coated for a pumping wavelength of ~975 nm, by diode arrays. The rod is pumped through focusing prisms, which are used as emitting-area converters, similar to a lens duct.[14] The total peak power of the diode arrays is 1.2 kW, with a 500-μs pumping duration. A one-dimensional temperature gradient is induced in the rod by unidirectional heat flow, which results in thermal-induced birefringence, astigmatism, and bifocusing. The birefringence and bifocusing are reduced when the oscillating beam is linearly polarized in parallel or perpendicular to the direction of the heat flow. We compensate for the astigmatism by arranging two pumping heads in series along the optical axis, and the side surfaces in contact with the heat sinks intersect perpendicularly. This arrangement also partially compensates for birefringence and bifocusing. The focal length of the thermally induced lensing effect for the single pumping head is 11 and 60 cm parallel and perpendicular to the heat flow, respectively. The single-pass maximum small-signal gain $g_0 l_{\mathrm{Rod}}$ of the module was measured to be approximately 0.32 at the wavelength of 1.54 μm, in good agreement with the designed value. Combined with a 70-mm-long flat–flat resonator, this pumping module produces a maximum laser output energy of 126 mJ in full multimode operation at the laser-diode output energy of 1.2 J. The threshold laser-diode output energy is 0.58 J, and the slope efficiency is as high as 20.3%.

To obtain a pulse width of more than 200 ns with a small-signal gain of 0.32 requires a long cavity length of 2 m. In addition, the small aperture size of the rod, 1.7 mm × 1.7 mm, limits the TEM_{00}-mode size at the rod position. This cavity condition gives a low Fresnel number of 0.24 and high diffraction loss for the laser operating in TEM_{00}-mode. We have devised a flat–flat symmetrical telescopic cavity that can reduce the effective cavity length and increase the equivalent Fresnel number of the cavity. The schematic diagram of the cavity is shown in Fig. 2. The pumping module is located at the center of the cavity between two telescopes. The beam size at the rod position is optimized by magnification M of the telescopes to maximize TEM_{00} laser output. At the same time, the stable zone of the cavity is shifted to the maximum pumping power by a change in the focal length of the telescopes to yield a cavity parameter[15] $g_1 g_2$ of 0.5. The telescopes are located so close to the rods that optical axis misalignment owing to misalignment of the high-reflection mirrors (HR1 and HR2) becomes almost the same as that of the flat–flat cavity that is M times larger. For the designed telescope magnification M of 3.0, the mirror misalignment sensitivity necessary to reduce the output energy by 10% is calculated by two-dimensional Fox-Li analysis to be 680-μrad.[16]

By use of the pumping module and the cavity configuration, a single-frequency Q–switched TEM_{00} laser was constructed. Figure 3 shows a schematic diagram of the developed Er, Yb:glass laser. We fold the optical path of the 2-m-long cavity eight times to realize a compact assembly. A β-barium borate Pockels cell, which has a high damage threshold of typically 10 J/cm^2 for a 10-ns pulse and no piezo-optic effect, is used for the electro-optic (EO) Q-switch. The polarizer–output–coupler composed of a high-energy cube-type polarizer (P1) and a quarter-wave plate (QWP) is used to obtain linearly polarized laser output. The output-coupling ratio is adjusted by rotation of the axis direction of the QWP. The cavity-length tuner is composed of two roof prisms and a piezoelectric transducer that can vary the spacing between two prisms. A commercial external-cavity single-frequency laser diode is used as an injection-seeding light. The fiber-coupled output power is ~8 mW, and the linewidth is less than 100 kHz for a period of 10 μs. A part of the laser diode output is frequency shifted by an intermediate frequency of 85 MHz at the acousto-optic shifter (AO shifter) and injected into the pulsed laser cavity through the P1 as an injection-seeding light. To realize stable and single-longitudinal-mode oscillation, we use a cavity-length control method based on stabilizing the beat frequency between the pulsed laser output and the seeded light. The monitor light of the pulsed laser is mixed with the laser diode output at the optical detector. The detector generates a beat signal. When the pulsed laser output frequency coincides with the seeded light's frequency, the frequency of the beat signal coincides with the intermediate frequency. A frequency discriminator, which consists of a low-pass filter and a high-pass filter for the intermediate frequency, generates an error signal from the difference between the beat frequency and the intermediate frequency. The error signal is averaged for a period of 300 ms and fed back to the piezoelectric transducer in the cavity-length tuner to keep the beat frequency constant.

