This Switch Takes the Heat

A powerful laser pulse generates plenty of heat. Some lasers, like Livermore's National Ignition Facility or the older Nova laser, produce a highly intense burst of light and then must cool for hours before another shot can be fired. Other laser systems are designed to operate almost continuously. The challenge in designing this latter variety, known as average-power lasers, is to maintain the beam quality in the presence of heat. Heat can cause aberrations to the laser beam, degrading its quality.

Livermore physicist Chris Ebbers and technician Keith Kanz, working with visiting scientist Hitoshi Nakana from Japan's Kinki University, have helped to solve this problem by developing a Q-switch that compensates internally for the heat from the laser beam. They received an R&D 100 Award for their innovation.

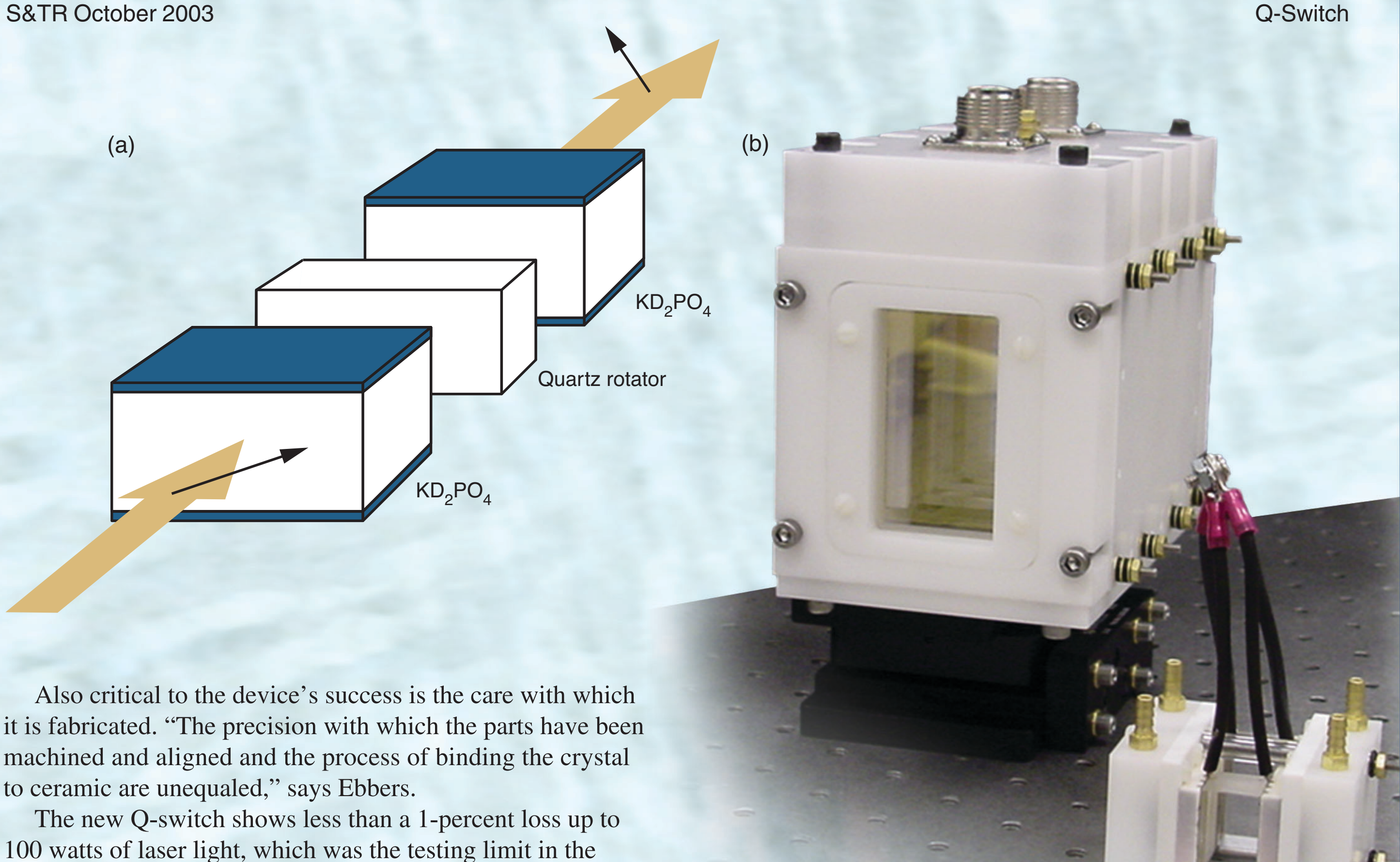
Q-switches, which maintain the quality, or "Q," of the beam, stop unwanted laser oscillations—laser pulses before and after the main laser pulse. An efficient Q-switch is essential for a high-energy, multipass laser to function at all. In fact, the thermally compensated Q-switch enables an entirely new type of laser architecture—a higher-average-power system that is more compact and more efficient than was previously possible. The team designed the award-winning switch for Livermore's Mercury laser, which has an unusually large beam size, but the switch can be used for any high-average-power laser.

