GOM '03
Invited

2575

Fibre-optic cavities for the observation of single guided atoms

Peter Horak, Bruce G. Klappauf, and Peter Kazansky

Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ, United Kingdom
e-mail: peh@orc.soton.ac.uk

We investigate a variety of designs to use standard fibre technology for optical access to atoms trapped in miniaturised magnetic traps on the surface of silicon or glass substrates.

The main advantage of optical fibres for atom detection or manipulation is the tight transverse confinement of the guided modes. Typically, the waist of a light beam emerging from the end of a single-mode fibre is of the order of a few microns, which is about a factor of ten smaller than the waist of light modes in present cavity QED experiments. Thus the effective interaction of an atom with a single photon is increased by two orders of magnitude. We therefore find that fibre-based cavities provide strong coupling to single atoms even for relatively modest mirror reflectivity. As an example, we discuss single-atom detection by such devices.

First, we investigate theoretically the properties of a standing wave cavity [1]. The cavity consists of two fibre pieces with Bragg mirrors or reflective coatings on one side of each fibre with the non-reflecting ends facing each other. The gap of several microns between the two fibres is large enough to accommodate an atom micro-trap or guide. The cavity is resonantly driven by a laser through one of the mirrors and the transmission through the other mirror is measured. A drop in the cavity output indicates the presence of an atom in the gap, as shown in figure 1(a). We find that a mirror reflectivity as low as 97-99% is sufficient for the detection of single atoms with good signal-to-noise ratios and with only a few photons scattered spontaneously by the atom during the detection time. This also holds taking into account atomic motion and momentum diffusion under realistic conditions in a trap.

Another possibility consists of a ring cavity built out of a 2x2-port fibre coupler where one input and one output fibre are coupled to each other via a small gap. In this case the additional counter-propagating mode creates a range of additional effects. We have found that, in contrast to the standing-wave cavity, a ring-cavity is very sensitive to the actual size of the gap, i.e., whether the gap itself together with the Fresnel reflection at the fibre ends forms a resonant or off-resonant micron-sized cavity, see figure 1(b) and (c). Optimising the ring cavity parameters leads to single-atom detection efficiencies which are similar to those of the standing wave cavity.

We have realised a fibre-coupler ring cavity and a standing-wave cavity with gold mirrors on 2cm lengths of fibre. We measured the loss in the gap as a function of gap size and verified that it behaves as predicted. The finesse of these first efforts was limited by internal losses in the coupler respectively by the quality of the gold mirrors. With improved reflectivity a finesse of 100 or more seems achievable in both cases. Another effort was a standing-wave cavity built with two gold-coated gradient index (GRIN) lenses. This has the advantage that the focusing effect of the lenses allows much larger gap sizes (of the order of 100 μm) without excessively large losses. On the other hand, it is much more difficult to obtain single transverse mode operation in such a system. The highest finesse in the GRIN-lens cavity is limited by the reflectivity of the gold coatings and is again of the order of 100.

[1] P. Horak et al., e-print quant-ph/0210090 (2002).

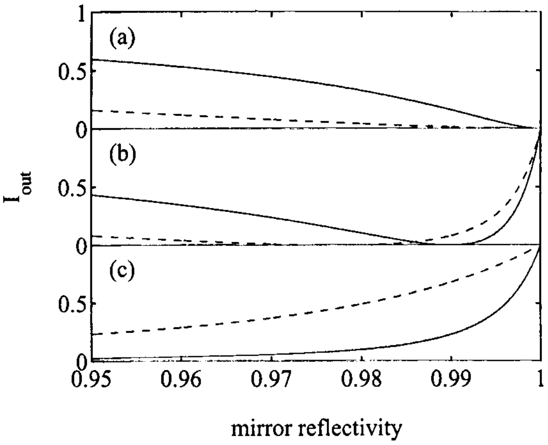

Figure 1: Intensity of light transmitted through the cavity without an atom (solid lines) and with an atom (dashed lines) versus mirror reflectivity. The size of the cavity gap containing the atom is about 7.3 μm. (a) Standing wave cavity with resonant gap. (b) Ring cavity with resonant gap. (c) Ring cavity with off-resonant gap. In all cases the atom is resonant with the pump light. Cavity frequency and atomic position are chosen to maximise the change in cavity output.