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All-solid-state high power dual-wavelength Ti: sapphire laser

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A diode-pumped Q-cw (quasi-continuous wave) with simultaneous dual-wavelength laser operation at 744.8 nm and 860.9 nm in a single Ti: sapphire crystal is demonstrated. The birefringent filter is employed as the tuning apparatus for its low loss. A total output power of 4.8 W at the two wavelengths was achieved at the incident pump power of 23 W. To our knowledge, this is the highest value of the all-solid-state quasi-continuous dual-wavelength lasers which employ the Ti: sapphire as the gain medium.

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1. Introduction

In terms of frequency coverage, Ti: sapphire laser is the most widely tunable laser resource ever known. And with its broad tuning range and large stimulated emission cross section [1], Ti: sapphire is ideal for producing more than one wavelength simultaneously. Conventionally, sum frequency generation (SFG) and difference frequency generation (DFG) require two independent laser sources, which complicate the system, because the geometrical and temporal adjustment of pulses is required to have a high degree of accuracy in a nonlinear crystal. Dual-wavelength operation in a single laser is thus attractive for SFG and DFG. [2] In addition, such dual-wavelength pulses can also be applied for differential spectroscopic measurement techniques, such as differential absorption lidar (DIAL).

Dual-wavelength Ti: sapphire laser was first reported by Richard Scheps and Joseph F. Myers [3] which was operated in CW state and pumped by an Ar+ laser. From then on, some groups have examined dual-wavelength oscillation in a single Ti:Al_2O_3 laser under pulsed[4], cw[5,6] and mode-locking operations [7,8]. Methods most frequently used to realize dual-wavelength include double-prism-dispersion cavity, two-mirror-resonator with birefringent filter (BRF) as its tuning instrument, two independent seeds injection [9,10] and controlling two wavelengths by adjusting the two radio frequencies supplied to the acousto-optic tunable filter (AOTF) crystal inside the laser cavity [11,12].

The dual-wavelength Ti: sapphire laser we reported in this paper is charactered by its high power, all-solid-state, Q-switched operation, and simply cavity configuration as well. Comparing with the CW operating method, Q-switch has a substantially increased gain to achieve more peak power and average power. Also it can extend the spectra range. When pumped by laser diode (LD) pumped frequency-doubled Nd: YAG laser of 23 W and a repetition rate of 6.3 KHz, the maximum total output power of 4.8 W is achieved at both 744.8 nm and 860.9 nm. To our knowledge, this is the highest power of all-solid-state quasi-continuous dual-wavelength Ti: sapphire.

2. Dual-wavelength laser theory

We employ BRF as tuning apparatus for three reasons: first, it could simplify the experimental settings; second, it gives lower loss and higher output power; third, the two wavelengths will be emitted collinearly, which is extremely essential for DFG and SFG process.

There have been a lot of theoretical calculations in regard to BRF's wavelength tuning principle, and the oscillating condition, i.e. the threshold condition of two wavelengths can be described approximately by the following equation:

$$\ln(1/\gamma) = 2L\left[(\sigma/\sigma i)\alpha i - \alpha\right] + (\sigma/\sigma i)\ln(1/\gamma i) \qquad (1)$$

where σ , α and γ denote the stimulated emission cross section, single-pass loss and reflection of output mirror of one wavelength while σi , αi and γi denote the *i* set of parameters. σ denotes the direct correlation with the wavelength directly. We can use the conventions established by J. M. Eggleston [13]:

$$\sigma(v) = \sigma_s \langle m \rangle^p / P! \qquad (2)$$

where σ_s is a constant with the value of 1.663, and $\langle m \rangle$ is the expected value of emission photon number of 7.074. $P = (v_0 - v)/v_p$, v_0, v_p and v represent the frequency of zero phonon at 626 nm, average phonon and emission photon, respectively. $v_0 = 16178 cm^{-1}$, $v_P = 543.4 cm^{-1}$. All values given here is in the π polarization condition.

In the Ti: sapphire spectrum range, if the ratio between γ and γi is proper corresponding to different $\sigma, \sigma i$ so as to make $\alpha, \alpha i$ fit in the equation (1), the operation of dual-wavelength Ti: sapphire can be realized. BRF is not only the wavelength-turning apparatus, but also the loss-turning apparatus.

