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Development of a Prototype Optical Refrigerator.

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Abstract

This is the final report of a one-year, Laboratory Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). We have carried out a range of tasks directed toward the construction and testing of a proof-of-principle optical refrigerator prototype. We procured and tested new cooling elements that are at the heart of an optical refrigerator. The cooling element absorbs pump radiation and then fluoresces with nearly unity quantum efficiency. We constructed and tested a cooling chamber with low thermal emissivity walls that reduces the parasitic heating.

Background and Research Objectives

Normally, shining intense laser light at an object will heat it up, or even vaporize it. Nevertheless, under the right conditions this normally searing radiation can actually cool solid objects. Since the 1920s, scientists have theorized that bright light should be able to chill objects. When light hits a solid object it usually deposits energy or heat. However, in some systems light can absorb energy from microscopic thermal vibrations in the solid and thus decrease the object's temperature. Specifically, if an object excited by radiation at one frequency is forced to emit radiation at higher frequencies, which carry more energy, the object cools. In essence, light pours into the object, soaks up some of the vibrational or heat energy of the object, then carries away the excess energy.

To create laser cooling, we shined a beam of infrared light — nearly as intense as the light at the sun's surface — at ultra-pure glass impregnated with ions of the element ytterbium. Ytterbium ions radiate over only a single band of frequencies that are much higher than the possible frequencies at which the glass could vibrate. Therefore, when we pump the glass with laser light at the right frequency, it produces cooling. These early experiments

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produced a cooling power that was a few percent of the absorbed laser power. This is a respectable efficiency for potentially cooling high-tech devices to extremely low, or cryogenic, temperatures.

Importance to LANL's Science and Technology Base and National R&D Needs

A solid-state cryocooler based on laser cooling would be a superior alternative to the currently available cryogenic systems in several ways. Since it would have no moving parts, it would not produce vibrations, and it would be rugged and long-lived. Additionally it would be compact and not subject to electromagnetic interference. Optical refrigerators would be ideal for space applications where they could cool a wide variety of detectors and instruments mounted on satellites. This capability would be of great benefit for nonproliferation and treaty verification instruments operating at infrared or gamma-ray energies, or for other remote sensing or laboratory applications.

Scientific Approach and Accomplishments

We tested cooling elements composed of a fluoride glass doped with ytterbium ions. To efficiently use the pump radiation, we deposited high-quality dielectric mirrors on the ends of a cylindrical sample. Laser light enters the sample through a small hole in one of the mirrors and remains trapped until the ytterbium ions absorb it. We tested and characterized one mirrored cooling element and found measurable cooling. Using these results, we designed an improved cooling element.

To limit the major source of parasitic heating for an optical refrigerator, thermal radiation from the warm environment, we constructed a specially coated chamber to house the cooling element. The coating absorbs the one-micron fluorescence, but has a low emissivity at thermal wavelengths near 10 microns. We found that this chamber reduced the heat load by a factor of three. The next generation chamber should provide heat reductions of more than a factor of ten.

Publications

1. Mungan, C. E., Buchwald, M. I, Edwards, B. C., Epstein, R. I. & Gosnell, T. R. "Internal Laser Cooling of Yb³⁺-Doped Glass Measured Between 100 and 300 K," *Appl. Phys. Lett.*, **71**, 1458 (1997).
2. Fajardo, J. C., Sigel, G. H., Jr., Edwards, B. C., Epstein, R., I., Gosnell, T. R. & Mungan, C. E. "Electrochemical Purification of Heavy Metal Fluoride Glasses for Laser-Induced Fluorescent Cooling Applications," *J. of Non-Crystalline Solids*, **213**, pp 95 (1997).
3. Mungan, C. E., Edwards, B. C., Epstein, R. I., Gosnell, T. R., & Buchwald, M. I. "Spectroscopic Determination of the Expected Optical Cooling of Ytterbium-doped Glass," *Mat. Sci. Forum* , **239-241**, 501 (1997).
4. Mungan, C. E., Buchwald, M. I, Edwards, B. C., Epstein, R. I. & Gosnell, T. R. "Laser Cooling of a Solid by 16K Starting from Room Temperature," *Phys. Rev. Letters*, **78**, 1030 (1997).

Los Alamos Solid-State Optical Refrigerator

Los Alamos National Laboratory

Figure 1. This design shows the key elements for a prototype optical refrigerator. Light produced by a diode laser flows through an optical fiber to the cooling element where it is trapped, absorbed and re-emitted. The waste light that extracts heat from the cooling element is absorbed by the warm walls of the cooling chamber