

Optical Engineering

OpticalEngineering.SPIEDigitalLibrary.org

Optical Refrigeration and Radiation-Balanced Lasers

Richard I. Epstein
Mansoor Sheik-Bahae

SPIE.

Richard I. Epstein, Mansoor Sheik-Bahae, "Optical Refrigeration and Radiation-Balanced Lasers," *Opt. Eng.* 56(1), 011101 (2017), doi: 10.1117/1.OE.56.1.011101.

Optical Refrigeration and Radiation-Balanced Lasers

Richard I. Epstein

ThermoDynamic Films, LLC
1313 Madrid Road
Santa Fe, New Mexico 87505
E-mail: richard.epstein@gmail.com

Mansoor Sheik-Bahae

University of New Mexico
Department of Physics and Astronomy
Albuquerque, New Mexico 87131-0001
E-mail: msb@unm.edu

The laser cooling of solids by anti-Stokes emission has been advancing on many fronts. Work on the laser cooling of rare earth-doped solids has expanded to include materials comprised of ytterbium, thulium, holmium, and erbium dopants in a variety of crystal and glass hosts. The growth techniques and quality of these cooling materials have greatly improved. With these improvements, laser cooling may soon approach liquid nitrogen temperatures. Rare earth-based cryogenic optical refrigerators may find applications in cooling infrared cameras, low-noise electronics, high-purity germanium gamma ray spectrometers, and high-temperature superconductors. Laser cooling in semiconductor devices has also been pursued intensively, and net cooling in CdS nanostructures was recently reported. In parallel, “athermal” or radiation-balanced lasers, which exploit anti-Stokes fluorescence to balance the heat generated by quantum defect in rare earth-doped lasers, may enable the development of extremely high-power lasers with excellent beam quality.

Several papers in this special section explore the growth of rare-earth doped crystal and the use of these crystals in laser cooling. [Cittadino et al.](#) describe the Czochralski technique as developed at the University of Pisa for growing large, defect-free cooling crystals. They explain the growth parameter and the processes that are necessary to avoid contamination inside crystals like OH⁻ ion and how to avoid reduction of Yb³⁺ to Yb²⁺. [Volpi et al.](#) and [Zhong et al.](#) report on the optical cooling of LiLuF₄ single crystals. LiLuF₄ is an isomorph of YLF where yttrium is replaced by lutetium. Optical cooling was observed by exciting the Yb transition in a single pass of laser light at a wavelength of 1025 nm. [Krishnaiah et al.](#) discuss the development of glass ceramics containing CaF₂ crystals doped with ytterbium. If laser cooling could be achieved in glass ceramics, it would provide a much more flexible approach to developing cryogenic optical refrigerators. [Bowman](#) examines the laser material performance as the quantum defect of the laser is reduced and the effects of

anti-Stokes cooling are included. The special case of a net zero quantum defect is shown to provide two orders of magnitude lower heat generation at the cost of roughly 10% loss in extraction efficiency. [Gragossian et al.](#) investigate an astigmatic Herriott cell to improve laser absorption at low temperatures. This cavity enables one to use unpolarized high-power fiber lasers, and to achieve much higher cooling powers.

Some of the papers deal with the exciting prospects of laser cooling of solids. Prof. Xiong's group at the Nanyang Technological University in Singapore reported first cooling of semiconductors a few years ago. Since then a number of groups have been working to confirm and extend these results. [Smith et al.](#) measured the nonlinear optical absorption coefficient of optically trapped cadmium-sulfide nanoribbons through observations of their Brownian dynamics during single-beam laser-trapping experiments. [Du et al.](#) have grown CdS bulk crystals by a modified optical floating zone method. These high-quality CdS bulk crystals show strong photoluminescence upconversion. [Wang and Sheik-Bahae](#) have developed a power-dependent photoluminescence measurement technique to efficiently determine the external quantum efficiency of potential laser cooling semiconductors.

Richard Epstein received his BS degree in engineering physics from Cornell University, and his MS and PhD in applied physics from Stanford University. For many years he worked for Los Alamos National Laboratory where he was a Laboratory Fellow. He is now the CEO of ThermoDynamic Films, LLC and a research professor at the University of New Mexico. He is a fellow of the Optical Society of America. He has contributed to several areas of applied physics and theoretical astrophysics.

Mansoor Sheik-Bahae is a Distinguished Professor of Physics and Astronomy and the chair of Optical Science and Engineering at the University of New Mexico. He graduated from the State University of New York (Buffalo), and subsequently worked as a research scientist at CREOL-University of Central Florida before joining UNM. He is a fellow of the Optical Society of America, and the co-recipient of the OSA's Wood prize in 2012.