A laser refrigerator: Cooling with light

by Mark Wilsey

The laser is often thought of as the ultimate cutting torch. The intense energy of a laser's light beam can generate searing heat in a wide array of materials, from hardened steel to human tissue, making it an extremely versatile tool. Now, set that notion aside. Scientists at the Los Alamos National Laboratory in New Mexico, have demonstrated for the first time that laser light can be used to *cool* a solid object.

Combining advanced laser technology and optical materials with some quirky atomic physics has yielded what could promise to be a new generation of low-temperature refrigerators, cryocoolers. Such devices would be very compact and durable, ideal for applications in space, where they could cool sensors and instruments on board satellites. Or, perhaps, one day laser coolers could be incorporated into desk-top computers to cool superconducting circuits which would operate hundreds of times faster than the conventional electronics of today.

In the past several years, researchers in various laboratories around the world have achieved spectacular results in using lasers to cool atoms to incredibly low temperatures, a few millionths of a degree above absolute zero (0°K, see *21st Century Science & Technology* magazine, Fall 1995, p. 54). However, these experiments involved only a relatively small number of atoms in a gas phase. In contrast, the experiments at Los Alamos use a solid piece of material and employ different physical principles. Richard Epstein and his co-workers reported their findings in *Nature* magazine on Oct. 12.

More than 65 years ago, scientists theorized that it might be possible to cool an object though its interaction with light, but only recently has the technology existed to successfully attempt it. Epstein explains that it is today's high-efficiency lasers and high-purity fiber optic materials that make it possible. Inefficiencies would make the cooling effect impractical. Impurities, which lead to heating, would make it impossible.

While it may seem counter-intuitive, the physics is fairly straightforward. The trick is to match the laser light and the properties of the material such that the material, when excited by the light at one frequency, will emit light, or fluoresce, at higher frequencies, which carry more energy, and cool the material. The temperature of an object is related to the heat energy it contains, which is associated with the motion or vibrations of the atoms within the object. One way to view this cooling effect is that the incoming light sops up some of the vibrational or heat energy of the material, that is then removed by the fluorescent light.

In the experiments at Los Alamos, the researchers used a small sample of ultrapure metal-fluoride glass impregnated with ytterbium ions. The glass is exposed to a laser beam of infrared light. The wavelength of the light, about one micron, is selected such that the light only interacts with the ytterbium and none of the other components of the glass.

The simplest picture to help explain the atomic physics involved, is to think of the ytterbium ions as having, for the sake of this example, three different energy levels. Let's label them A, B, and C. Levels A and B are very close to each other, and C is at a much higher energy level. The laser light pumps energy into the ytterbium, exciting it from level B to C. At level C, it releases this excess energy by emitting light, which, roughly half of the time, takes it down to level A. It emits a slightly greater amount of energy going from C to A, than it received going from B to C. The energy needed to restore equilibrium, that is, to go from A back to B, comes out of the vibrational energy of the material, thus cooling it slightly. In reality, nature is a bit more complicated, but that is the general idea.

For the small sliver of material used in the experiments, Epstein and his colleages recorded a temperature drop of just 0.3°K, but more than enough to demonstrate the principle. In the present setup, the laser simply passes through the material once. Future experiments will use mirrors at both ends of the material, to reflect to light back into material. Allowing the light to make several passes would enhance the cooling effect, and make better use of the light.

What about other materials? Epstein explains that they have used these materials because they are familiar with them and they are readily available. But he doubts these are the optimal materials. "The best materials are still to be found," he said.

The Lassor

These initial experimental results have been sufficient to enable researchers to project what the performance of a first-generation laser cryocooler might be. They've dubbed such a future device the Los Alamos Solid-State Optical Refrigerator, or Lassor. They predict that it should able to achieve temperatures of 60°K. Such temperatures are well within the range of today's high-temperature superconductors, opening the possibilities for a myriad of applications. The Lassor, being an entirely solid-state device, would have no moving parts, nor working fluids, making it well-suited for use in space. Here, reliability is second only to size and weight in importance in the design of spacecraft systems. These could be ready for uses in satellites within a few years, researchers say.