Superconducting atom chips

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Abstract

Atom chips with micron-sized current-conducting wires realize flexible magnetic traps for laser-cooled atoms. Chips based on superconducting wires are particularly interesting. Extremely long trapping times can be expected, due to the ultra-high vacuum conditions in a cryogenic environment and to the reduced Johnson-Nyquist current noise in the conducting surfaces. These chips open the way to the coupling of atomic samples with mesoscopic quantum circuits and to the deterministic preparation of individual Rydberg atoms for cavity QED experiments [1, 2].

We have realized a superconducting chip setup [3]. The niobium thin-film wires are coated by a gold surface, used to create in front of the chip a mirror-MOT, which captures a low-velocity atomic beam. The atoms are then transferred to a Ioffe-Pritchard trap resulting from the superposition of a constant adjustable bias field with that created by an on-chip Z-shaped wire.

We have measured the trapping lifetime as a function of the distance from the gold layer. At large distances (400 μm), it is over ten minutes. At a shorter distance (30 μm), it is reduced to $\simeq$40 s, in agreement with predicted atomic spin-flip rate due to the Johnson-Nyquist current noise in the cold normal metal layer [4]. When the atoms are brought close to the superconducting wires underneath the mirror, we observe hysteretic modifications of the trapping potential due to the permanent currents in the superconductor [5]. This observation is promising for the realization of programmable permanent trap structures.

Much longer lifetimes are expected when atoms approach a naked superconducting surface. We have developed a detailed model of the lifetime, taking into account vortex dynamics in the thin film [6]. We predict lifetimes significantly shorter than those obtained in other less detailed models, but still three orders of magnitude larger than for a normal metal at the same temperature. This result is very encouraging for coherent atomic manipulation on superconducting chips.

In these ideal conditions, we readily obtain Bose-Einstein condensation on the chip [7], with about 10^4 atoms in a $30\times1\times1$ μm cigar-shaped volume. A slightly tighter confinement will lead to the deterministic preparation of individual Rydberg atoms using the dipole blockade mechanism. These atoms could then be trapped on chip for coupling to superconducting circuits or on-chip cavity [1]. They can also be Stark-accelerated and launched in 3D very high quality superconducting cavities [2].

Keywords: ATOM CHIPS, BEC, RYDBERG ATOMS

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