Highly Efficient Room-Temperature Yb:YAG Ceramic Laser and Regenerative Amplifier

Room-temperature, Yb-doped YAG ceramics are attractive materials for high-efficiency broadband lasers and scalable amplifiers.[1–5] Their properties make them an excellent choice for high-energy, broadband, diode-pumped lasers and amplifiers.[6] They have a reasonably large emission cross section (2×10^{-20} cm^2), a long upper-level lifetime (>1 ms), a high saturation fluence, a small quantum defect (8.6%), and broadband absorption (18 nm) and emission (>100 nm) spectra. Their hardness and fracture toughness are higher than for YAG crystals, high doping levels are possible (up to 20%), and active elements with large apertures (tens of centimeters) are available. In addition, they function as a quasi-three-level system at room temperature and a four-level system at liquid-nitrogen temperature, and they are polarization insensitive, enabling one to easily configure multipass amplifiers using polarization switching schemes.

A room-temperature diode-pumped Yb:YAG ceramic pulsed laser has been developed that produces 120 mJ at 1030 nm in free-running mode with a high optical efficiency (laser output power divided by diode pump power) of 51%. The laser (Fig. 128.14) has a folded, ~280-cm linear resonator that is close to semiconcentric. The mode diameter in the active element is tuned by moving the 3-m concave end mirror along the resonator axis. Initially, the mode diameter was set to 550 μm at the $1/e^2$ level. The $8 \times 8 \times 10$-mm, 7% Yb-doped YAG ceramic active element[7] is wedged and AR coated for the pump and laser wavelengths. A 940-nm, 250-W–rated, fiber-coupled pump diode (Jenoptik JOLD-250-CPXF-2P2) (Ref. 8) is used in pulsed mode with a 1-ms pulse width at a 5-Hz repetition rate. The pump radiation is 1:1 re-imaged from a 0.4-mm fiber core into the active element. Approximately 235 mJ of pump-pulse energy is absorbed in the active element at the maximum 140-A diode-driver current.

A single-pass, small-signal gain of 160 has been measured at the maximum driver current. The laser output energy was maximized by optimizing the output-coupler reflectivity, using a set of flat mirrors with reflectivities from 10% to 90% with 10% steps. The optimum reflectivity has been found to be 50%, resulting in output energy in excess of 102 mJ.

Further optimization was accomplished by fine tuning the mode size inside the active element to achieve the highest-possible energy. A mode-diameter increase from 550 μm to 665 μm (when the pump-to-mode-diameter ratio is 0.6) led to an output-energy increase from 102 mJ to 120 mJ, corresponding to an optical-to-optical efficiency of 51%. The output energy of the laser as a function of absorbed pump energy is shown in

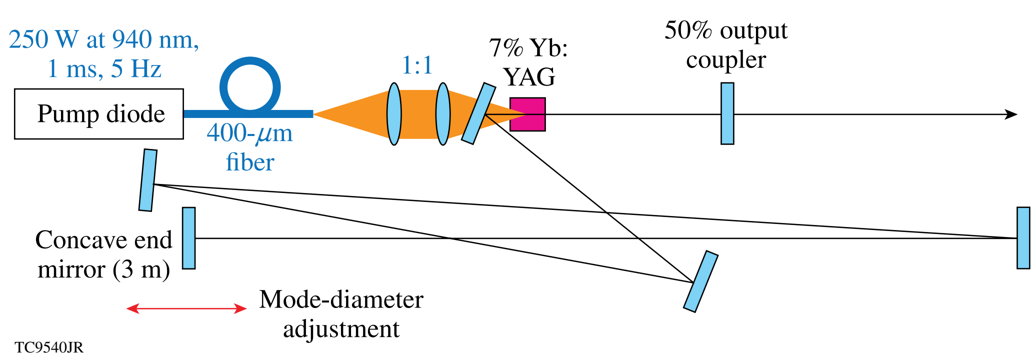

Figure 128.14
Block diagram of the Yb:YAG ceramic laser.

