In-band Pumped $Nd:LuVO_4$ Laser Mode-locked by Negative $\chi^{(2)}$-lens Formation in an Intracavity LBO Crystal

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Abstract: Self-starting $\chi^{(2)}$–lens mode-locking of an in-band pumped, $Nd:LuVO_4$ laser using second harmonic generation in LBO is demonstrated. Pulses as short as 4.7 ps and average powers reaching 3.1 W at 110 MHz are achieved.

OCIS codes: (140.3530) Lasers, neodymium; (140.4050) Mode-locked lasers; (140.3480) Lasers, diode-pumped.

In the past decade orthovanadate crystals $\mathbf{T}VO_4$ ($\mathbf{T}$ = Y, Gd, Lu) have become one of the most important host materials for the neodymium active ions. The large absorption and stimulated emission cross-sections are properties attractive for the development of efficient diode pumped laser systems. The $Nd:YVO_4$ laser has been widely used both in research and in commercial diode pumped lasers. Another vanadate crystal, $Nd:GdVO_4$ and mixed vanadate crystals $Nd:Gd_xY_{1-x}VO_4$ have also been investigated extensively in continuous-wave (CW), Q-switched, and mode-locked operation regimes. The third representative of this family, $Nd:LuVO_4$, is known to possess absorption and emission cross sections higher than $Nd:YVO_4$ and $Nd:GdVO_4$ and also somewhat wider fluorescence emission spectrum (1.5 nm) [1,2], but this material is still not so widely spread and its laser properties are still subject of research. Improvements in the growth technology make crystals of $Nd:LuVO_4$ available nowadays, in dimensions and laser quality that are comparable with those of $Nd:YVO_4$. However, in all these laser materials the thermal lensing effects are a major drawback restricting the maximum achievable output power in CW as well as in mode-locked operation [3]. By direct in-band pumping of the upper laser level using laser diodes emitting around 880 nm, it is possible to minimize the thermal load, while the absorption coefficient remains high enough for efficient laser operation.

In this work we study mode-locking of $Nd:LuVO_4$ laser in-band pumped at 880 nm. Mode-locking approach based on intracavity type-I SHG in LBO nonlinear crystal has been applied where $\chi^{(2)}$-lens formation is a dominant effect and it is assisted by the frequency-doubling nonlinear mirror (FDNLM) effect. This technique recently has been developed and demonstrated in $Nd:YVO_4$ [4] and $Nd:GdVO_4$ [3] lasers with PPKTP and PPMgSLT nonlinear crystals, respectively. Comparison with the results obtained at 808 nm pumping show that pumping at 880 nm is advantageous in terms of mode-locked laser output power and output pulse duration.

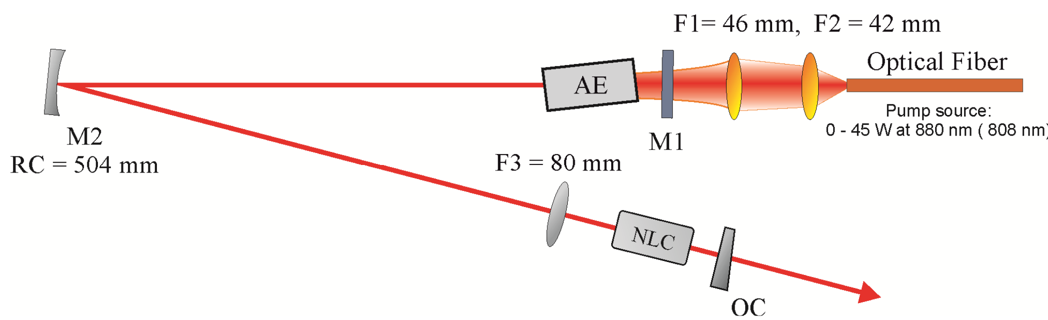

Fig. 1. Schematic of the laser cavity: F1, F2 - pump objective; AE - $Nd:LuVO_4$ active element; M1, M2 - highly reflecting mirrors; F3 - focusing lens; NLC – LBO nonlinear crystal; OC - output coupler.

