Fiber cavities for atom chips

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Abstract: We present experimental realizations of several micro-cavities, constructed from standard fiber optic components, which meet the theoretical criteria for single atom detection from laser-cooled samples. We discuss integration of these cavities into state-of-the-art 'atom chips'.

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The last few years have seen tremendous progress in the miniaturization of traps for neutral atoms. Several groups have successfully trapped atoms in the magnetic field created by current-carrying wires on top of a glass or silicon substrate (atom chips). Such traps can in principle be used for scalable quantum information processing. So far, however, they lack on-chip optics for integrated detection and manipulation, in particular, for nondestructive single atom detection. We have constructed several micro-cavities for atom detection from standard optical components and discuss their integration onto the atom chip.

Theoretical analysis of fiber-based standing wave cavities shows that even modest values of the cavity finesse allow for efficient atom detection due to the small cavity mode (typically several microns) [1]. The basic cavity consists of two fiber pieces each with high reflection mirrors on one side. The non-reflecting ends face each other leaving a gap of several microns to accommodate an on-chip atom micro-trap or guide. Thus configured most of the resonant mode remains in the fibers allowing for tuning and variation of parameters. A resonant laser drives the cavity through one mirror and the transmission is monitored through the other mirror. A drop in the cavity output indicates the presence of an atom in the gap. As an example, Fig. 1 shows the number M of photons which are spontaneously scattered by a single rubidium atom during a measurement time which leads to detection with signal-to-noise ratios of S = 5, 10, and 20. We see that a finesse over 100 is sufficient for atom detection with minimum disturbance of the atom. Similar results were obtained for off-resonant pumping and homodyne detection of the phase shift of the output light induced by the atom.

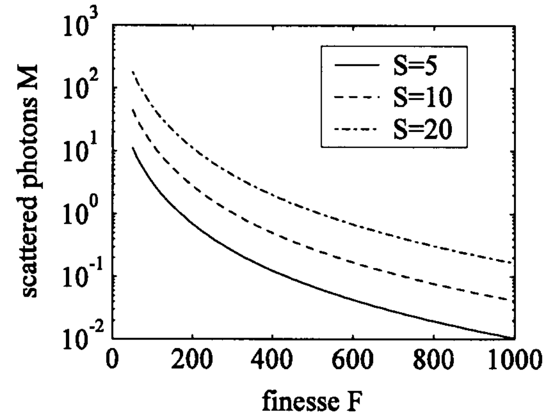

Fig. 1. Photons scattered by atom

The short, mirrored fiber cavity described above has been realized off-chip using gold mirrors on 2 cm lengths of fiber. Various issues involving on-chip alignment and tuning are being investigated. Initial studies indicate that thin film heating via a metallic coating on the fiber offers one feasible solution to the tuning, however effective passive alignment seems to be a difficult problem. Variations of this cavity are possible and we have examined other experimental realizations of these cavities with gradient index (GRIN) lenses and fiber couplers.

One interesting variation used a 2x2-port fiber coupler where one input and one output fiber face each other to form the gap. In this case the additional counter-propagating mode creates a range of additional effects. For example, in contrast to the standing-wave cavity, a ring-cavity is very sensitive to the actual size of the gap since it forms a small cavity which can couple light between the modes. The ring cavity allowed us to measure the loss in the gap as a function of gap size and verify that it behaves as predicted. The finesse of this first effort was limited by internal losses in the coupler, but a finesse of better than 100 seems achievable with better quality couplers.

A standing-wave cavity built with two gold-coated GRIN lenses has the advantage that the focusing effect allows gap sizes of hundreds of microns with small losses. Single transverse mode operation is much more difficult however. The finesse is limited to less than 100 by the reflectivity of the gold. For improved standing wave cavities we will need dielectric or Bragg mirrors. For now we focus on the problem of chip mounting and hope to make the first efforts at atom detection in the near future.

[1] P. Horak et al., "Toward single-atom detection on a chip," e-print quant-ph/0210090 (2002), http://lanl.arXiv.org/.