Four-pass amplifier for the pulsed amplification of a narrow-bandwidth continuous-wave dye laser

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We demonstrate a new type of four-pass dye laser amplifier that can reduce the possibility of parasitic oscillation between optical components used in the amplifier. Pumping the amplifier with a 5.6-mJ Q-switched doubled Nd:YAG laser output, we obtain high-peak-power pulsed output of an incident cw narrow-bandwidth dye laser beam with a power gain greater than $2 \times 10^6$. Subsequent amplification of the pulse with a conventional dye amplifier yields 42% energy efficiency. When a temporally stretched pumping pulse is used, the eventual bandwidth of the final output is measured to be 130 MHz.

Since the introduction of pulsed dye lasers, many studies have tried to achieve single-longitudinal-mode operation for high-resolution spectroscopic application. Most have used highly dispersive elements such as diffraction gratings or a Fabry–Perot étalon inside the laser cavity. In many cases, however, the pulse duration is too short to establish a single longitudinal mode and results in a bunch of modes whose frequencies jitter from shot to shot within the overall bandwidth. The other method is the injection-locking process of a narrow-bandwidth cw dye laser, in which another external laser cavity is used for the pulse laser oscillator. The characteristics of the pulse output combine the power of the pulsed laser and the spectral qualities of the cw laser. However, this method requires a complicated control sequence for simultaneous frequency tuning of the external oscillator with the cw master oscillator. Recently, several authors have investigated an alternative method, that is, the direct pulsed amplification of a cw narrow-bandwidth dye laser beam. This method is quite simple in principle and gives good single-mode stability during frequency tuning. For high gain, however, it is essential for the cw beam to pass through the active gain medium of the amplifier several times. For this purpose, in this Letter we introduce a four-pass dye amplifier that is different from previous amplifiers used for other applications.

An amplifier in which the laser beam travels back and forth four times on a single line through a gain medium, changing its direction and polarization alternately, was first reported by Andreyev and Matveyev. They adopted the four-pass configuration shown in Fig. 1(a) for the amplification of an incident pulse in a solid-state laser system. Later, Han and Kong reported that this configuration could compensate for the depolarization caused by thermal birefringence induced during flashlight pumping of a solid-state gain medium. The depolarization is known to result in parasitic oscillation between M1 and M2, which gives the output pulse shape a severely modulated tail. Avoiding this oscillation requires careful optical alignment so that the beam depolarized at GM1 can exactly follow its trajectory after reflecting back at M1 and thus return to its original linear polarization state after passing through the medium again. However, this is applicable only for a solid-state medium where the depolarization is caused mainly by birefringence.

In cases where dye solution is used as a gain medium, the depolarization is induced by anisotropic distribution of gain and loss that occurs with a linearly polarized pumping laser field. Therefore the polarization cannot be restored and generally increases instead. In this Letter we build a new configuration for four-pass amplification of a dye laser as shown in Fig. 1(b) and investigate its operational characteristics through the amplification of a cw ring dye laser. To reduce the depolarization degree, the amplifier cell (GM2) is placed between two crystal polarizers (P4 and P5). We use only one Faraday rotator (FR3) and a pair of Fresnel rhomb polarization rotators (PR2 and PR3). The incident cw beam is propagated through P3, FR3, PR2 (45°), and P4 and reaches dye gain medium GM2. After GM2, the beam passes through P5 and reflects twice at M3 and M4, and then its polarization rotates

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The pinhole size is the divergence of the final output beam we place a telescope between two amplifiers that consists of a lens–pinhole–lens combination. The pinhole size is 50 μm in diameter and also serves as a spatial filter.

The isolation ratio of the configuration in Fig. 1(b) was measured to be >30 dB.

To confirm that the cw beam was successfully amplified, we measured the spectrum of the output beam as shown in Fig. 2(a). We used a single-grating monochromator (Jobin-Yvon THR 1000) for measurement with resolution of <0.05 nm. In the spectrum, amplified spontaneous emission (ASE) that spread over 20 nm from 560 to 572 nm was greatly depleted by pulsed amplification of the cw laser beam, by a factor of 4.5, and the laser beam at 573 nm was greatly enhanced, whereas the beam was negligible without the pumping beam. We observed a reduction of the ASE portion as the cw intensity was increased. Without using any highly dispersive element or any frequency-selection device, we could reduce the ASE to less than 15% of total radiation energy at 573 nm. We also observed that the ASE portion could be further reduced as the wavelength of cw laser approached 566 nm, which corresponded to peak intensity of the ASE.

Fig. 2. Spectra of the output from a four-pass amplifier (a) with and (b) without the cw laser beam.
Fig. 3. Bandwidth measurement of the output laser beam. The free-spectral range of the étalon used is 3 GHz, and the finesse is 125.

The output pulse from the four-pass amplifier was then forwarded to a main amplifier. The dye solution used was the same as that in the four-pass amplifier and pumped by the same Nd:YAG laser. We finally obtained a pulse energy of 32 mJ with 6.5-ns duration at total pumping energy 77 mJ. We measured the bandwidth of the pulse, using a confocal scanning Fabry–Perot interferometer (Burleigh) with a 3-GHz free-spectral range and a finesse of 125. The result is shown in Fig. 3, in which the bandwidth was measured to be less than 130 MHz. To see the effects of temporal stretching of the pumping laser pulse width on the bandwidth, we tried pumping the amplifier without stretching. In this case, the measured bandwidth was 180 MHz.

In conclusion, we have demonstrated a new configuration of a four-pass amplifier for pulsed amplification of a cw narrow-bandwidth dye laser. It is found that the power gain of the four-pass amplifier reaches $2 \times 10^6$. When we use an additional dye amplifier, we obtain an energy efficiency of 42% and a bandwidth of 130 MHz.

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