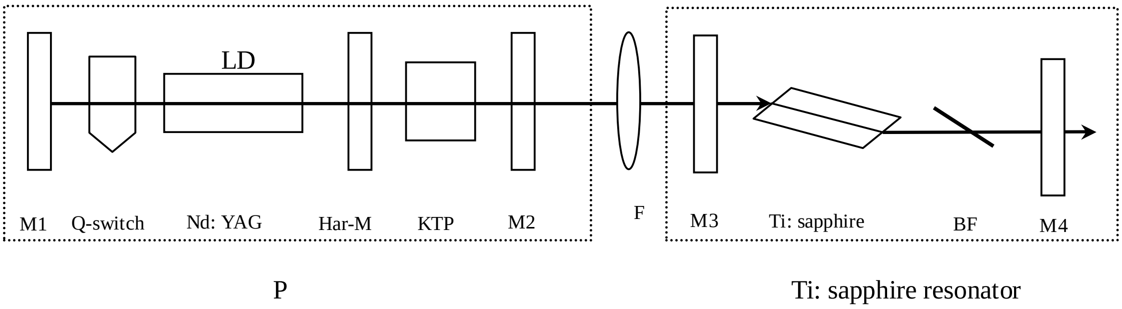

Fig. 1. Schematic of the dual-wavelength Ti: sapphire laser.

3. Experimental setup and results

The experimental setup is illustrated as Fig. 1. The figure lists the LD pumped frequency-doubled Nd: YAG laser and dual-wavelength Ti: sapphire resonant cavity. P is the pump resource of Ti: sapphire resonator; F is the focusing lens with the focus of 150 mm, so as to reduce the pump beam diameter to 100 um or so after passing through it; M3 and M4 form Ti: sapphire resonator for the 700~900 nm broadband: M3 is high transmission at 532 nm pump laser and high reflection at 700~900 nm, M4 has a transmission of T=15% at the centric wavelength of 800 nm. The ends of the rod are at Brewster angle face and are in the direction of c axis. To extract the deposited heat, the laser crystal is in contact with a water-cooled copper plate.

By rotating the BRF slightly, and when the pump laser power of 532 nm is 23 W with the repetition rate of 6.3 kHz and pulse width of 61.2 ns, we acquire the 4.8 W output power of dual-wavelength Ti: sapphire at 744.8 nm and 860.9 nm with the duration of 29.2 ns. The spectrum of this dual-wavelength laser is detected by an Agilent optical spectrum analyzer and depicted in Fig. 2.

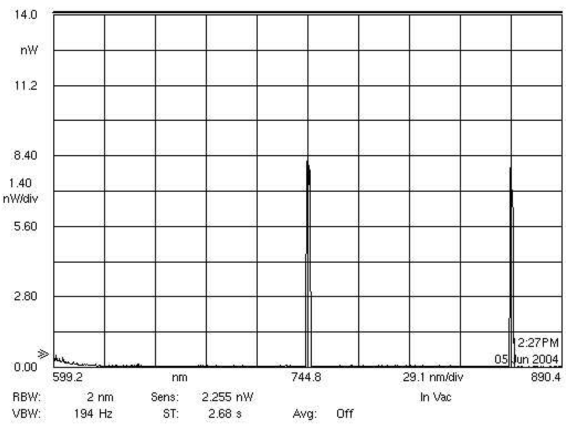

Fig. 2. Spectrum of dual-wavelength laser operated at 744.8 nm and 860.9 nm. The total output power obtained in this case was 4.8 W.

We can see from Fig. 2 that the two wavelengths have almost the same power, duration and shape, which can be accounted for the net gain [2]. Also they should have the same delay value relative to a pump pulse for dual-wavelength's synchronization [14].

