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Nanowire Force Microscopy and Dynamic Cantilever Magnetometry

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We describe the use of grown nanowires (NWs) as scanning directional force sensors. By virtue of slight asymmetries in geometry, a NW's flexural modes are 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. This capability, combined with the exquisite force sensitivity of NW sensors, allows for a type of atomic force microscopy especially suited to measuring the size and direction of weak tip-sample forces [1]. 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. 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. We present measurements of the vectorial electrostatic field of a sample with multi-edged gate electrodes and distinguish two different types of tip-sample forces. These results demonstrate the potential of NWs as highly tunable mechanical resonators that can be used as functional elements in a new type of scanning force microscopy.

The detection of magnetic moments of individual nanoscale particles presents an additional experimental challenge. Here, we present measurements of nanometer-scale magnets based on sensitive mechanical detection of magnetic torque: dynamic cantilever magnetometry (DCM) [2]. With the use of ultrasensitive cantilevers, DCM allows us to collect information on the saturation magnetization, anisotropy, switching behavior, and magnetic phases. We discuss DCM measurements of the magnetic skyrmion phase in MnSi nanowires [3] and in $GaVa_4S_8$, which supports a Néel-type skyrmion phase. We also show results from experiments on ferromagnetic nanotubes [2, 3], interesting because of their potential flux-closure ground state at low applied magnetic fields. Using this technique, we were able to detect the entrance of vortices at the NT ends, nucleating the magnetization reversal. These features correspond well with micromagnetic simulations of the NT reversal process, showing that our samples can be described as idealized ferromagnetic NTs.

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