Atom-surface interactions on an atom chip

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The combination of atom chips and Bose-Einstein condensates (BEC) [1, 2, 3, 4], has opened up many possibilities for the coherent control of matter waves. Bose-Einstein condensates and ultracold atoms at temperatures $\leq 1\,\mu$K can be trapped and guided magnetically at distances of less than $100\,\mu$m from the room temperature metallic surfaces. One application is the construction of very sensitive chip based atom interferometers [5]. With the addition of optical and electrostatic potentials, atom chips are also a promising candidate for realising atomic quantum logic gates. For all these applications, it is essential to understand how the atoms interact with the surface of the chip.

On our atom chip, the atoms are magnetically trapped above a $500\,\mu$m diameter guide wire held in a channel on a glass substrate. The atoms are confined axially by “end wires” that pass below guide wire. The atom chip is loaded by collecting 10^8 ^{87}Rb atoms in a “mirror MOT” 4 mm above the chip. We transfer 2×10^7 of these atoms to the magnetic trap. Using forced RF evaporative cooling we reach BEC with 2×10^4 atoms $220\,\mu$m from surface. By adjusting the current through the wire for the last 1 s of the evaporation ramp, cold thermal clouds or Bose-Einstein condensates can also be produced at distances as low as $\sim 10\mu$m from the surface of the guide wire.

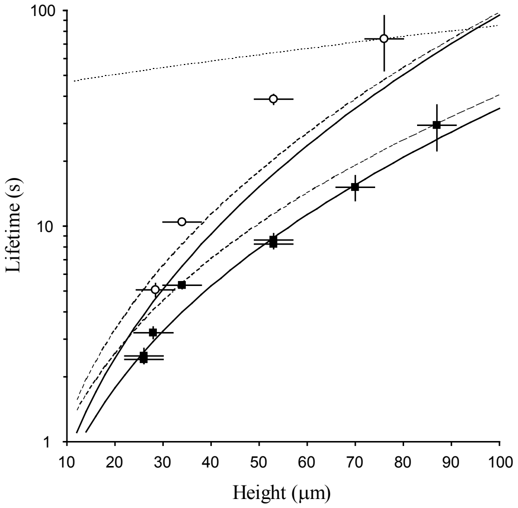

Figure 1: Lifetime of trapped atoms versus distance from the surface of the wire. Filled squares (open circles): measurements with spin flip frequency $f_0 = 560\,$kHz ($f_0 = 1.8\,$MHz). Solid (dashed)lines: calculated lifetimes above a thick slab of copper (aluminium) for these two spin flip frequencies. The dotted line shows the expected scaling for technical noise.

By studying how the magnetic trap lifetime varies as a function of distance from the surface, we have observed for the first time the coupling between cold atoms and the thermal electromagnetic near field of the surface [6]. The finite resistivity and temperature of the wire give rise to Johnson noise currents in the wire. As a result, the electromagnetic field near the wire also fluctuates. This fluctuating magnetic field can drive spin flip transitions, leading to loss from the magnetic trap. We have performed a calculation of the thermal spin flip lifetime above an infinite metal slab, following ref. [7]. Although the theory is for a slab whereas the experiment is above a cylindrical wire, the agreement between the two is remarkably good, as shown in figure 1. This atom-surface coupling sets fundamental constraints on the coherent control of atoms on atom chips.

When the cloud approaches the surface of the wire, it breaks up into lumps, as observed by [3, 4]. It has previously been shown [3, 4] this fragmentation close current carrying wires is due to corrugations of the potential caused by a spatially varying *axial* component of magnetic field produced by the current in the wire [8]. By analysing axial profiles of the density distribution of the atoms, we have measured the size of this anomalous magnetic field as a function of axial position and distance from the wire. We observe that the corrugations are approximately periodic, with period $\lambda = 230$ μm. Using the height dependence of the amount of fragmentation, we show that the decay of the anomalous magnetic field component is well described by the Bessel function $K1(2\pi y/\lambda)$, as one would expect for the far field of an oscillating or helical distribution of current in the wire [9].

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