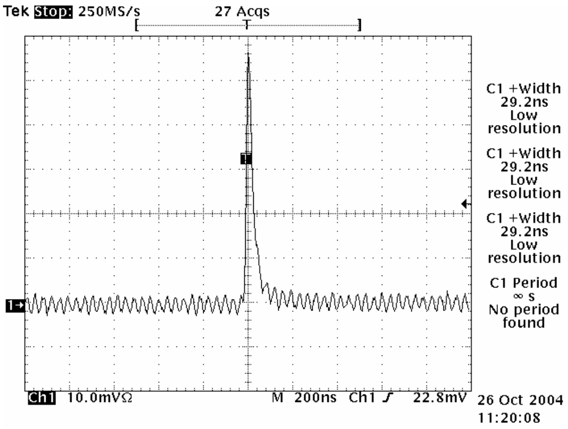

Fig. 3. Duration of dual-wavelength Ti: sapphire laser.

Fig. 3 shows the duration of dual-wavelength Ti: sapphire laser. It is narrower than that of 532 nm pump laser because of the effect of gain switch. Although the system is operating under dual-wavelength method, the pulse shape has not any difference with single-wavelength operating.

Then if we rotate the BRF in a few angles continuously, dual frequency operation move over several nanometers: The shorter wave turns from 743.3 nm to 746.6 nm and the longer wave turns from 859.1 nm to 862.2 nm. Meanwhile, the total output power of this range is almost the same. As we mentioned above, BRF gives higher power and ensures that the two wavelengths will be emitted collinearly, but it has the obvious limitation that the separation between the two wavelengths cannot be changed after fabrication. As a consequence, the range for dual wavelength operation is limited. And if we rotate the BRF continuously, two wavelengths turns to be only one wavelength for the reason that gain competition prevents operation at two frequencies when the net gain of one is substantially lower than that of the other. The single wavelength of 864.7 is shown as Fig. 4.

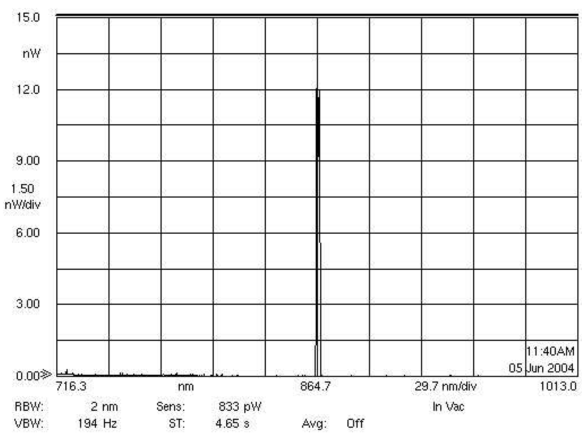

Fig. 4. Spectrum profile of 864.7 nm.

In the experiment, we find that dual-wavelength operation is harder to achieve comparing with that of single-wavelength. First, in dual-wavelength oscillation, as the tail of the population inversion did not deplete well, and was much smaller than that with a single-wavelength oscillation, the pumping pulse energy was not utilized effectively, so the threshold is higher than single-wavelength oscillation. Second, the fluctuations observed in the experiment doubled compared with those observed during single-wavelength operation can be explained by the competition between the dual wavelengths. In Norihito Saito's theory [12], when the energy of the pumping pulse changes, the variation of output power of dual-wavelength is twice as much as that of single-wavelength, namely, stability requirement of dual-wavelength for pump pulse is twice as critical as that for the single-wavelength operation.

4. Conclusions

In summary, we have demonstrated an all-solid-state, Q-switched, dual-wavelength Ti: sapphire laser. When pump laser of 532 nm is 23 W, the maximum total output power of 4.8 W at both 744.8 nm and 860.9 nm is achieved. To our knowledge, this is the highest power in the field of all-solid-state quasi-continuous dual-wavelength Ti: sapphire so far.

Dual-wavelength laser is a promising laser source for many applications, such as DFG, which is a feasible method to realize Terra Hz-a popular research field nowadays. While taking into account its geometrical and temporal advantages, dual-wavelength Ti: sapphire laser is an ideal choice.

Although the birefringency can not permit the wavelength to be tuned in a wide spectrum range, it gives higher output power, which provides the necessary foundation for many applications. If we take the prism in exchange for the BRF, we should attain more flexible dual-wavelength, meanwhile wider tuning range. Continuing development is currently underway.

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