

Multi-operation laser oscillator: an example of multi-operation laser

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Abstract A multi-operation laser oscillator is developed and built with multiple operation modes (OMs): injection-seeding mode, cavity-dumping mode and Q -switching mode. With the same electrical energy pumping, the multi-operation laser oscillator provides different output energies and pulse durations for different OMs. In the Q -switching mode, the output coupling is optimized for different electrical energy pumping. The laser oscillator operation can be switched between different modes conveniently. The multi-operation laser sources could be operated in multiple OMs for various research and application requirements.

Keywords multi-operation laser, injection-seeding, cavity dumping, Q -switching

1 Introduction

The laser was invented by T. H. Maiman in 1960, which is a milestone in the development of optics [1]. With a flashlamp pumping, the laser pulse consisted of irregular spikes [2]. To solve this problem, R. W. Hellwarth proposed an important technique known as Q -switching [3]. For a laser oscillator, higher quality factor Q means lower energy losses, and vice versa [4]. In the Q -switched laser, laser oscillation is initially disabled due to a low Q factor, and then large population inversion can be created in the active medium. When the oscillator Q is switched to a high value, laser oscillation builds up, and the stored energy will be converted to a so-called “giant laser pulse” [4,5]. In 1962, the actively Q -switched laser was experimental demonstrated with a Kerr-cell Q -switch [5]. The Q -

switched lasers achieved high peak power levels and opened the way for nonlinear optics [6]. Compared with passively Q -switched lasers, the active Q -switches are more controllable and can support higher laser power [4,7]. In addition, the active Q -switches can contribute to cavity dumping, dumping optical energy out of the oscillator cavity [7]. The techniques of Q -switching and cavity dumping can also be employed in regenerative lasers with injection seeding [4,8]. Expanding the application of lasers, it is important to develop these laser techniques further. Here we proposed a novel kind of laser source, multi-operation laser, which has different lasing characteristics for different operation modes (OMs). Most of laser sources are usually operated in one or two OMs, while the multi-operation laser can be operated in more OMs. The multi-operation laser could be operated in different OMs for different application requirements. The multi-operation laser could be very helpful to the comparison research of different laser techniques [7,9], and would be a promising “all-rounder” for various applications [6,10]. To date, little attention has been devoted to the research of multi-operation lasers. The multi-operation laser technology would be quite important for the efficient and versatile utilization of laser sources. Therefore, more effort should be required for the development of multi-operation laser technology.

In this letter, a novel multi-operation laser oscillator, as an example of the multi-operation laser, was developed and built with multiple OMs. Here the OMs included injection-seeding mode (named OM1), cavity-dumping mode (named OM2) and Q -switching mode (named OM3). With the same electrical energy pumping, the multi-operation laser oscillator provided different output energies and pulse durations for different OMs. In OM3, the output coupling was optimized for different electrical energy pumping. The laser oscillator operation can be switched between different modes on demand. This novel kind of

multi-operation laser sources would serve as a versatile tool to meet various research and application requirements.

2 Experiment and results

A schematic setup of the multi-operation laser oscillator is shown in Fig. 1. The oscillator cavity mainly consists of two thin-film polarizers (TFP2 and TFP3), a DKDP (KD_2PO_4) Pockels cell (PC2), two quarter-wave plates (QWP1 and QWP2), and a diode-pumped Nd:phosphate glass rod placed between two plane mirrors (M1 and M2). The 3% Nd-doped glass rod has a diameter of 3 mm and a length of 6.5 cm. Pumped at 808 nm, the oscillator works at a wavelength of 1053 nm. TFP2 acts as the output coupler for OM1/OM2, while TFP3 for OM3. A pulse selector comprised of two thin-film polarizers (TFP1 and TFP2), a DKDP Pockels cell (PC1) and a half-wave plate (HWP) are employed for seed-pulse injection in OM1 and output-pulse ejection in OM1/OM2. The TFPs allow p -polarized (horizontally polarized) pulses to pass through, while reflect s -polarized (vertically polarized) pulses. The HWP and QWP1 have their optic axes oriented at a 45° angle to the direction of p -polarization. The optic axis of QWP2 is parallel to p -polarization or s -polarization in OM1/OM2, while oriented at a θ angle to the direction of s -polarization in OM3.

A half-wave voltage was applied to PC1 for seed-pulse selection in OM1, while a quarter-wave voltage was applied to PC2 for Q -switching in the three OMs, and then the PC2 voltage switched back to zero for cavity dumping in OM1/OM2. As shown in Fig. 2, the temporal window t_2t_3 is for seed-pulse selection, while t_4t_5 for laser amplification or laser oscillation. In the experiments, the oscillator was operated at a repetition rate of 10 Hz, and the laser diode (LD) was driven with 200 μs electrical pulses. The LD driving voltage was fixed at 70 V with variable driving current. If we assume the LD pumping starts at $t_0 =$

0 μs , PC2 will be switched to quarter-wave retardation at $t_4 = 232 \mu\text{s}$ typically. The output pulse duration was on order of 1 ns for OM1, while 10 ns for OM2 and 200 ns for OM3, relating to seed pulse duration, roundtrip transit time and photon decay time in the laser resonator [10], respectively.