Figure 4 presents the laser output characteristics in TEM_{00}-mode operation. The maximum output

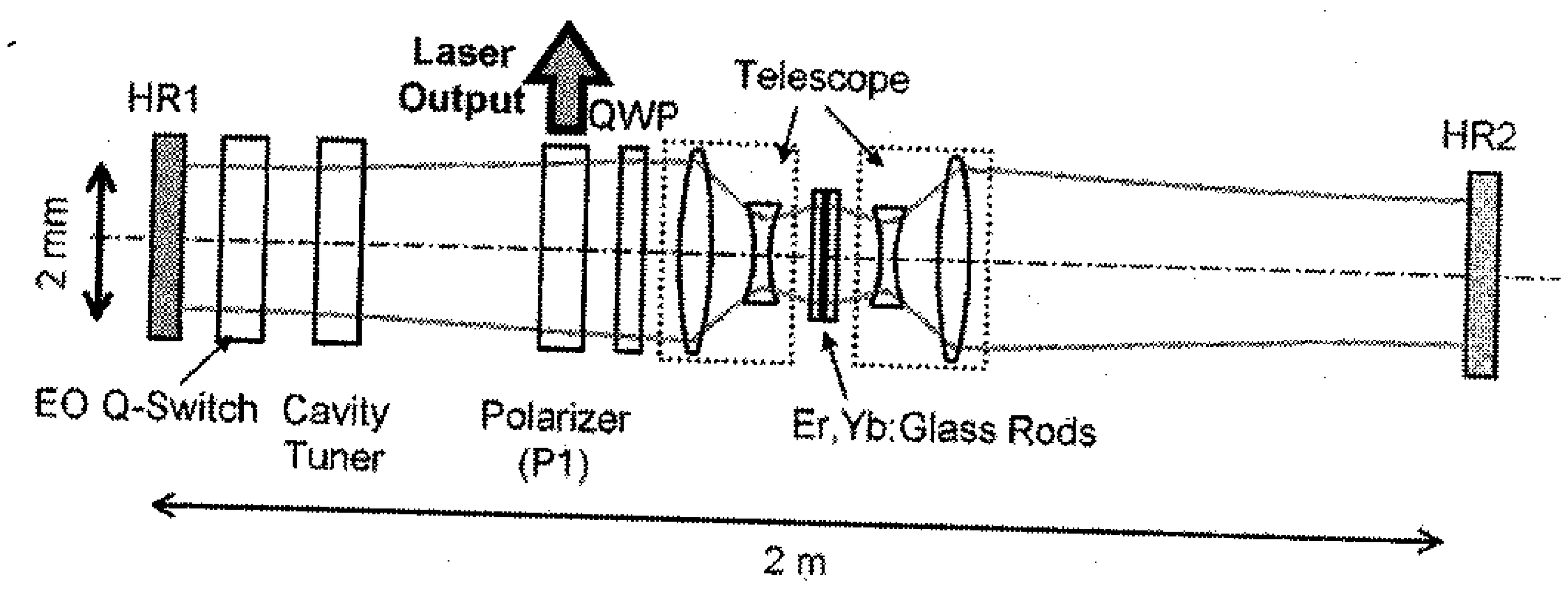

Fig. 2. Schematic diagram of the flat–flat symmetrical telescopic cavity. QWP, quarter-wave plate; EO, electro-optic. See text for definitions.

