Cavity Optomechanics with Free Electrons

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In 40 years, the paradigm of laser cooling has solidly established as the method of reference for controlling mechanical motion down to the quantum level [1]. Its principle essentially relies on the interaction between a mechanical system and a resonant degree of freedom that can efficiently harvest the mechanical energy. In this work, we demonstrate the first dynamical backaction cooling mechanism that is not mediated by a resonant interaction [2]. Using a focused electron beam, we report a 50-fold reduction of the motional temperature of a nanowire. Our result primarily relies on the sub-nanometer confinement of the electron beam and generalizes the phenomenology of cavity optomechanics [3] to any delayed and topologically confined interaction, with important consequences for near-field microscopy and fundamental nanoscale dissipation mechanisms.

Our experimental setup is depicted on Fig. 1(a): A focused beam of electrons is sent onto a vibrating Silicon Carbide nanowire (length $150\,\mu m$, diameter $250\,nm$) inside a Scanning Electron Microscope (SEM). The Secondary Electrons (SE) resulting from this interaction are detected by means of an Everhart-Thornley Detector (ETD), whose output is further sent onto a spectrum analyser. The sharp dependence of the SE emission rate with respect to the position of the nanowire enables sensitive detection of the thermally induced nanomechanical fluctuations. When displacing the point of impact of the electron beam towards the edge of the nanowire a strong suppression of the thermal motion is observed, proportional to the increase of the mechanical damping rate (see Fig. 1(b)). This reveals the presence of strong dissipative gradients, similar to those encountered in cavity optomechanics. We find that these gradients are to be attributed to the extreme topological confinement of the electro-thermal force exerted by the electron beam [2].

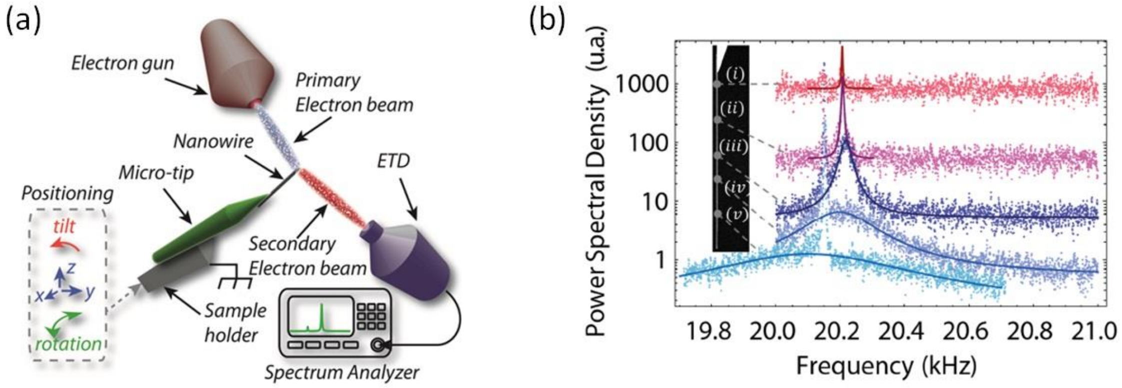

Fig. 1 (a) Experimental Setup. A focused electron beam is sent onto a vibrating nanowire inside a Scanning Electron Microscope. The secondary electrons resulting from this interaction are detected by means of an Everhart-Thornley Detector (ETD), whose output fluctuations are sent onto a spectrum analyser. (b) Dynamical backaction cooling using free electrons. When displacing the point of impact of the electron beam towards the tip of the nanowire (see SEM image on the inset), a strong suppression of the nanomechanical fluctuations is observed, proportional to the increase of the measured damping rate.

More generally, we demonstrate that the phenomenology of cavity optomechanics extends to any topologically confined interaction in principle, with prominent consequences for the fundamental understanding of nanoscale dynamics.

References

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