Hybrid Fibre-Atomic Optical Frequency Standard

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The advent of high-quality hollow-core photonic-crystal fiber (HC-PCF) offers the potential to build robust and compact optical frequency standards with a total volume of below 1 litre. We are pursuing just such a standard by loading HC-PCF with Rubidium vapour that is interrogated using two-photon Doppler free excitation [1].

In this work we examine how various fibre core diameters and optical guidance techniques (both photonic-crystals and Kagome-style microstructures) can influence the Rb spectral features. The goal of this work is to search for a fibre design that produce the strongest and narrowest two-photon resonances, while minimizing light and collisional shifts, so as to optimize the performance of the frequency standard.

The Rb is simultaneously loaded into five different hollow-core optical fibers, all around 25cm long, which are mounted within a UHV apparatus with a surrounding Rb vapour at 50°C. We excite a two-photon resonance (5S to 5D) in the fibre-trapped rubidium using counter-propagating lasers at 780nm and 776nm. This dual-colour excitation gives a much higher transition rate than one can gain from single-colour 778nm excitation. The high intensity conditions, together with the long length of the fiber, results in substantial absorption of IR light (>90%). This is in strong contrast to typical cell-based two-photon Rb standards which scatter ~10^{-8} of the incident intensity [2].

The spectral features of the trapped Rb demonstrate subtle variations which reflect the influence of the fibre parameters on the two-photon spectrum of Rb. We observe a two-photon linewidth ranging from 10MHz down to 4MHz in the various fibres (see Fig. 1 with three example spectra): the majority of this variation arises from variations in transit-time because of the characteristic size of the light field. In the case of the multi-mode fibre the overlap of the two light beams was only on the scale of ~4 microns. The basic linewidth in all cases shows residual Doppler broadening due to the wavelength mismatch between the counter-propagating beams.

We have previously demonstrated a frequency stability of 9.8 x 10^{-12} (at 1 second) with a 45 micron diameter core [3]. This previous work was deleteriously affected by strong high-order spatial modes within the fibre, which led to poor overlap in the counter-propagating beams. This led to a high transit-time broadening as well as sensitivity to changes in input-mode alignment. We have shown that the new optical fibres can: (a) be operated in a single-mode (with care in input coupling) which leads to excellent mode-overlap and minimal alignment sensitivity and, (b), have a larger core diameter and thus lower transit-time broadening and smaller light shifts for given input power. Using the measured characteristics of the spectrum, together with measurements of the mode excitation profile, we calculate a potential frequency stability in the low 10^{-13} range (1s integration time) for a 60 micron core fibre that is excited in a single mode.

We will present at the conference the frequency stability of these new hollow-core frequency standards (compared against a high-stability optical cavity standard). We believe that this approach offers a path to a new generation of high performance standards on a highly robust and compact platform.

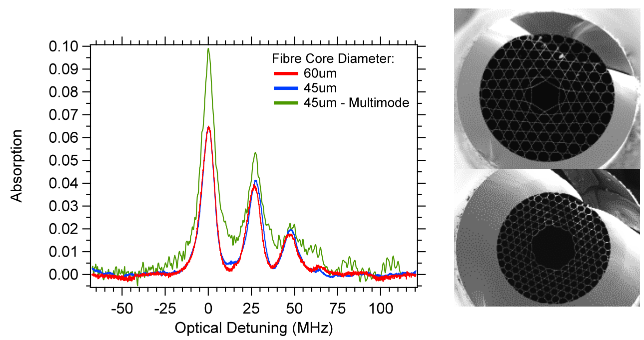

Fig. 1: Two-photon Rb spectra at the same intensity from two optical fibres using a Kagome guiding structure: one has a 45 micron core while the other has a 60 micron core. The spectral shape is dominated by a residual Doppler broadening [1]. Inset: micrographs of the two optical fibres shown.

The described work was supported by the Australian Research Council under grants DP0877938 and FT0991631. The research group would also like to thank the South Australian Government for their generous support through the Premier's Science and Research Fund.

References

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