The laser cavity is schematically shown in Fig. 1. The active element (AE) was a plane-parallel, 6 mm long, $Nd:LuVO_4$ crystal with 0.4 at. % doping. It was *a*-cut and used for operation in the π-polarization. The end faces were antireflection (AR) coated for minimum losses at the laser wavelength. Nevertheless, the crystal was slightly tilted in order to avoid etalon effects in the laser cavity. It was mounted in a Cu holder whose temperature was stabilized at 25°C by circulating water. The $Nd:LuVO_4$ laser was longitudinally pumped by the unpolarized radiation of a 880 nm laser diode bar coupled into a 400 μm optical fiber (NA=0.22). The output beam from the optical fiber was focused by reimaging objective and delivered onto the $Nd:LuVO_4$ crystal with a spot diameter of ~500 μm through the highly reflecting end mirror M1 which transmits the pump radiation (Fig. 1). Lens F3 with a focal length of 80 mm is used to form a beam diameter ~200 μm in the 25-mm-long LBO crystal.

Phase-mismatched SHG in the NLC introduces nonlinear $\chi^{(2)}$-lens into the laser resonator. Consequently, mode-locked operation was obtained only when tilting the nonlinear crystal in one direction far from perfect phase-matching, corresponding to negative nonlinear lens formation for the fundamental beam. Mode-locking was studied with an output coupler (OC)transmitting 20 % at the fundamental wavelength and highly reflective at the second harmonic wave. Figure 2 shows the measured CW output power versus absorbed pump power. The laser threshold was at 1.7 W of absorbed pump power and mode-locking occurred between 13.7 and 14.5 W. The maximum output power in mode-locked regime reached 3.1 W, at a pump level of 14.5 W.

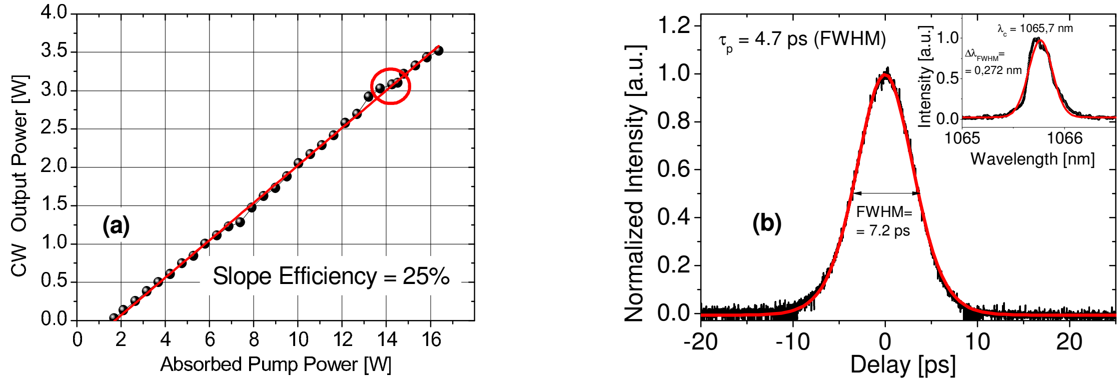

Fig. 2. (a) Laser input-output CW characteristics with 20% OC. The mode-locking range is marked by the red oval. (b) Intensity autocorrelation function measured by non-collinear SHG in $LiIO_3$, together with the measured spectrum (the inset).

The FWHM of the measured autocorrelation trace, 7.2 ps (Fig. 2b), corresponds to pulse duration of 4.7 ps assuming $sech^2$ pulse shape. The measured spectrum (see the inset) in this case has a FWHM of 0.272 nm, which gives as a time-bandwidth product of 0.337, which is close to the Fourier limit. Replacing the 880 nm pump source by a similar one emitting at ~808 nm we have achieved maximum average output power in the steady-state mode-locked regime of ~2.1 W and the corresponding output pulse duration was ~7 ps.

In conclusion, we have demonstrated steady-state passive mode-locking of an $Nd:LuVO_4$ laser in-band pumped at ~ 880 nm. $\chi^{(2)}$-lens formation assisted by the frequency-doubling nonlinear mirror (FDNLM) effect in type-I SHG LBO has been employed successfully for laser mode-locking. Average output power of 3.1 W and pulse duration of 4.7 ps have been obtained. For comparison, in the same pump configuration, using the same fibre, pumping by a diode laser with a central wavelength around 808 nm, the obtained stable mode-locking operation was only with 2.1 W of output power and also the pulse duration was longer (7 ps). In both cases the time-bandwidth product was close to the value corresponding to Fourier-transform limited pulses.

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