Scalable infrastructure for Sr optical clocks with integrated photonics

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Optical-lattice clocks with alkaline-earth metal vapors are among the most stable and precise sensing platforms in all of physics [1]. Moreover, their ultranarrow atomic transitions provide quantum calibration of not only timing signals, but they can be converted to calibrate numerous physical observables and as a basis for quantum information. Disrupting the photonics, laser, and systems technologies required for optical-lattice clocks with scalable and manufacturable integrated-photonics is a universally acknowledged goal [2]. The critical step of transitioning from complicated, hand-assembled, free-space optics to integrated photonics will pay dividends not just for advanced quantum sensors but throughout quantum information science, advanced computing architectures, and high-capacity, secured data links.

We demonstrate laser cooling and trapping in a novel, fully integrated metasurface (MS) optics platform, engineered to support both broad-line and narrow-line cooling of strontium. Metasurface optics offer complete control of free-space propagation and co-integration, hence we realize the aligned configuration required for magneto-optical trapping (MOT) upon assembly. Furthermore, we phase-lock the lasers needed for broad-line and narrow-line cooling of strontium by use of supercontinuum generated with fiber-coupled, tantalum-pentoxide nonlinear waveguide modules. The supercontinuum modules transform a low-power Er-fiber comb to Sr reference combs at 690 nm, 780 nm, 813 nm, and 922 nm.

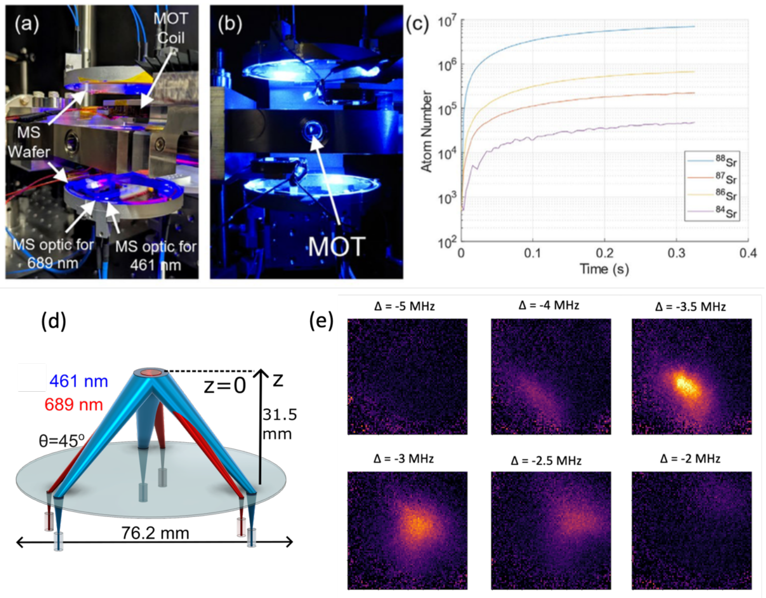

Fig.1. Magneto-optical trapping on the 461 nm and 689 nm transition of strontium with laser beams generated from twelve metasurface optics integrated on a fused silica wafer. (a) Image of the compact Sr apparatus with three-inch metasurface optics wafers for scale. (b) Sr MOT on the 461 nm transition. (c) Demonstration of Sr 461 nm MOT loading for the four most abundant isotopes. (d) Schematic arrangement of the metasurface optics system with optical fiber illumination at 461 nm and 689 nm. (e) Exploring a metasurface optics Sr MOT on the 689 nm transition.

Figure 1 shows an image of our compact and scalable Sr system with metasurface optics to generate the broad- and narrow-line MOTs. This talk will explore integrated photonics technologies for robustly reconfigurable use in atomic physics systems and the development of our scalable Sr lattice clock system. We use a low-power Sr beam oven and a counterpropagating 461 nm beam to assist MOT capture. With this MOT beam configuration generated from metasurfaces, we have the capability to trap four Sr isotopes in their isotopic abundances, demonstrating robust, 3D, polarization diverse optical configurations. Our system further enables laser cooling to microkelvin temperature on the 689 nm transition.

References

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[2] J. Grotti et al., *Geodesy and Metrology with a Transportable Optical Clock*, Nature Physics **14**, 437 (2018).