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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Quantum detectors

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 $N$ 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.

![Graph](image)

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.