# The Power of Combined Laser Light

FROM their use in technologies as simple as laser pointers to as complex as the National Ignition Facility, lasers have a wide range of applications in today's world. Typically, laser-based devices rely on a single-output system, where the laser is produced from a solitary source and then amplified through sophisticated optics. In contrast, spectral beam combining (SBC) is a technique in which several individual beams with nonoverlapping optical spectra are combined to produce one high-power beam.

SBC systems generally use fiber lasers as the beam source because they are robust, efficient, and compact. Fiber lasers can also operate over a range of wavelengths. The lasers are coupled with a dispersive optical element, such as a diffractive grating or prism, which can deflect incident beams according to each beam's wavelength and spatially overlap the beams so that they propagate in the same direction. However, these optical elements typically cannot handle the higher power needed for advanced material processing applications, scientific research, and certain military purposes.

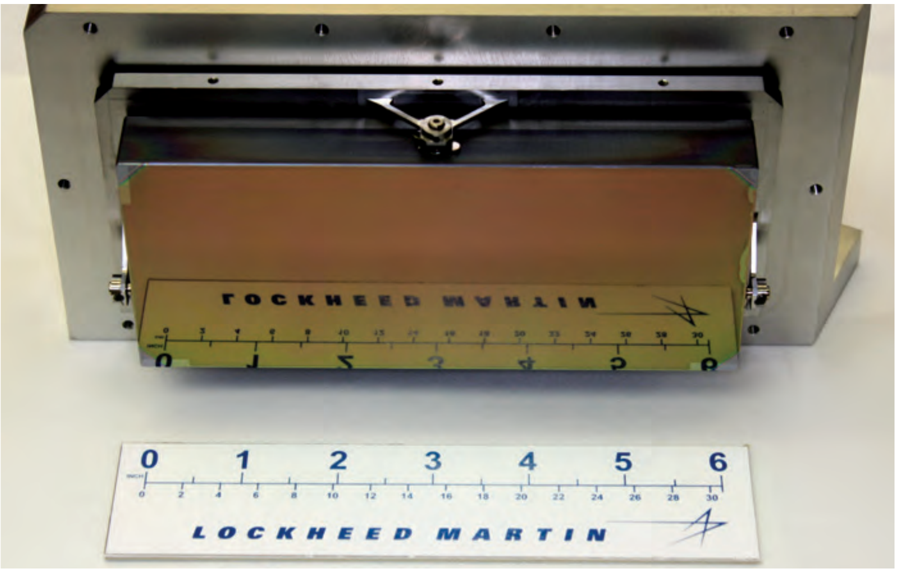
An R&D 100 Award–winning team comprising researchers from Lawrence Livermore, Lockheed Martin, and Advanced Thin Films, Inc., has developed the extreme-power, ultralow-loss, dispersive element (EXUDE) for adapting SBC to high-power applications. EXUDE integrates improved optical coatings, a novel surface-relief grating structure, and innovative fabrication and processing techniques to enable an electrically efficient, near-diffraction-limited multikilowatt SBC laser system.

## Scaling Up the Power

The increased demand for high-power laser sources with diffraction-limited beam quality has led to significant scaling in the output power of laser systems. Attempts at scaling single-output lasers to more than 100 kilowatts has revealed issues with removing waste heat, maintaining beam quality, and avoiding optics damage at the higher powers. Electrically driven solid-state lasers have demonstrated more than 100-kilowatt output, but thermo-optical distortions in the bulk laser materials degraded beam quality, limiting the beam's irradiance.

An SBC system that can effectively combine diffraction-limited beams of varying wavelengths into a single beam with broad gain bandwidth provides a straightforward approach to power scaling. Until EXUDE, the output power of SBC systems was limited by the ability of the beam combiner to minimize power loss. EXUDE is a precisely designed and fabricated surface-relief grating structure embedded into the topmost

Development team for the extreme-power, ultralow-loss, dispersive element (EXUDE): (from left) Hoang Nguyen, Curly Hoaglan, James Nissen, Cindy Larson, Tom Carlson, Jerry Britten, and Mike Aasen. (Photo by George A. Kitrinos.)




EXUDE is a surface-relief grating structure embedded into the topmost layer of a highly reflective, multilayer dielectric thin film. The device spectrally combines laser beams from multiple sources into a single, high-power beam to achieve unprecedented output levels. (Photo courtesy of Lockheed Martin.)

layer of a highly reflective, ultralow-loss, multilayer dielectric thin film.

EXUDE combines the beams from many laser sources of the same type, in particular fiber lasers, wherein the sources operate at specific wavelengths. The operating wavelength and incidence angle of each fiber laser is tuned to a precise value so that all of the output beams overlap to produce a single beam. Because fiber lasers can produce nearly diffraction-limited beams at very high electrical to optical efficiency, the output of the SBC system can also be nearly diffraction-limited, with minimal loss resulting from the element itself.

In a recent demonstration conducted by Lockheed Martin, the EXUDE-based SBC system successfully combined fiber lasers into a single 30-kilowatt beam of light. "Even at these high powers, our EXUDE optic maintained excellent efficiency and beam quality, paving the way for advanced defense applications," says Jerry Britten, the Livermore team lead. "EXUDE also provides the laser industry with a way to meet critical commercial demands for compact, highly efficient, multikilowatt laser systems."

## An Expert Collaboration

EXUDE provides an excellent example of how experts in different scientific and research disciplines can work together to create technologies with superior capabilities. "Livermore was responsible for designing and fabricating the surface-relief grating structure that enables multiple output beams at different angles to come off an optic at the same angle, allowing their powers to add," says Britten. The diffraction grating is manufactured on top of an optic that comprises a multilayer stack of high- and low-index materials to provide the maximum diffraction efficiency.

Advanced Thin Films, Inc., fabricated the ultralow-loss multilayer dielectric films for the optic. The proprietary optical coating, designed by Livermore, allows for the stacking of more than 100 film layers to achieve ultralow-loss, parts-per-million transmission levels, high diffraction efficiency, and large bandwidth. The company also postprocessed the films to ensure a flatter diffractive wave front. The surface-relief grating structure is precisely impedance matched to the thin-film stack for improved optical performance. Additionally, both the surface-relief grating structure and the optical thin films can be placed on thermally conductive materials.

The final gratings were delivered to Lockheed Martin, which integrated the components with the rest of the fiber-laser hardware and conducted the tests. "The 30-kilowatt demonstration validates our approach for an efficient, near-diffraction-limited, high-power laser system," says Britten. "In the future, we expect to achieve significantly higher power levels to address critical defense needs."

Through this collaboration, the EXUDE team proved that unprecedented efficiency and beam quality can be achieved in a high-power system by spectrally combining fiber lasers or other types of lasers to the desired output powers. Furthermore, the modular approach of using multiple fiber lasers to produce the higher powers simplifies manufacturing and maintainability. With the advent of EXUDE, the range of laser-based applications has been even further expanded.

*—Caryn Meissner*

**Key Words:** diffraction-limited; extreme-power, ultralow-loss, dispersive element (EXUDE); fiber laser; output power; R&D 100 Award, spectral beam combining (SBC).

***For further information contact Jerry Britten (925) 423-7653 (britten1@llnl.gov).***