Single-mode semiconductor emitters are limited in power to the few-hundred-milliwatt range, while many applications often require 2 to 10 W of near-diffraction-limited power. A diode-laser bar typically consists of many laser emitters along a 1-cm width. This arrangement provides efficient power generation, but the beam quality of the diode bar is about 1000 times the diffraction limit. Using a grating-based, external-cavity approach, our group spectrally beam combined (SBC) the outputs of up to 1400 laser emitters to achieve high-power, near-diffraction-limited performance from a diode-laser bar.

Although spatially overlapping the beams of multiple lasers operating at the same wavelength can produce a high-power spot, the beam cannot be effectively propagated, making it useless for many applications. In an SBC configuration, a prism combines several wavelengths into a single beam, yielding a high-power, usable output beam (see figure). The telecommunications industry uses a grating-based form of SBC to multiplex pump sources for erbium-doped fiber amplifiers. Each emitter must be controlled in drive current and temperature, however, effectively limiting the number of combined sources to around 10. To increase the number of emitters while controlling the number of components in our system, we combined the grating multiplexer with an external-cavity design for wavelength stabilization.

Our SBC cavity incorporates a single collimating lens located a focal length away from a 1-D array of laser emitters operating at different wavelengths, with the grating positioned another focal length away on the other side of the lens. This geometry ensures that the diverging beams from each laser are both collimated and overlap spatially at the grating. If we used emitters at the same wavelength, they would overlap at the grating but diverge afterward. The combination of wavelength variation and grating allows us to create a diffraction-limited, multi-spectral beam that can be propagated.

An output coupler uses a second reflection from the grating to return a fraction of the power back to each laser and form the external resonant cavity. This optical feedback allows us to stabilize the laser wavelengths so that we do not have to maintain individual thermal control or current control over each laser. The design thus requires only a few optical elements to combine hundreds of laser emitters.

To maintain the required beam quality and sufficient feedback to each emitter, the collimating lens must operate off axis. The off-axis angle increases as we move from the center of the bar to the edge, however. In addition, the divergence angle from each emitter is 5° to 10°, yielding relatively “fast” beams with f-numbers of about three. Such f-numbers, combined with off-axis angles, produce serious off-axis aberrations when combined with a simple collimating lens. As a result, we must add a lens array to the diode laser bar.

In general, a diode laser bar would require a rod lens to collect the fast-axis diode output beam. We incorporate this optical power in our lens array so that each emitter requires only one element to reduce the slow-axis divergence by at least a factor of three. This increases the working f-number for each emitter to greater than 10 and reduces the off-axis aberrations to less than the diffraction limit. It also allows the use of a simple, single-element collimating lens, resulting in a compact, low-weight, and low-cost optical design.

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References