An electronically controlled shutter is required to stop unwanted laser oscillations, and it must respond in a time frame as short as the desired laser pulse. A Q-switch—also known as a Pockels cell or an electro-optic switch—uses a crystal whose refractive index is dependent on the voltage applied to it. It is one of the few electrically driven devices that can respond in a nanosecond. Because light travels approximately 1 foot (or 0.3 meter) in 1 nanosecond, a light switch must change the propagation direction of the laser light on this nanosecond time scale.

The problem with existing electro-optic cells is that heat absorbed from the laser beam prevents the cell from functioning. At average powers above 30 watts, the cell's crystal heats up. The switch then allows light to "leak" because the laser beam is depolarized. That leaked light can be amplified as well, creating spurious parasitic laser beams, degrading the quality of the initial beam, reducing the average power output, and possibly damaging the laser's optics.

Traditional electro-optic Q-switches use a single electro-optic crystal made of potassium di-deuterium phosphate, also known as deuterated KDP or KD_2PO_4. All single-crystal Q-switches exhibit a temperature-dependent loss of power above 15 to 30 watts, which allows light to leak. Livermore's thermally compensated Q-switch is made of the same material, but it incorporates a quartz rotator and a second, identical crystal, as shown in the figure on the next page. The leakage, or depolarization loss, exhibited by the first crystal is canceled because the leaked light is propagated through the polarization rotator and the second crystal.

Chris Ebbers (left) and Keith Kanz show the high-average-power electro-optic Q-switch.



Livermore's thermally compensated Q-switch. (a) Light leaking from the first crystal is propagated through the polarization rotator and the second crystal. (b) Livermore's Q-switches for large aperture (3.25-by 6-centimeter) and smaller aperture (1.5- by 3-centimeter) high-average-power laser systems. The switches are made of carefully machined and aligned potassium di-deuterium phosphate (KD_2PO_4).

Also critical to the device's success is the care with which it is fabricated. "The precision with which the parts have been machined and aligned and the process of binding the crystal to ceramic are unequaled," says Ebbers.

The new Q-switch shows less than a 1-percent loss up to 100 watts of laser light, which was the testing limit in the laboratory. "Extrapolating from these measurements, we expect the device to operate up to and even beyond 300 watts," says Ebbers. That range is 10 times higher than any equivalent commercially available electro-optic Q-switch. A laser system using Livermore's new switch could thus generate an unprecedented 5 kilowatts of average power or more without significant light leakage.

Putting the Q-Switch to Work

Livermore's Q-switch is one of several devices and systems developed in recent years to enable the construction of the Mercury laser, a large-aperture (large-beam-size), high-average-power laser with a high repetition rate. The Mercury laser is a smaller version of a potential prototype for an inertial fusion energy driver. As such, it will be used to study how high-intensity light interacts with matter. It will produce 100-joule pulses at a repetition rate of 10 hertz, for an average power of 1 kilowatt. Funding from the Laboratory Directed Research and Development Program has been key to developing the Mercury laser and components such as the Q-switch that make this unique laser possible.

Similar high-average-power lasers are also being considered for defense and civilian applications. For example, a compact laser in a helicopter would function as a very bright flashlight to detect mines, look for bodies in murky water, or search for obstacles on the floor of an ocean bay. The high repetition rate and short pulse width made possible by the Q-switch would give this detection tool excellent time resolution.

Laser peening, a process developed at Livermore several years ago to strengthen metals, also makes use of high-average-power lasers. By inserting the Q-switch into this system, the laser's pulse could be tailored to any desired shape to match the needs of the material being peened.

—Katie Walter

Key Words: high-average-power lasers, laser peening, Mercury laser, R&D 100 Award, thermally compensated Q-switch.

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