Fig. 128.15(a). Taking into account that contemporary pump laser diodes can provide an electrical-to-optical efficiency of up to 80%, a Yb:YAG ceramic laser can potentially achieve a wall-plug efficiency of >40%. The fine tuning of the mode diameter made it possible to achieve a slope efficiency of 78%, which is slightly higher than has been previously achieved in a room-temperature Yb:YAG ceramic laser.[1,2] Figure 128.15(b) shows a good-quality output-beam profile with lineouts through the center that are approximately Gaussian.

The active element has also been demonstrated in a regenerative amplifier (regen) used to amplify 8-ns FWHM (full-width-at-half-maximum) square pulses (Fig. 128.16). Here optical damage was avoided by increasing the mode and pump-beam diameters. The pump fiber was re-imaged into the active element with a 50% expansion, producing a 600-μm pump spot. The regen mode diameter was optimized for maximum output energy with a pump–to–mode-diameter ratio of 0.62. The output energy was limited to 5 mJ because of intracavity polarizer

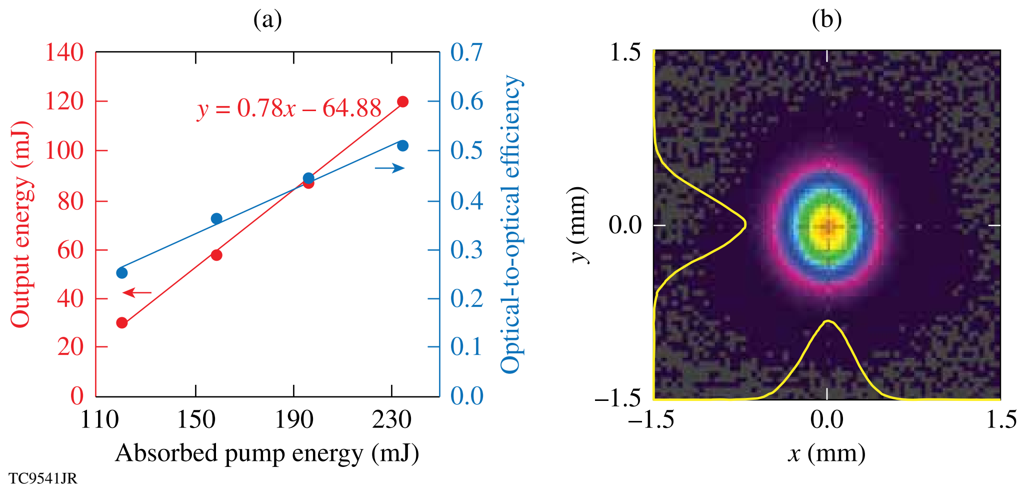

Figure 128.15
(a) Output energy and optical efficiency as functions of absorbed pump energy for the optimized Yb:YAG laser. (b) Near-field image of the laser output at maximum energy with one-dimensional (1-D) lineouts overlaid.

