High output energy tunable alexandrite laser

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We present a continuously tunable Alexandrite laser. By means of chromatic dispersion prisms, the output spectrum in the range of 725−781 nm has been obtained. The output energy at the center wavelength of 750 nm has achieved 1 J per pulse. To obtain the highest output energy, the best transmission rate of output mirror has been briefly studied. By reducing the transmission rate of the output mirror, the output range of spectrum has been extended to 725−791.4 nm. The difference between tuning with one and two prisms has also been analyzed experimentally.

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The alexandrite, common name for chromium-doped chrysoberyl (Cr^{3+}:$BeAl_2O_4$), is among the most outstanding performance solid-state crystals. It lases upon a vibronic sideband and provides broadly tunable wavelength range from 700 to 818 nm, using the energy levels of trivalent chromium in the crystalline host. Chromium is favored for its chemical stability, broad pumpband and large energy level splitting. Furthermore, the alexandrite crystal is a mechanically very strong, relatively good thermal conductor. All these mentioned above allow it to be Q-switched, able to withstand higher repetition rates, and emit a higher average output power. Besides, the absorption spectrum along the b direction of the crystal contains a narrow-band absorption peak at 680 nm, which means that it could be pumped by LD with corresponding wavelength, and in this way an all solid-state laser could be achieved, showing excellent application foreground[1−5].

The common elements for tuning wavelengths of laser include birefringent tuner, optical grating, and chromatic dispersion prism. In the experiment we have chosen the prisms for tuning due to the considerable inserting loss of the multi-plates birefringent tuners and the low optical damage threshold of the grating. The chromatic dispersion prisms we have used is made of glass Z Flint 5 (ZF5), for the reason that the chromatic dispersion of which is remarkable. The prism in the resonator is disposed in such a way that the incident angle of the laser beam to the prism is the Brewster'angle at the center wavelength for the purpose of reducing inserting loss. The experiment setup is shown in Fig. 1. M_O is the output mirror, the transmissivity of which at the center wavelength is 17%. M_R is the reflecting mirror providing high reflection over the range of 700−800 nm. The doping of the Alexandrite rod we used is about at 0.12%, with a dimension of $\phi 6 \times 110$ (mm).

The refraction of ZF5 for different wavelengths can be obtained from its chromatic dispersion equation[6]

$$\begin{aligned} n &= A + B/\lambda^2 + C/\lambda^4 \\ &= 1.70715 + 0.01148379/\lambda^2 + 0.000756465/\lambda^4, \end{aligned} \quad (1)$$

where the dimensional of λ is the micron. The refractive index of ZF5 at the center wavelength of 750 nm is 1.729, and the corresponding Brewster's angle $i_0 = \tan^{-1} n_0 = 59.97°$. In practice 60° is used as a matter of fact. The laser beams with different wavelengths is separated due to the chromatic dispersion of the prism. Provided that the M_R, as is shown in Fig. 1, revolves in order to make the reflecting surface of M_R perpendicular to the incoming laser beam with different wavelengths, then tuning is realized.

Figure 2 shows the deflexion of incoming beam after passing through the prism, and a_λ is the deviation angle depending on wavelength. In the experiment we have also added another ZF5 for tuning which is exactly the same as that of Fig. 1. Both of the two prisms are placed properly so that the incident angle of the laser beam is the Brewster's angle, as shown in Fig. 3.

Figure 4 shows the measured change of output energy with the injected energy when one prism is used for tuning. Although there is no transmission film on the penetrance faces of the prism, it can be obtained that the

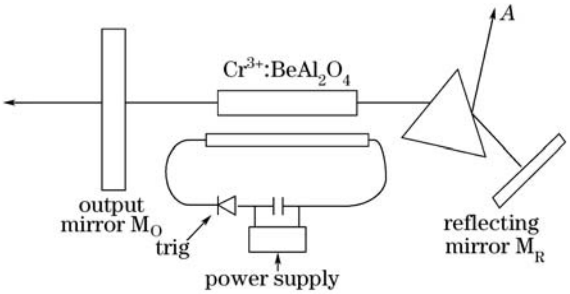

Fig. 1. Schematic of tunable laser using prism for dispersion.