According to the operation states of PC2, OM1 can be described by three phases: pump phase with PC2 voltage at zero, amplification phase with PC2 switched to quarter-wave retardation, cavity dump phase with PC2 voltage switched to zero [4]. During the pump phase t_0t_4 , laser oscillation is prevented in the resonator, with energy stored in Nd:glass. When PC1 is switched to half-wave retardation, a p -polarized pulse of 0.2 μJ would pass through the pulse selector, and be injected into the resonator as a seed pulse. After passing through QWP1 twice, the seed pulse would become s -polarized. During the amplification phase t_4t_5 , the seed pulse would no longer experience polarization rotation, therefore be trapped and amplified in the resonator. After 40–140 round trips, the amplified pulse could be p -polarized with PC2 voltage switched off, and then dumped out of the resonator cavity through TFP2. With PC1 voltage at zero, the amplified pulse would be s -polarized after passing through the pulse selector, and reflected by TFP2 for ejection.

Similar to OM1 operation, OM2 can also be described by pump phase, laser oscillation phase and cavity dump phase. During the pump phase, the energy of LD radiation was absorbed and stored in Nd:glass. When a quarter-wave voltage was applied to PC2, the stored energy would be converted to optical radiation in the resonator. With PC2 voltage switched off, the optical energy could be dumped out of the resonator cavity to generate a short laser pulse. Figure 3 shows the output pulse energy as a function of LD driving current for OM1/OM2. With LD driving current larger than 59 A, the output pulse energy in OM2 was higher than that in OM1; and vice versa. According to Fig. 3, the electrical slope efficiency was a little lower with injection seeding.

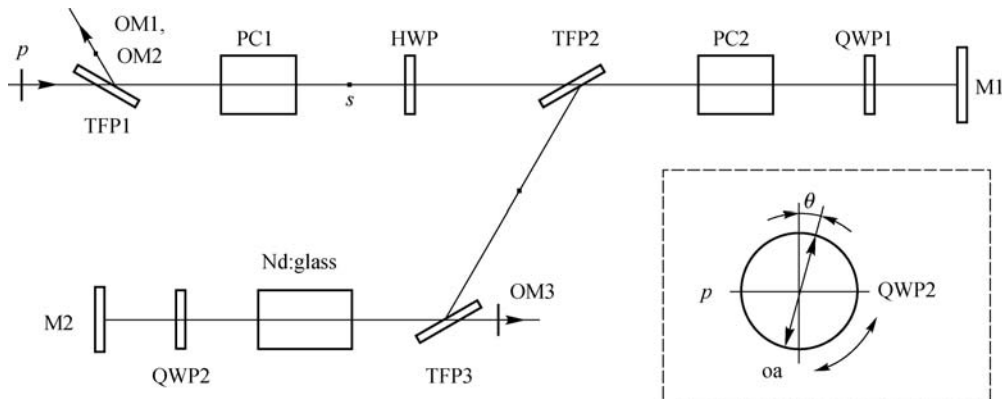


Fig. 1 Schematic of multi-operation laser oscillator. TFP1, TFP2, TFP3, thin-film polarizers; PC1, PC2, Pockels cells; QWP1, QWP2, quarter-wave plates; HWP, half-wave plate; M1, M2, mirrors. The inset shows the front view of QWP2, $\theta = 0^\circ$ for OM1/OM2

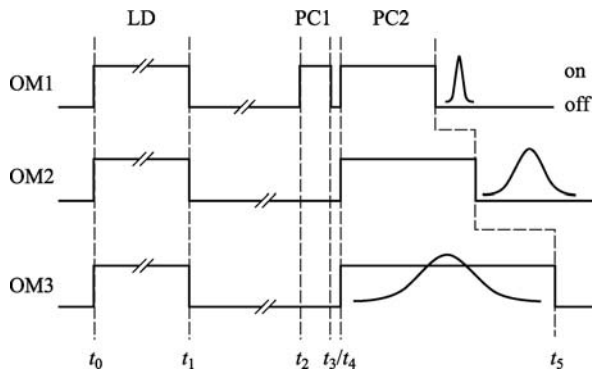


Fig. 2 Temporal operations of PC1/PC2 in OMs. The time period t_4t_5 has different optimum values for different OMs

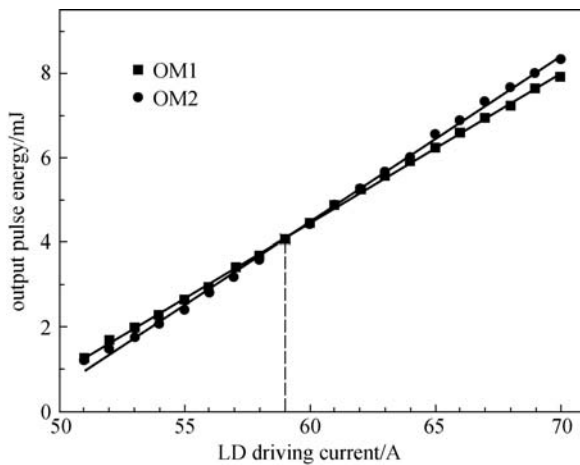


Fig. 3 Output pulse energy versus LD driving current for OM1/OM2. The slope of linear fitting curve for OM2 is higher than that for OM1

