Chapter 3 Diode-pumped passive mode locking $Nd:GdVO_4$ laser by semiconductor saturable absorber mirror

3-1 Experimental setup

The schematic of the Z-shaped laser setup is shown in Fig. 3-1. A 4x4x8 mm^3 a-cut $Nd:GdVO_4$ crystal (with 0.5% Nd^{3+} concentration) is end-pumped by a fiber-coupled laser diode (FAP-81-16C-800-I, Coherent Inc.) at 808 nm.

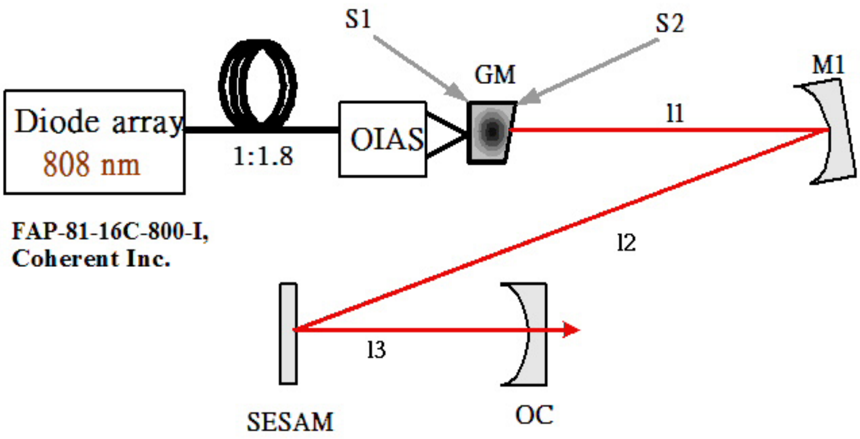

Fig. 3-1 Cavity configuration of the diode pumped solid state laser with semiconductor saturable absorber mirror.

The pump beam coming out from the fiber is imaged on the crystal through the 1:1.8 optical imaging accessories (OIA's, Coherent Inc.). Therefore, the radius diameter of the pumping beam in the gain medium (w_p) is around 225 mm that is slightly larger than the estimated radius of the cavity mode at the gain medium (w_g) around 210 mm by using the ABCD law [2] and considering the thermal lensing effect [3] on the $Nd:GdVO_4$. The laser crystal was wrapped with indium foil and mounted in a water-cooled copper block in which the water temperature was maintained at 15°C. One side of the $Nd:GdVO_4$ crystal is highly reflecting (HR) coated at 1064 nm and anti-reflecting (AR) coated at 808 nm pumping wavelength. The other side of the crystal with 2° wedge is AR coated at 1064 nm. In use of SESAM, the laser cavity consists of two concave mirrors with M1 (the radius of curvature R= 500 mm) and M2 (R = 200 mm) as an output coupler (OC) mirror with the reflectivity of 90% at 1064 nm. The SESAM (from BaTop Optoelectronics) with the saturation fluence ~50 J/cm, saturation absorption 3.0%, and the relaxation time of 10 ps was cooled by TE-cooler at 20 °C and inserted in the cavity with the distance l_3 to 1_1 cm from the OC.

The total length of the laser is 121 cm with the distance l_1 of 30 cm from the laser crystal to M1 and l_2 = 80 cm between two curved mirrors. A high speed InGaAs detector (Electro-Physics 17 Technology ET 3000) placed outside M1 was used to detect the small radiation of the cavity light (1064 nm) that was displayed on the oscilloscope (LeCroy LT372, Bandwidth 500MHz) and Rf spectrum analyzer (Hewlett Packard 8560E).

3-2 Experimental results

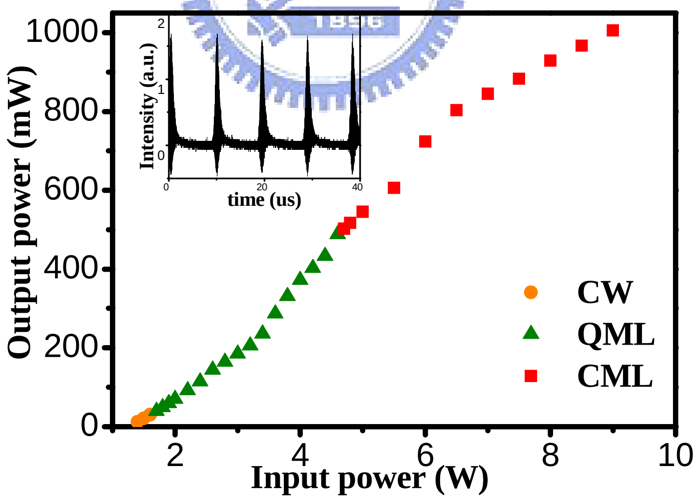

Fig. 3-2 Output versus pumping power for different operation: CW-continous wave, QML-Q switched mode locking, CW-ML-continous wave mode locking.

