Optical refrigeration of rare-earth-doped single crystals

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Laser cooling traditionally refers to the technology for refrigerating trapped atoms or ions to a few kelvin or millikelvin temperatures. Lasers can also refrigerate solid-state materials to cryogenic temperatures (<150°C) through a different mechanism known as anti-Stokes fluorescence. The simple laser excitation of an optically active medium enables cooling it down via fluorescence taking away the lattice phonons, thereby reducing the medium's temperature. This technology has opened a path for all-solid-state optical cryocoolers, offering compact and vibration-free cooling solutions that require no cryogenic liquids. Such coolers show particular promise for miniaturized space satellites for infrared observation missions and high-precision metrology applications.

Fluoride single crystals doped with rare-earth ions are particularly well-suited to this technology, primarily owing to their high quantum efficiency compared with semiconductor materials. The current state-of-the-art material, Yb-doped $LiYF_4$ (Yb:YLF), demonstrated cooling to temperatures below 90 K, and even lower temperatures, e.g., 77 K, are theoretically feasible by improving the crystal quality and purity.

We successfully and reproducibly grew Yb^{3+}-doped fluoride crystals by the Czochralski technique and our crystals exhibit among the lowest parasitic absorption ever reported in the field. In a simple configuration as depicted in the figure below, the crystal cooled down to <150 K under laser excitation at a wavelength of 1020 nm in a vacuum environment. In the presentation, I will present the fundamental principles of solid-state laser cooling and laser-cooling-grade crystal growth techniques, and overview the technological progress in the last decades.