High-power focused beams for industry

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Careful design can remove distortions that limit the use of thin-disk lasers at kilowatt power levels.

Multi-kilowatt beams with high brightness offer advantages for fast and precise material processing applications such as remote cutting, where the beam must propagate over large distances. Thin-disk lasers, like the one shown in Figure 1, are available commercially and are widely used for material processing in the automotive, solar, and microelectronic industries. They can provide the desired combination of high-power and highly focused beams because the thermally induced aberrations of the laser are orders of magnitude lower than in conventional rod- or slab-shaped crystal lasers. Furthermore, thin-disk crystals can be pumped intensively and still be cooled very homogenously and efficiently due to the high surface-to-volume ratio.

In recent years, researchers have proved the theoretical and practical scalability of thin-disk lasers to very high power levels. With high-quality crystals and optimized heat sinks, it is possible to generate beams with several kilowatts of power and very high efficiencies (typically 60–65%) by simply increasing the pump spot diameter. However, air turbulence in the cavity and a thermally-induced phase distortion (on the order of a tenth of the wavelength) in the disk itself limit the beam quality at higher powers. We have designed a high-power, high-quality thin-disk laser suitable for remote cutting.

We avoided the air turbulence by operating the laser cavity in a helium atmosphere and developed a mirror with an aspherical profile (see Figure 2). This compensated for the distortion of the optical phase caused by the temperature difference between the pump spot and the un-pumped region in the laser disk. Calculations confirmed by precise interferometric measurements showed a phase distortion in the laser experiments of about 100nm with a supergaussian edge profile.

Our design used an ytterbium-doped yttrium aluminum garnet (Yb:YAG) thin-disk laser crystal attached to a diamond heat sink. A pump cavity with 20 passes through the thin-disk crystal ensured an efficient absorption of the diode laser pump.
We configured the resonator in a simple V-shape. This consisted of a high-reflective (HR) end mirror, the HR-coated thin-disk reverse as the folding mirror, and a spherical output coupler. This design can easily be implemented in industrial lasers. Figure 3 compares the output power of a plane-end HR mirror resonator with that of an aspherical-end HR mirror resonator, for the same pump power.

The results show that the insertion of the aspherical resonator mirror allows us to achieve higher output powers for the same pump power, due to the compensation the mirror provides for the phase distortion caused in the thin-disk crystal. To further increase the output power of our laser system we applied a defocusing of the pump spot in order to reduce diffraction effects which cause additional losses. With the latter configuration, an output power of 3.4kW at an optical efficiency of 49% and a beam parameter product of 2.4mm×mrad (M²~8) were generated from one disk.

We have demonstrated that careful design can remove distortions that limit the use of thin-disk lasers at kilowatt power levels. The higher output power with improved brightness of the thin-disk laser allow longer working distances for welding and cutting of finer structures and, most important for industry, higher cutting speeds. Future research into thin-disk laser technology will look at power-scaling in combination with passive mode-locking, Q-switching at high repetition rates, and higher harmonic generation.

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References