

## Passively Mode-Locked Quasi-Three-Level Nd:LuVO<sub>4</sub> Laser with Semiconductor Saturable Absorber Mirror \*

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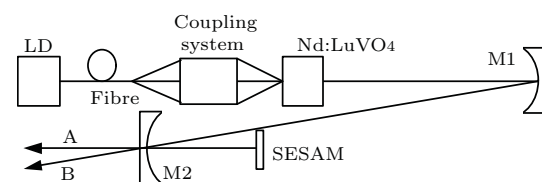
We demonstrate a passively cw mode-locked Nd:LuVO<sub>4</sub> laser operating on the quasi-three-level at 916 nm with a Z-folded resonator. Using a semiconductor saturable absorber mirror (SESAM) as the passive mode-locking device, we achieve stable cw mode locking with 6.7 ps pulse duration at repetition rate of 133 MHz and 88 mW average output power under the pump power of 17.1 W.

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Mode-locked Nd<sup>3+</sup> quasi-three-level laser at around 900 nm has attracted significant interest in recent years. In 2005, Schlatter *et al.*<sup>[1]</sup> demonstrated a passively mode-locked Nd:YVO<sub>4</sub> laser operating at 914 nm by using a standard delta cavity with a Ti:sapphire laser as the pump source, laser pulses with average output power of 42 mW and duration of 3 ps were obtained at a repetition rate of 233.8 MHz. Last year, a diode-pumped passively mode-locked Nd:YVO<sub>4</sub> laser at 914 nm was reported by Blandin *et al.*<sup>[2]</sup> They obtained 8.8 ps pulses at a repetition rate of 94 MHz and an averaged output power of 87 mW. In the same year, we successfully realized a passively mode-locked Nd:GdVO<sub>4</sub> laser at 912 nm.<sup>[3]</sup> Up to now, besides Nd:YAG crystal, Nd:YVO<sub>4</sub> and Nd:GdVO<sub>4</sub> crystals were mainly used as the laser gain media emitting the laser wavelength near 900 nm in view of their significant optical properties. Recently, a new laser host of Nd:LuVO<sub>4</sub> in the vanadate family was introduced, which has not only larger absorption and emission cross sections than those of Nd:YVO<sub>4</sub> and Nd:GdVO<sub>4</sub>,<sup>[4]</sup> but also good thermal properties.<sup>[5]</sup> Moreover, it has a high damage threshold and can be grown to a large dimension.<sup>[6]</sup> With all its merits the Nd:LuVO<sub>4</sub> crystal has attracted extensive attentions. In 2006, we realized the cw 916 nm Nd:LuVO<sub>4</sub> laser with a linear resonator for the first time.<sup>[7]</sup> Then we realized the 458 nm Nd:LuVO<sub>4</sub> laser with linear and Z-type resonators,<sup>[8,9]</sup> and the operation of A-O Q-switched 916 nm Nd:LuVO<sub>4</sub> laser.<sup>[10]</sup> In this Letter, we report the successful operation of a passively cw mode-locked quasi-three-level 916 nm Nd: LuVO<sub>4</sub> laser for the first time.

Figure 1 shows the experimental layout. A standard Z-folded resonator was used. The pump source

was a high-brightness fibre-coupled diode laser with a fibre core diameter of 200 μm and numerical aperture of 0.22. A coupling system was used to inject the pump laser into the Nd:LuVO<sub>4</sub> crystal which was cut in dimensions 3 × 3 × 5.5 mm<sup>3</sup> and doped with 0.1 at.% Nd<sup>3+</sup> concentration. To keep the stable and efficient operation, the Nd:LuVO<sub>4</sub> crystal was mounted in a water-cooled heat sink ( $T = 10^{\circ}\text{C}$ ). The left facet of the Nd:LuVO<sub>4</sub> crystal was coated for HR at 916 nm and HT at the wavelengths of 808 nm, 1066 nm and 1342 nm. The right side was coated for AR at the wavelengths of 808 nm, 1066 nm and 1342 nm. The radius curvature of the M1 and the M2 mirror was 300 mm and 200 mm, respectively. The M1 was coated for HR at 916 nm and the M2 was coated for 1% transmission at 916 nm. The left facet of the Nd:LuVO<sub>4</sub> crystal was used as one end-mirror of the laser cavity and the SESAM was used as another. The 916 nm laser can oscillate between the two end mirrors. The whole length of the cavity was 1342 mm.



