheme – Physics Project

PROJECT TITLE: Non-linear quantum optomechanics

Lead Supervisor: Luca Dellantonio

Profile Webpage: https://experts.exeter.ac.uk/40577-luca-dellantonio

Co-Supervisors: Prof. Saverio Russo, s.russo@exeter.ac.uk

Project details: Achieving partial control of 127 quantum bits (qubits) [1] shed light on the progress in the field of quantum computing, but also on the critical limitations in coherence times, gate fidelities, noise mitigation and connectivity. To fill this gap, we will aim at extending the applications of mechanical platforms to information processing [2, 3], as both an addition (e.g., for memories) and as an alternative to other platforms. Their ultra high-quality factors [4] and the possibility of condensing more qubits into a single unit [5, 6] can be a step change in boosting the qubits' integration as well as their performance.

For the first time, we will directly control the non-linear opto-mechanical coupling that allows manipulating the mechanical state beyond what is classically possible [7]. This requires nanoscale resonators made from graphene or carbon nanotubes, which due to their extremely low mass are sensitive to the minuscule momentum transferred by reflecting a photon. This project will breach the boundaries of classical physics and pave the way to novel quantum applications that – in addition to computing – include signal enhancement, noise reduction, mechanical signal processing, filtering, and transduction [8, 3, 2].

Conventional opto-mechanics exploits the linear interaction between an electromagnetic cavity containing n_{opt} photons and a resonator with displacement x, mediated by an interaction Hamiltonian $\propto g_1 n_{opt} x$, where g_1 is the coupling strength. However, this interaction can only create Gaussian (semi-classical) states of the resonator. To generate the non-classical states necessary for advanced sensing and for quantum information processing [7], we require a non-linear coupling, i.e., a term $\propto g_2 n_{opt} x^2$. This term is only significant in the very smallest and lightest mechanical resonators, and non-linear opto-mechanics has so far remained out of reach [2, 3]. Theoretical studies [9, 10, 11] have found two main challenges: (1) parasitic linear couplings and (2) hybridization of optical/electrical modes. Although a full microscopic theory is still missing, these works suggest that harnessing the non-linear coupling is possible, provided the device satisfies well defined requirements in terms of electrical and mechanical quality factors as well as the ratio g_2/g_1.

In this project, we will devise a new generation of opto-mechanical devices that can attain the quantum non-linear optomechanical regime. We describe the envisioned device. Two capacitively coupled electrodes enable the interaction between the electrical and the first asymmetric vibrational modes, giving raise to the opto-mechanical couplings $C^{-1}(x) \propto g_1 x + g_2 x^2$. The fabrication steps of suspended structures will follow similar steps as for suspended graphene [15, 54] and superconducting [55] devices demonstrated at the University of Exeter. In the case of graphene membranes, we will enhance the mechanical quality factor and localize the mechanical mode by exploiting phononic crystals (panel (g) and [12]) with defects (panel (h) and [4]). The Imaging suite and Graphene Centre clean-room facilities will provide access to the state-of-the-art equipment required for the fabrication and preliminary characterization of the envisioned ambitious structures.

Project specific entry requirements: Master in Physics

Potential PhD programme of study: PhD Physics

Location: Physics Building, Streathamn Campus, Exeter

Please direct project specific enquiries to: Luca Dellantonio (L.Dellantonio@exeter.ac.uk)

Please ensure you read the entry requirements for the potential programme you are applying for.

To Apply for this project please click on the following link - **APPLY HERE**

Bell Burnell Graduate Scholarship Scheme – Physics Project