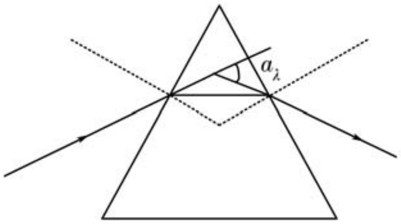

Fig. 2. Radiation path of wavelength.

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slop efficiency of about 2% is achieved. Figure 5 shows the measured output optical spectrum at the center wavelength. The FWHM (full width at half-maximum) is 4 nm. The reasons for the broadened spectrum line rest with the high output energy and the 3-mm cross section radius of the laser beam in the resonator. The large cross section area of the laser beam has weakened chromatic dispersion of the prism.

Figures 6 and 7 are the measured tuning spectrum line and the output energy at corresponding wavelength under the same pump level, with one and two prisms for tuning respectively. From Fig. 6(a) it can be seen that the maximum output energy at the center wavelength reaches 1 J per pulse. The measured FWHM at the two wavelengths of 725 and 780 nm, namely at the two edges of the output optical spectrum line, are broadened to be about 6 nm. The reasons lie in that the gain falls when the resonating wavelength deviates from the center wavelength, and the corresponding transmissivity at that wavelength is elevated, which can be seen from the measured transmissivity curve of the output mirror over the range from 700 to 800 nm in Fig. 7.

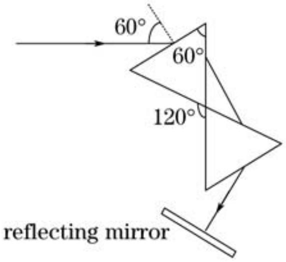

Fig. 3. Layout of two prisms for dispersion.

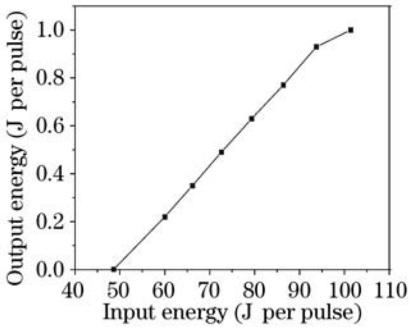

Fig. 4. Output energy versus input energy.

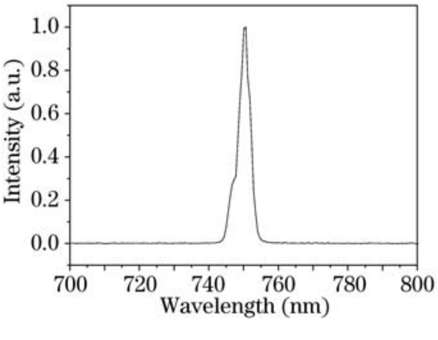

Fig. 5. Output spectrum at center wavelength of 750.4 nm. The FWHM is 4 nm.

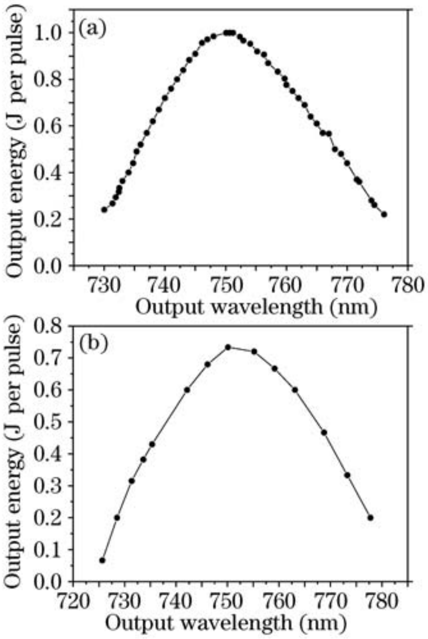

Fig. 6. Tuned spectra with (a) one and (b) two prisms.