**Fig. 1.** Schematic diagram of the diode-pumped mode-locked Nd:LuVO<sub>4</sub> laser.

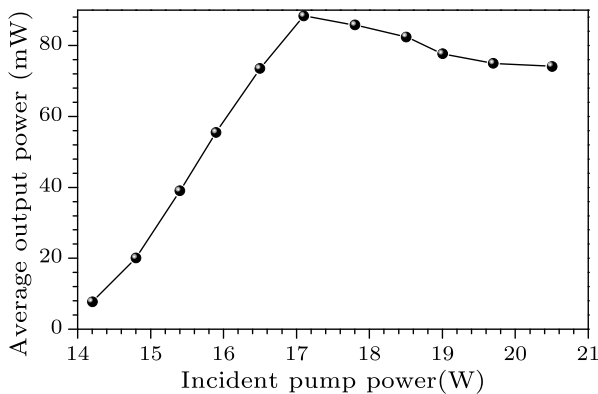
The laser has two output branches because the folded concave mirror M2 was used as the output coupler. We measured the average output power of the B branch and illustrated the output characteristics of the passively mode-locked laser in Fig. 2. In the experiment, it was found that the threshold pump

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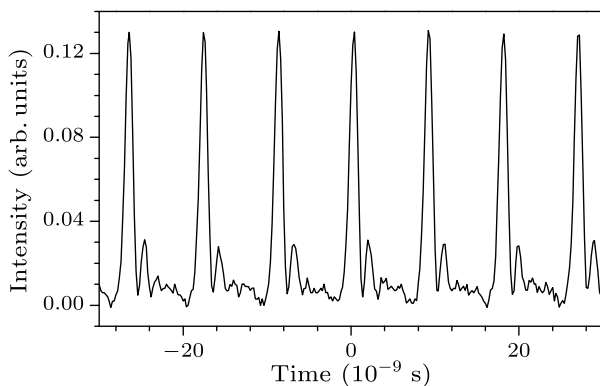
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power was 14.2 W. When the pump power was increased to 17.1 W the stable cw mode-locking operation appeared and average output power of 88 mW was obtained. Figure 3 shows the trace of the mode-locked pulses on the oscilloscope. The repetition rate of laser pulses was 133 MHz. With the increasing incident pump power, on the one hand, the output power no longer grew due to the thermal lens effect. On the other hand, the stable cw mode-locking signal was only observed in a narrow range when the incident pump power was increased from 17.1 W to 18.5 W, and the corresponding output power decreased from 88 mW to 82.5 mW. When the incident pump power was increased to above 18.5 W, the mode-locking signal became unstable, and *Q*-switched mode-locking operation was observed. The similar phenomenon was mentioned in the related paper.<sup>[3]</sup> We think that this phenomenon occurs for two possible reasons: one reason is that the wavelength of the 916 nm laser is at the edge of reflective band of the SESAM. The other reason is that the laser transverse mode could not remain good for the thermal lens effect. The actual cross-section of the laser on the SESAM becomes larger with the increasing incident pump, which means that the laser intensity on the SESAM drops conversely.

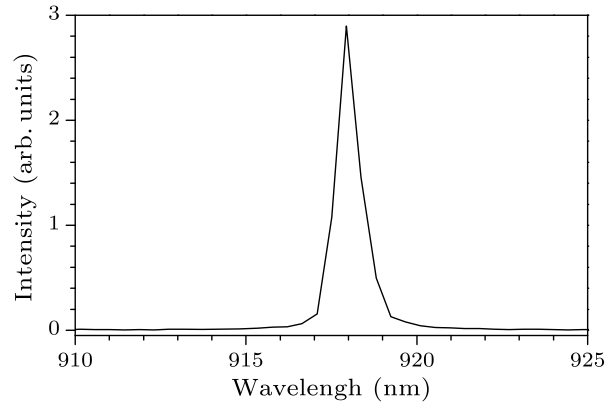


**Fig. 2.** Output characteristics of the average output power versus incident pump power.

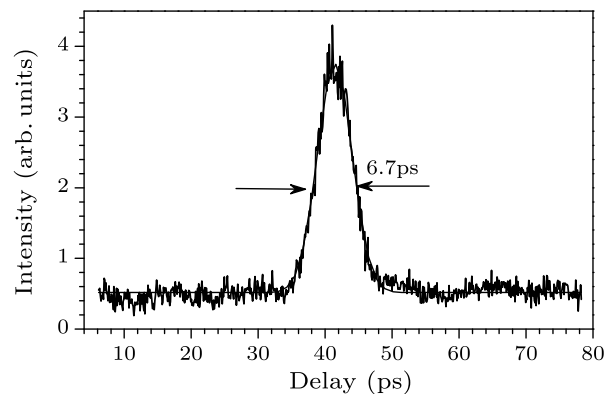


**Fig. 3.** Oscilloscope trace of the mode-locked laser pulses.

The laser spectrum of the mode-locked laser pulses was also measured and the result is shown in Fig. 4. It is found that the peak emission is located at the wavelength of 916 nm. Figure 5 is the autocorrelation trace of the mode-locked laser pulses. The Gaussian fit to the autocorrelation trace obtains an FWHM pulse duration of 6.7 ps.



**Fig. 4.** Spectrum of the mode-locked laser pulses.



**Fig. 5.** Autocorrelation trace of the mode-locked Nd:LuVO<sub>4</sub> laser.

In conclusion, a stable passively cw mode-locked Nd:LuVO<sub>4</sub> laser at 916 nm has been realized. In the stable cw mode-locking regime, the maximum average output power of 88 mW is obtained at the pump power 17.1 W, and the autocorrelation measurement shows the pulse duration of 6.7 ps.

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