Super-extended nanofiber-guided field for coherent coupling to hot atoms

R. Finkelstein[1], G. Winer[1], D. Z. Koplovich[1], O. Arenfrid[1], T. Hoinkes[2,3], G. Guendelman[1], M. Netser[1], E. Poem[1], A. Rauschenbeutel[2,3], B. Dayan[1], and O. Firstenberg[1]

[1] Weizmann Institute of Science, Israel
[2] TU Wien, Vienna, Austria, [3] Humboldt-Universität zu Berlin, Germany

Light-matter interaction can be enhanced by using a tight optical mode and by collective coupling of this mode to an ensemble of atoms. While reduced mode volumes are achieved in small optical cavities or with tightly focused beams in free space, they are typically incompatible with large ensembles of atoms due to the associated short Rayleigh range. An alternative approach employs a tightly confined optical mode that is supported by a low-loss waveguide over an extended length. When coupled to thermal vapor, the transverse motion of the atoms through the optical mode results in transit-time broadening and in a reduction of the absorption cross-section.

In this work, we tackle these challenges by realizing a guided optical mode with an evanescent field part that extends several wavelengths away from the waveguide surface, as illustrated in Fig. 1. We fabricate a tapered optical fiber with an extremely thin waist, which supports a super-extended mode with a diameter as large as 13 times the optical wavelength, residing almost entirely outside the fiber and guided over thousands of wavelengths (5 mm). This unique configuration balances between strong confinement, as evident by saturation powers as low as tens of nW, and long interaction times with the thermal atoms, thereby enabling fast and coherent interactions. We demonstrate narrow coherent resonances (tens of MHz) of electromagnetically induced transparency for signals at the single-photon level and long relaxation times (10 ns) of atoms excited by the guided mode. The dimensions of the guided mode's evanescent field are compatible with the Rydberg blockade mechanism, making this platform particularly suitable for observing quantum non-linear optics phenomena.

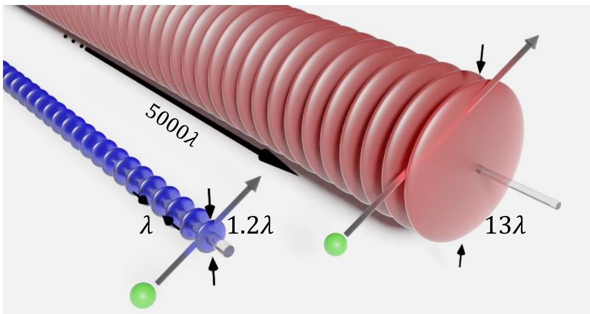

Figure 1. Illustration of the extent of an optical mode surrounding a thin optical fiber. The fiber on the left (fiber diameter $D = 0.9\lambda/n$, where n is the refractive index of the fiber) has a guided mode with field diameter MFD=1.2λ, comparable with the wavelength λ. The fiber on the right ($D = 0.37\lambda/n$) has a mode extending to MFD=13λ, guided over a distance of 5000λ.

[1] R. Finkelstein, G. Winer, D. Z. Koplovich, O. Arenfrid, T. Hoinkes, G. Guendelman, M. Netser, E. Poem, A. Rauschenbeutel, B. Dayan, O. Firstenberg, Optica (in print); arXiv:2010.08935.