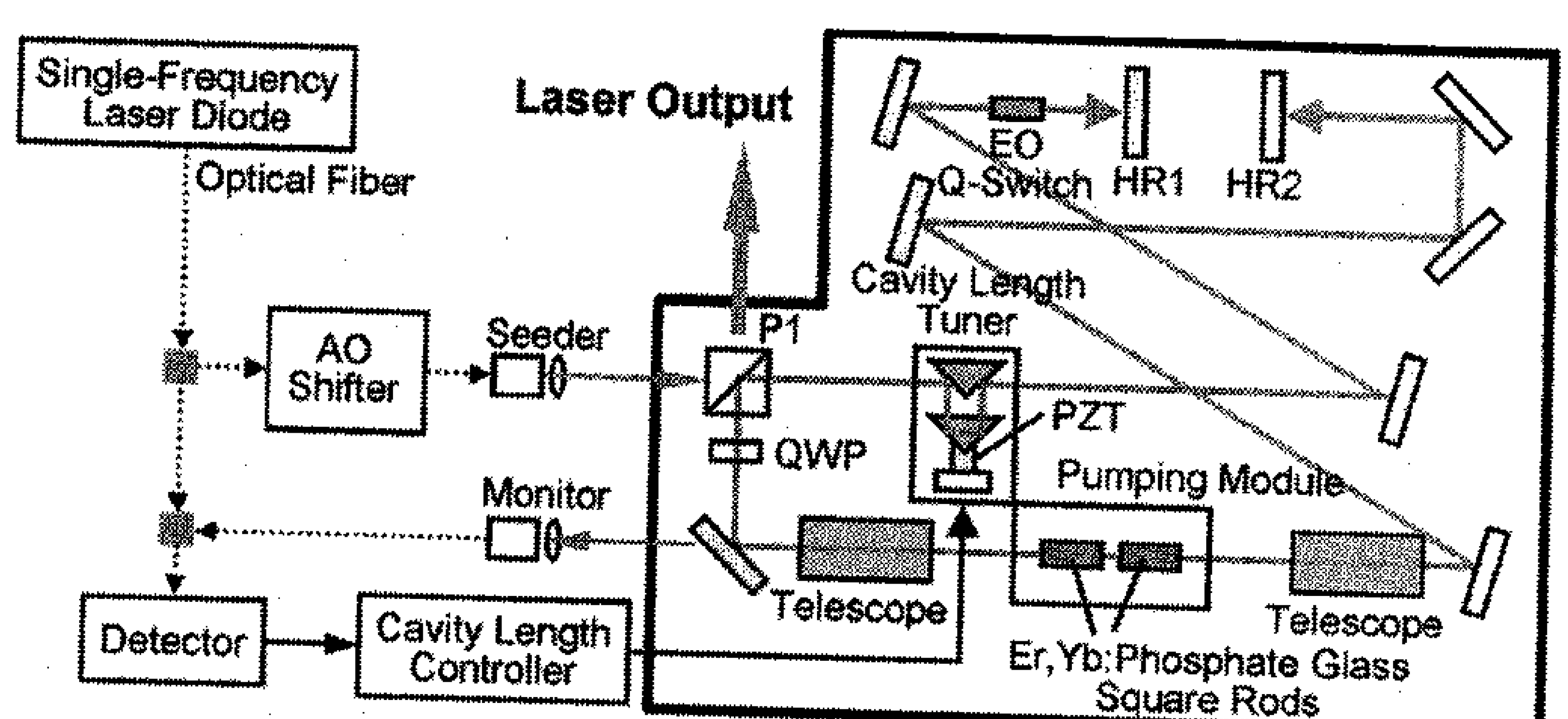

Fig. 3. Schematic diagram of the developed single-frequency diode-pumped Q–switched Er, Yb:glass laser. PZT, piezoelectric transducer. See text for other definitions.