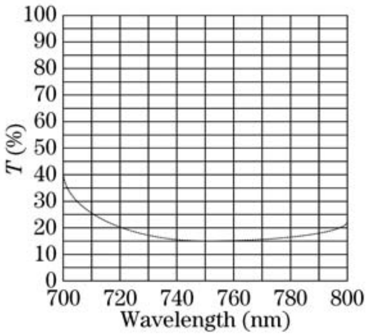

Fig. 7. Measured transmissivity of the output mirror in the range of 700−800 nm.

As the loss promotes, more longitudinal modes are able to resonate just slightly above threshold at the same time with the aid of the homogeneous spectrum line broadening characteristic of alexandrite and the limited pump power. The optical spectrum line width is almost unchanged when two prisms are used for tuning, while the maximum output at 750 nm is only about 0.75 J per pulse, as shown in Fig. 6(b). The main reason is the added inserting loss brought by the prism. Besides, the rotated angle of the reflection mirror for tuning is doubled compared to that of the case in which only one prism is used.

We have shown in the experiment that the range of tunable wavelength is narrower than expected. It is considered that there are the higher transmissivity and the relatively lower gain at the two sides of the output spectrum than that of the center wavelength. So part of the wavelengths are not able to resonate because of the high optical loss at the same pump level. We have used a mirror with high reflection over the range of 750−800 nm to take place of the output mirror in the situation

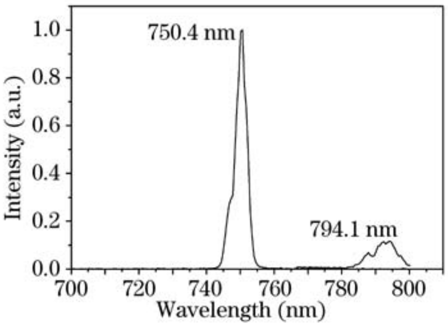

Fig. 8. Contrast of extended 794.1 nm with center wavelength.

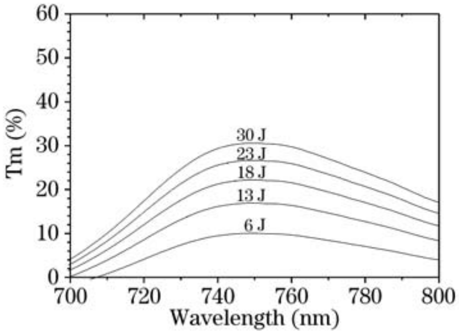

Fig. 9. Optimized transmission curve of output mirror in the range of 700−800 nm corresponding to different energies injected into the laser rod.

that only one prism is used for tuning. As a result, a laser output from the a direction in Fig. 1 is found, and the output wavelength is extended to 794.1 nm. The output spectrum at 750 and 794.1 nm under the same pump level are shown in Fig. 8.

For the purpose of getting the highest output energy from the corresponding wavelength in the range of 700-800 nm, the transmissivity curve of the output mirror should be optimized. Generally, the transmissivity at the center wavelength is higher than that of the two sides of the output optical spectrum. The appropriate transmissivity Tm(λ) could be obtained from[7]

$$\mathrm{Tm}(\lambda) = \beta\{[E_{\mathrm{in}}/E_{\mathrm{th}}(\lambda)]^{\frac{1}{2}} - 1\} \quad (2)$$

where β is the laser medium loss, which is mainly decided by the inserting loss of the alexandrite and the prisms. In the experiment the measured resonator loss is about 0.24 when only one prism is used. $E_{\mathrm{th}}(\lambda)$ is the threshold of pump energy of the corresponding wavelength, which can be obtained from Ref. [8]. Tm(λ) is calculated according to equation (2), as is shown in Fig. 9. Tm(λ) is plotted over the range of 700−800 nm with different energies injected into the alexandrite rod respectively. According to Fig. 9, Tm(λ) varies along with the output wavelength and raises in peace with the increment of injected energy.

A high output energy continuously tunable Alexandrite whose output spectrum in the range of 725−781 nm has been presented. By reducing transmissivity of the output mirror in the long wavelength range, the output spectrum line has been extended from 725−794.1 nm. The best transmissivity of the output mirror has been analyzed briefly and might be helpful for application.

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