All-solid-state cryocooler becomes a reality

August 21, 2018

A breakthrough in cryogenics

The ability to cool objects to cryogenic temperatures transcends many disciplines and is essential to a wide range of scientific and national security applications. To date, mechanical refrigeration has been the only technology for cryocooling devices that operate continuously in remote locations such as in space. However, all mechanical cryocoolers have moving parts that not only limit their reliability but also introduce mechanical vibrations and microphonic noise that limit system performance.

Markus Hehlen of the Laboratory's Engineered Materials group and collaborators have — for the first time — demonstrated an all-solid-state optical refrigerator that operates at cryogenic temperatures and has no moving parts. Their work represents a breakthrough in cryogenics. It has been published in the *Nature* journal *Light: Science & Applications* and was featured in *Nature Photonics*.

Cryocooling effect first observed at Los Alamos

All-solid-state cryocooling is an optical effect that occurs in certain materials via anti-Stokes fluorescence. In this process, a solid is excited by a laser and subsequently fluoresces at a slightly greater mean energy (shorter wavelength) than that of the exciting laser. The corresponding energy difference is provided by phonon energy (heat) that is extracted from the solid and carried away as light, thus cooling the solid in the process. This effect was first observed by Richard Epstein at Los Alamos National Laboratory in 1995.

Ultrapure rare-earth-doped crystals such as Yb^{3+}-doped $YLiF_4$ (YLF:Yb) developed by the project team over the past two decades offer the required spectrally narrow optical transitions and >99 percent quantum yields. Previous work had only cooled the YLF:Yb crystal itself. Cooling a useful payload such as a sensor by using a YLF:Yb crystal, however, posed a range of additional engineering challenges.

Key advances open doors to new applications

In the most recent effort, the team developed the following:

- a custom-shaped thermal link that connected the YLF:Yb crystal to the sensor with good thermal conductivity while rejecting the intense crystal fluorescence
- an adhesives-free bond between the thermal link and the YLF:Yb crystal
- silica aerogel supports that secured the cooled assembly inside the cryocooler with minimal conductive heat load.

These advances have enabled laser-cooling of a HgCdTe infrared sensor to 135 K for the first time (see figure below). This represents a breakthrough in the field of cryogenics and opens the door to using this technology for a variety of applications that benefit from a reliable cryogenic refrigerator having no moving parts and no associated vibrations.

The project team was led by Hehlen and included Lab employees Christopher Hamilton and Tana Cardenas of Engineered Materials, Steven Love of Space and Remote Sensing, Kevin Baldwin of the Center for Integrated Nanotechnologies, Todd Williamson of Nuclear and Radiochemistry, along with University of New Mexico collaborators Junwei Meng, Alexander Albrecht, Eric Lee, Aram Gragossian, Richard Epstein and Mansoor Sheik-Bahae.

This research supports the Laboratory's Science of Signature mission and Materials for the Future science pillar. The work leverages Los Alamos expertise in high-purity inorganic synthesis, halide crystal growth, thin-film deposition, silica aerogel fabrication, optical spectroscopy, high-power lasers and thermal/optical system design. The work used Lab capabilities such as the Target Fabrication Facility, the Center for Integrated Nanotechnologies and the TA-46 cleanroom infrastructure to realize the first optical cryocooler prototype.

Caption for image below: *Solid-state laser cooling of a HgCdTe sensor to 135 K using a YLF:Yb crystal. The solid curve shows the sensor temperature as a function of time after turning on the pump laser (47 W at 1020 nm). The inset is a picture of the optical cryocooler assembly developed in this project.*