A tool for measuring atomic properties at the quantum limit

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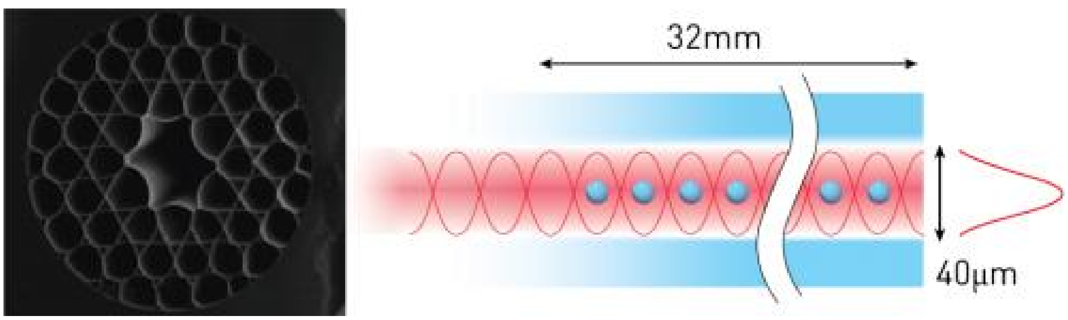

Figure 1: A hollow-core optical fiber supports a kagome lattice (left) that can confine atoms in the central channel in a regular coherent state (right). Credit: Reproduced from Ref. 1 and licensed under CC BY-NC-ND 4.0 © 2014 S. Okaba et al.

Performing high-resolution, high-sensitivity measurements of light and matter at the quantum limit requires extraordinary tools. Due to the difficulties of manipulating atoms with the necessary control, such measurements are often made by manipulating light. The measurement of atoms at this level of precision, however, is of much interest for applications such as atomic clocks, atomic spectroscopy and atom interferometry.

Hidetoshi Katori from the RIKEN Quantum Metrology Laboratory and Franco Nori from the RIKEN Center for Emergent Matter Science, in collaboration with co-workers from the University of Tokyo and a number of international institutions, have now developed a method to confine atoms in an 'optical lattice' formed inside a hollow-core optical fiber.

The researchers used a hollow-core optical fiber with a structure known as a kagome lattice—a honeycomb-like structure that supports a periodic optical 'potential' (Fig. 1). Atoms passing down the central channel of the hollow-core fiber are confined within the periodicity of this three-dimensional optical lattice. This confinement keeps the atoms isolated and protected from unwanted collisions with other atoms or the walls of the fiber, factors that have degraded the performance of similar approaches in the past. The optical lattice elegantly overcomes these problems and produces a minimally perturbed, optically dense atomic sample with improved regularity or 'coherence'.

Using their fiber system, the researchers were able to perform highly precise spectroscopic measurements of light absorption by a coherent sample of ultracold strontium atoms. Due to the tight confinement of the atoms within a wavelength of the interacting light, the measurements were able to resolve a very narrow spectral linewidth, free from the wavelength-shifting Doppler effects.

"A hollow-core fiber provides a unique system in which light and matter are strongly coupled," explains Katori. "Our system could serve as a universal platform for atomic experiments in quantum metrology, which require long coherence times of atoms and photons."

The researchers plan to try and squeeze even more atoms into the fiber to strengthen the light–matter interaction. Katori believes that it should be possible to trap as many as 100,000 atoms in a 3-centimeter-long fiber without causing atom–atom interactions. Such high-density atomic systems are particularly attractive as more stable and compact fiber-based atomic clocks.

"We hope to push the miniaturization of optical lattice clocks based on this fiber scheme," comments Katori. "If we could also realize continuous 'superradiant' lasing, such a fiber system could be used as an extremely compact light source for portable optical clocks."

More information: Okaba, S., Takano, T., Benabid, F., Bradley, T., Vincetti, L., Maizelis, Z., Yampol'skii, V., Nori, F. & Katori, H. "Lamb-Dicke spectroscopy of atoms in a hollow-core photonic crystal fibre." *Nature Communications* 5, 4096 (2014). DOI: 10.1038/ncomms5096

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