Vectorial scanning force microscopy using a nanowire mechanical resonator

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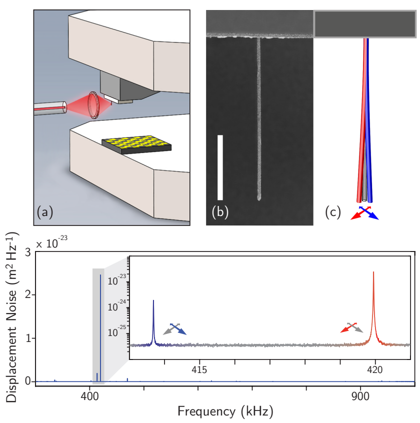

Figure 1 Setup

a, Overview of the setup. A fiber-optic interferometer is aligned with a single NW using piezoelectric positioners (top). A second stage (bottom) is used to position and scan the sample surface under the NW. **b**, A scanning electron micrograph of a single GaAs/AlGaAs NW. The scale bar represents 10 μm. **c**, A schematic diagram showing the two orthogonal fundamental flexural modes. (d) The displacement spectral noise density of the first two modes.

We describe the use of grown nanowires (NWs) as scanning directional force sensors. Due to their geometry, NWs are well-suited as scanning probes, when arranged in the pendulum geometry, i.e. with their long axis perpendicular to the sample surface (see Figure). NWs also have excellent mechanical properties, including low motional mass, high oscillation frequencies, and low dissipation rates. They can be grown in a variety of sizes and from different materials, allowing access to a wide range of mechanical frequencies and spring constants. Furthermore, NWs can be grown as heterostructures, making it possible to incorporate elements such as quantum dots. As demonstrated previously, these quantum dots can be coupled to the NW motion. Here, we use NWs as the functional elements in a new kind of vectorial scanning force microscopy.

By virtue of slight asymmetries in geometry, a NW's flexural modes can be split into doublets which oscillate along two orthogonal axes. By monitoring the frequency shift and direction of oscillation of both modes as we scan the NW above a surface, we construct a map of all in-plane tip-sample force derivatives. Furthermore, we measure the electrostatic vector force field of a sample with multi-edged gate electrodes and distinguish two different types of tip-sample forces. This capability, combined with the exquisite force sensitivity of NW sensors, allows for a type of force microscopy especially suited to measuring the size and direction of weak tip-sample forces. The results described here are very generic, in the sense that with proper functionalization of the NW, it can be used to measure a variety of forces in a vectorial manner.