Confining sound in superfluids via optomechanics

R.A. Harrison, W.W. Wasserman, G.I. Harris, A. Sawadsky, W.P. Bowen and C.G. Baker
ARC Centre of Excellence for Engineered Quantum Systems,
School of Mathematics and Physics, University of Queensland, St Lucia, QLD 4072, Australia.

Cavity optomechanics describes the coupling of light in an optical cavity with a mechanical degree of freedom. This coupling is generally limited to optical interactions (optical spring/dynamical backaction) that perturb a pre-existing mechanical eigenmode. This mechanical perturbation is mainly driven by the radiation pressure or imparted momentum from the light onto the cavity it is confined to. Leveraging this interaction has allowed many significant advances in science, through the development of ultra sensitive sensors and the ability to use dynamical back action for heating and cooling [1].

While these interactions are very useful, here we go beyond this regime into a new paradigm where light fully defines new mechanical eigenmodes. We propose this though the use of silicon on insulator (SOI) photonic chips, which have been planarized to remove all geometric boundary conditions. This planarization allows us to use radiation pressure from light guided within the photonic chip to deform a thin layer of superfluid covering its surface. The radiation pressure here acts in the same way an optical tweezer operates [2]. Superfluid films are advantageous due to their extreme compliance (over 6 orders of magnitude softer than most solids), which allows even modest radiation pressure to deform them appreciably in a localised region. Using this mechanical compliance we can deform the superfluid using the evanescent field of an optical resonator. This localised region will follow the shape of the optical resonator and have a different speed of sound. This will result in an optically defined ring of superfluid that will act as an acoustic resonator, containing mechanical eigenmodes. This will present a new landscape with acoustic eigenmodes completely defined by the optical field. Building on our experience with superfluid optomechanics, we can use this to make fluidic circuits that allow the controlled interaction of phonons in this superfluid acoustic landscape for sensing applications [3] and for fundamental investigations of the properties of superfluid helium [4, 5]. I will be discussing progress towards this work including development of a cryogenic packaging system [6] that allows easier testing of superfluid optomechanical devices.

[1] M. Aspelmeyer, T. Kippenberg and F. Marquardt, Rev. Mod. Phys. 4 86 (2014)

[2] A. Ashkin, Phys. Rev. Lett. 24 156 (1970).

[3] Y. Sachkou, et al, Science 366 6472 (2019).

[4] G. Harris, et al, Nat. Phys. 12 8 (2016).

[5] Y. Sfendla, et al, npj Quantum Inf. 7 62 (2021).

[6] W. Wasserman, et al, arXiv:2205.14143 [physics.ins-det] (2022).