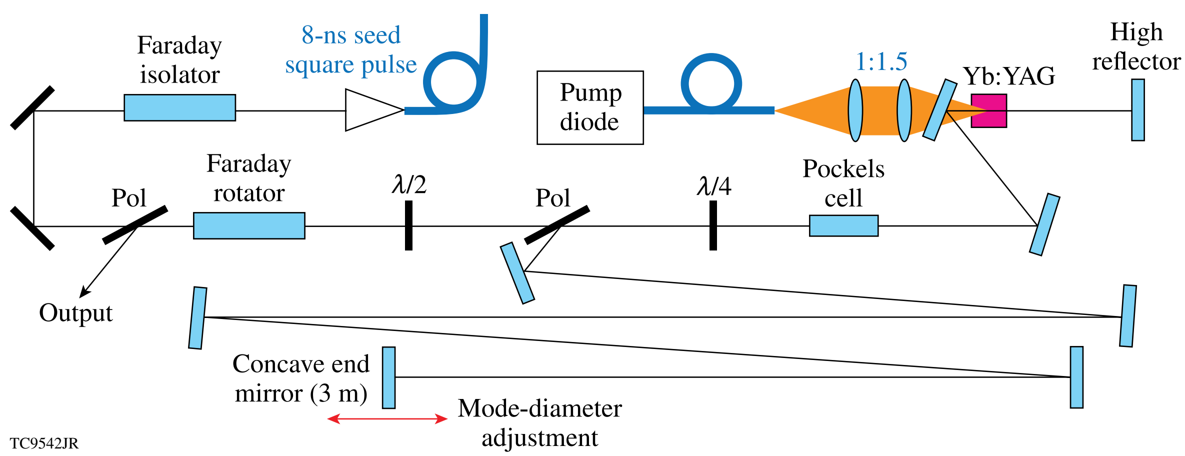

Figure 128.16
Yb:YAG ceramic regenerative amplifier. Pol: polarizer; $\lambda/2$: half-wave plate; $\lambda/4$: quarter-wave plate.

damage. The pump current was 80 A at this point, with the 140-A maximum current available indicating that more energy can be achieved from the regen with increased pump-volume diameter. The output-beam profile was of similar quality to that of the free-running laser and was close to TEM_{00}.

The pump-volume diameter was further increased to 670 μm with the mode diameter increased in proportion. Output energy of 14.5 mJ was produced at the 140-A maximum pump current [Fig. 128.17(a)]. The output energy variations decreased to ~0.2% rms as the output energy was increased, as a result of the increase of the gain/loss ratio.[9] The number of round trips in the regen at this point is 4, with the regen functioning more as a multipass amplifier, where the beam profile is defined not by the resonator but by the radial-gain variations in the Yb:YAG.

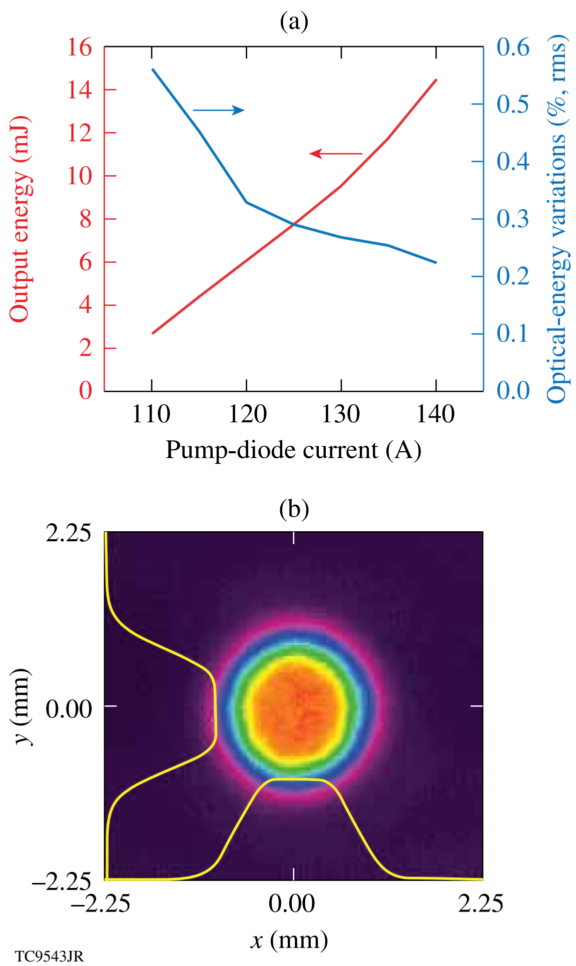

Figure 128.17
(a) Output energy and energy variations of the regen pumped with a 670-μm pump spot. (b) Near-field image of the output beam at maximum energy with 1-D lineouts overlaid.

The output profile was a fourth-order super-Gaussian, resulting from heavy gain saturation along the beam axis [Fig. 128.17(b)].

The broad bandwidth of the Yb:YAG makes this regen suitable for the amplification of stretched broadband pulses in chirped-pulse–amplification laser systems and also for systems that require bandwidth for SSD (smoothing by spectral dispersion).[10]

In conclusion, a room-temperature, diode-pumped pulsed Yb:YAG free-running laser with 78% slope efficiency has been demonstrated. It has been shown that fine tuning of the mode diameter to the diameter of the pumped volume is important to achieve maximum laser efficiency with a Gaussian-like beam profile. A regenerative Yb:YAG amplifier with maximum output energy of 14.5 mJ and a super-Gaussian beam profile has been built and tested.

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