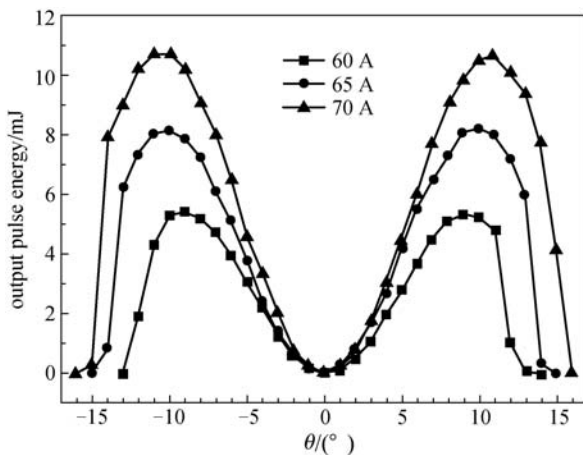


Fig. 4 Output pulse energy versus the angle θ for OM3. Angle θ has different optimum values with different driving current levels of 60, 65 and 70 A

Compared to OM1 and OM2, OM3 can be described only by pump phase and laser oscillation phase. During the

pump phase, Q -switch was off with PC2 voltage at zero. When PC2 was switched to quarter-wave retardation, laser oscillation would build up in the resonator, with the optical energy coupled out through TFP3. The output coupling could be adjusted by proper rotation of QWP2, as seen in Fig. 4. More accurately, the operation cycle of OM3 can also be divided into three phases: pump phase, laser oscillation phase and an idle phase, as shown in Table 1.

Table 1 Operation cycles for the OMs

| | t_0t_4 | t_4t_5 | t_5t_0 |
|-----|------------|-------------------------|-------------------|
| OM1 | pump phase | amplification phase | cavity dump phase |
| OM2 | pump phase | laser oscillation phase | cavity dump phase |
| OM3 | pump phase | laser oscillation phase | — |

For OM3, the optimum output energy can be expressed as

$$E_{\text{opt}} = E_{\text{el}}\eta \left(1 - \frac{1 + \ln z}{z}\right), \quad (1)$$

where E_{el} is the electrical pump energy of LD, and η represents the conversion efficiency of E_{el} to the available stored energy in Nd:glass [4,11]. The dimensionless parameter z is defined as

$$z = \frac{2\sigma n_i l}{\delta} = \frac{2\sigma\gamma E_{\text{el}}\eta}{\delta A h\nu}, \quad (2)$$

where σ is the stimulated emission cross section, δ is the roundtrip resonator loss, n_i represents the initial population inversion density, l is the length of Nd:glass rod, A is the effective beam cross-sectional area, $h\nu$ is the laser photon energy, and the factor $\gamma = 1$ for a four-level laser.

Corresponding to Eq. (1), the optimum value of the angle θ as shown in Fig. 1 would be given by

$$\theta_{\text{opt}} = \frac{1}{2} \cos^{-1} \left\{ \exp \left[\frac{\delta}{2} \left(1 + \frac{1-z}{\ln z}\right) \right] \right\}. \quad (3)$$

The calculated results are shown in Fig. 5, which agree well with the experimental results.

3 Conclusion

In conclusion, we developed and built a novel multi-operation laser oscillator with multiple OMs. The OMs included injection-seeding mode, cavity-dumping mode and Q -switching mode. For different OMs, the multi-operation laser oscillator had different lasing characteristics, such as electrical-optical energy conversion. In the Q -switching mode, the output coupling was optimized for different electrical energy pumping. The laser oscillator operation can be switched between different modes conveniently. Such novel kind of multi-operation laser sources would be a potential tool, adaptable for various

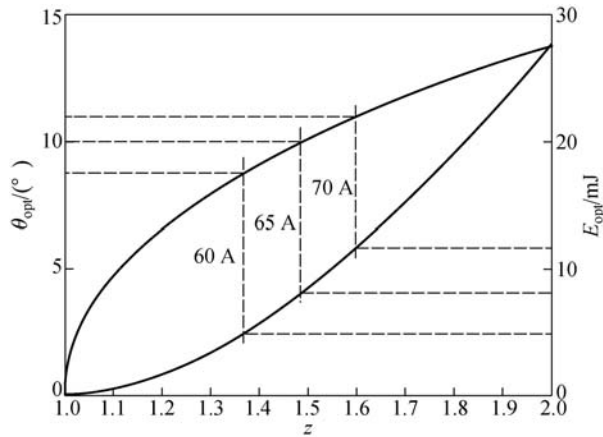


Fig. 5 Optimum values of θ and output energy versus the parameter z for OM3. $\theta_{\text{opt}} = 8.7^\circ$ and $E_{\text{out}} = 5.0$ mJ for 60 A driving current, 9.9° and 8.1 mJ for 65 A, 10.9° and 11.7 mJ for 70 A, respectively

research and application requirements. Hence it is very necessary to develop the technology of multi-operation lasers further.

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