Universal vectorial and ultrasensitive nanomechanical force field sensor

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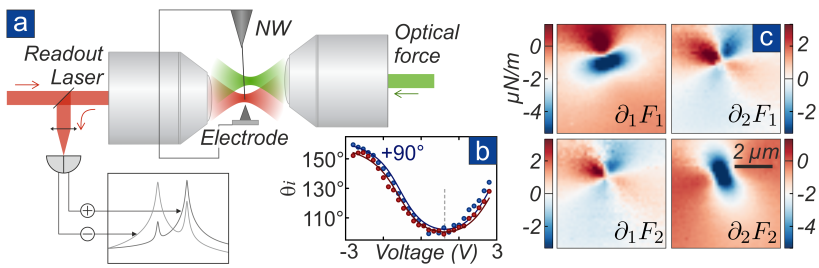
Nanomechanical resonators do not only display extreme sensitivities to force fields, but are also very readily sensitive to the vectorial character of these force fields. This particularly holds for nearly-degenerate multidimensional oscillators such as nanotubes and nanowires [1], optically trapped particles [2], or nanobeams under stress [3]. Here we demonstrate a fully vectorial force measurement principle based on the measurement of the frequencies and orientations of the two nearly-degenerate orthogonal mechanical polarisations of a singly-clamped SiC nanowire (NW) by a 2D force field.



a. Schematic setup with dual detection. **b.** Measured modes rotations in a conservative force field. **c.** Horizontal scan of the electrostatic force gradients.

In particular, we showed that mechanical polarisations undergo both a frequency modification and a rotation in multidimensional force fields [4]. This tuning of modes frequencies and orientations was studied by immersing the NW-probe in an electrostatic force field generated by a voltage bias between the nanowire holder and a counter-electrode while the NW Brownian motion was optically recorded on a dual-channel detection setup. The measurement process was automatized to build maps of all 4 force field gradients by scanning the electrode in a plane under the nanowire free extremity.

We then moved to a non-conservative force field by strongly focusing a laser on the NW extremity, as this arrangement was previously shown to generate non-irrotational force components[1]. We showed that the immersion in such force fields results in modes-"warping", that is, in breaking the natural orthogonality of mechanical polarisations. This observation is associated with an increase of the modes effective temperatures due to the accumulation of mechanical work along random trajectories in a non-conservative field. Non standard spectral lineshapes appear that are perfectly described by our formalism. Finally, by measuring the driven mechanical response, we demonstrate the violation of the standard fluctuation-dissipation theorem.

1. A. Gloppe *et. al*, *Bidimensional nano-optomechanics and topological backaction in a non-conservative radiation force field*, Nature Nano. 9, 920-926, 2014
2. G. Pesce *et. al*, *Influence of rotational force fields on the determination of the work done on a driven Brownian particle*, J. Opt. 13, 044006, 2011
3. T. Faust *et. al*, *Coherent control of a classical nanomechanical two-level system*, Nature Physics, 9, 485-488, 2013
4. L. Mercier de Lépinay *et. al*, *Universal Vectorial and Ultrasensitive Nanomechanical Force Field Sensor*, ArXiv, 2016