Light-Speed Spectral Analysis

SCIENTISTS and engineers have harnessed the power of laser light for an astonishing array of applications. High-intensity lasers are used extensively in basic science, energy, and defense research. However, the ever-greater levels of strength and brightness that these lasers can achieve make the amplified light a danger to the laser system's optical components. A team of researchers led by Paul Armstrong has won an R&D 100 Award for its lightning-fast solution to the threat of damaging laser light. The technology, called spectral sentry, was developed under the Mercury laser project for the National Ignition Facility (NIF) and Photon Science Principal Directorate.

When energized electrons are stimulated to produce an initially weak laser pulse, all the photons emitted will be the same wavelength, or color of light. Within a laser system, these initial pulses are amplified trillions of times. While the intense energy produced is essential for modern laser applications, it can, at upper limits, produce unwanted effects. High-power pulses can create intense acoustic waves that ruin experiments by distorting the pulses, scattering useful light, or even cracking laser optics. For example, stimulated Brillouin scattering (SBS), a damage-producing process, tends to disperse laser light backward toward low-energy laser components or perpendicularly, creating damage sites on optics while sapping energy from the laser beam. Even a single pulse could create enough damage to result in system repairs and downtime.

Broader Bandwidth Solution

Undesirable scattering is a source of great concern to high-intensity laser designers, who need the light to behave in a useful, focused, predictable way. Researchers have found that broadening the bandwidth—the range of colors—of the laser light before amplification can suppress SBS and stimulated Raman scattering as well as reduce hot spots in the beam's profile, which are created when a laser interferes with its own reflections. Broad bandwidth also enables creation of the extremely short-duration pulses that are necessary for many high-intensity physics experiments.

Spectral sentry ensures that high-intensity laser systems amplify only laser pulses with sufficient bandwidth, preventing potentially damaging low-bandwidth, high-energy laser pulses from being produced. This optical device can analyze a single laser pulse traveling at the speed of light and stop that pulse if it does not meet the minimum bandwidth requirements.

The spectral sentry device has been successfully tested and used on Livermore's Mercury laser and is the fourth R&D 100 Award-winning technology to emerge from the Mercury project. Mercury is a one-beam, high-average-power, solid-state laser used to develop and demonstrate fusion-energy system technology. When Mercury operates with single-color light, it may be run only at energies of up to 65 joules to prevent unwanted optical effects. When Mercury generates broader bandwidth light, the operating energy levels may be safely increased. However, the risk of a small

Spectral sentry development team: (front row, from left) Rob Campbell, William Molander, Paul Armstrong, Christopher Ebbers, and Noel Peterson; (back row) Steven Telford, Richard Shuttlesworth, Glenn Huete, Rodney Lanning, Nick Schenkel, and Andy Bayramian.

# of a Laser Pulse

Developer Paul Armstrong peers into the spectral sentry optical device used to protect laser systems from pulses with insufficient bandwidths.

electrical glitch, hardware failure, or human error causing narrow bandwidth beam production is great enough that the safe operating limit is still kept at the single-color level. With the addition of spectral sentry, the system can safely operate at 100 joules, in line with design goals, without fear of bandwidth-related damage.

The need for spectral sentry was clear for Mercury—its repetition rate of up to 10 shots per second is simply too fast for experimentalists to visually check diagnostics and confirm appropriate bandwidth for each shot. However, users of a range of other broad-bandwidth and high-energy lasers worldwide could also find spectral sentry's technology, generally referred to as bandwidth interlocking, essential for performing experiments requiring confidence that optics will be protected from damage.

Results within Nanoseconds

Spectral sentry completes its work in three steps, all in the span of 34 nanoseconds, during which time the beam continues on its path toward the laser's amplifiers. A small sample of the beam is first separated into its individual colors using a high-resolution spectrometer. This sample is divided into three spectral regions, and mirrors reflect the long- and short-wavelength portions onto the second part of spectral sentry, the two high-speed photodiode detectors. The central wavelengths are either terminated or propagated to yet a third detector for further analysis. The use of two photodiode detectors provides an additional level of verification that the beam truly has sufficient bandwidth, because a misaligned beam may appear to a single photodiode detector as having an adequate spectral spread. The final portion of spectral sentry is an electronic subsystem that receives signals from the photodiode detectors and logically analyzes them. If the bandwidth is acceptable, a digital signal is sent to an optical switch, allowing that individual pulse to pass.

The tremendous speed with which this detection and analysis process is completed allows it to be used on lasers with pulse repetition rates up to 5 million shots per second. "Speed is our 'wow' factor," says Armstrong. "Spectral sentry can measure pulses traveling at the speed of light and can actually get an electric signal ahead of the pulse by adding just a slight delay. Its job is to protect high-value lasers from unpredictable high-speed events."

Spectral sentry combines the extreme speed required for same-shot bandwidth interlocking with the flexibility needed for use in a wide range of applications. The adaptability component of the device enables it to address virtually any form or amount of bandwidth a laser designer may need. As technology improves and laser energy levels and repetition rates continue to climb, spectral sentry can be expected to safeguard lasers in many areas of research, including inertial fusion energy, defense, materials processing, and high-energy-density physics.

—Rose Hansen

Key Words: bandwidth, interlock, Mercury laser, optics damage, R&D 100 Award, spectral analysis, spectral sentry.

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