DAMOP09-2009-000081
Abstract for an Invited Paper
for the DAMOP09 Meeting of
the American Physical Society

Ultracold atoms coupled to micro- and nanomechanical oscillators: towards hybrid quantum systems

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Micro- and nanomechanical oscillators are presently approaching the quantum regime, driven by the continuous improvement of techniques to read out and cool mechanical motion. For trapped ultracold atoms, a rich toolbox of quantum control techniques already exists. By coupling mechanical oscillators to ultracold atoms, hybrid quantum systems could be formed, in which the atoms are used to cool, read out, and coherently manipulate the oscillators' state. In our work, we investigate different coupling mechanisms between ultracold atoms and mechanical oscillators. In a first experiment, we use atom-surface forces to couple the vibrations of a mechanical cantilever to the motion of a Bose-Einstein condensate in a magnetic microtrap on a chip. The atoms are trapped at sub-micrometer distance from the cantilever surface. We make use of the coupling to read out the cantilever vibrations with the atoms. Coupling via surface forces could be employed to couple atoms to molecular-scale oscillators such as carbon nanotubes. In a second experiment, we investigate coupling via a 1D optical lattice that is formed by a laser beam retroreflected from the cantilever tip. The optical lattice serves as a transfer rod which couples vibrations of the cantilever to the atoms and vice versa. Finally, we investigate magnetic coupling between the spin of ultracold atoms and the vibrations of a nanoscale cantilever with a magnetic tip. Theoretical investigations show that at low temperatures, the backaction of the atoms onto the cantilever is significant and the system represents a mechanical analog of cavity quantum electrodynamics in the strong coupling regime.