The output power of the $Nd:GdVO_4$ laser were measured by the power meter (Scientech 365) in both CW mode locking (CW-ML) and Q-switching mode locking

(QML) state. The QML state (triangle) is initiated as the pumping power is beyond the threshold of the laser with the value of 1.4 W as shown in Fig. 3.2. The inset is the stable QML pulse train displayed on oscilloscope. Further increased the pumping power to about 4.7 W, we found stable CW-ML state (circle). An average output power of 1.0 W from the CW-ML Nd:$GdVO_4$ laser were obtained as the pumping power was set up to 9 W. In Fig. 3.3 (a), the regular CW-ML pulse train with 8 ns spacing was displayed on the oscilloscope that corresponds to 124 MHz longitudinal frequency as shown in the RF spectrum. An 1 mm thick type-I BBO was used for the autocorrelation measurement. We obtained the pulse duration of 15 ps FWHM in Fig. 3-3 (b), if a $sech^2$ pulse shape is assumed [4].

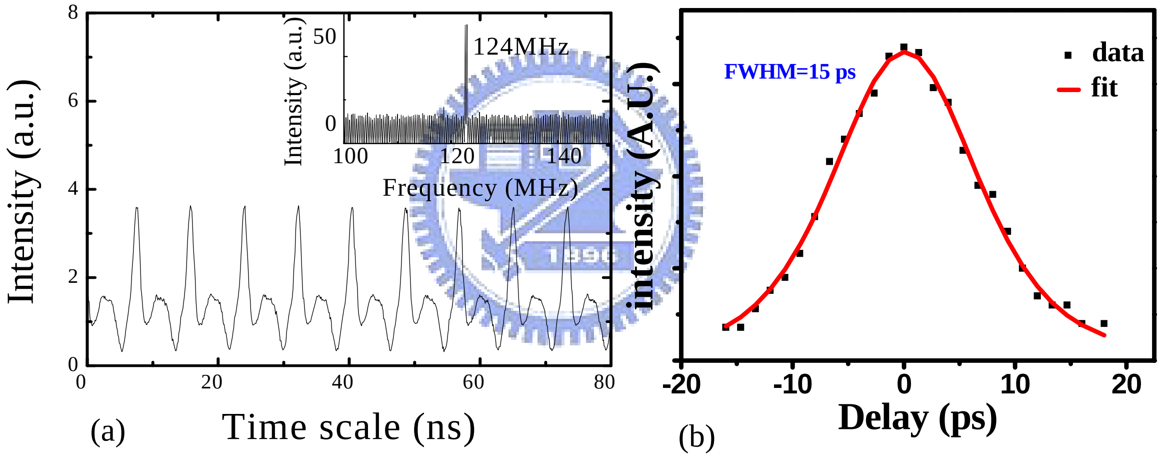

Fig. 3-3 (a) Mode locked pulse train of oscilloscope and RF spectrum of CW-ML repetition rate in Nd:$GdVO_4$ Laser with SESAM (b) autocorrelation of the CW-ML Nd:$GdVO_4$ laser using SESAM.

3-3 Discussion

In Chapter 2, we have reviewed the theory developed by Kartner et. al [1]. Here, we calculate the intra-caviy pulse energy and compare with the critical intra-cavity pulse energy of the theoretical value as show in Fig. 3.4. The CW-ML threshold (4.7 W) of our laser is close to the theoretical calculated value of 4.4 W. Finally, we did observe stable

CW-ML at P = 4.7W which is 3 times smaller than the previous reported result with the pump threshold of 13.7 W [2]. We will compare the peak power and other characters in Chapter 5 later.

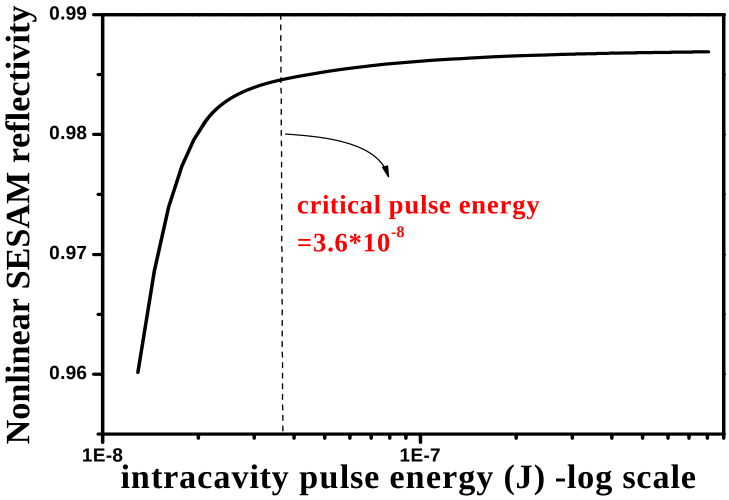

Fig. 3-4 Critical intra-cavity pulse energy versus nonlinear SESAM reflection

References

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[2] S. Zhang, E. Wu, H. Pan and H. Zeng, ”Passive mode locking in a diode-pumped Nd:GdVO4 laser with a semiconductor saturable absorber mirror,” IEEE J. Quantum. Electron. 40, 505 (2004).

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[4] 楊文勛, 指導教授謝文峰, “低臨界值半導體雷射激發摻釹釩酸釓被動鎖模雷射在半導體飽和吸收鏡及非線性鏡之相關研究,” 國立交通大學光電工程研究所碩士論文