Study of Brewster Plate of Single-Frequency Laser Using High Refractive SiC

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Abstract SiC crystals are used for a high refractive index material, as the frequency-selected device of Brewster plate. A stable single-longitudinal-mode green laser with an output power of 120 mW is achieved. Both the theoretical analysis and experimental results show that, compared with the common frequency-selected device using K9 glass as Brewster plate, the new frequency-selected device using the high refractive crystal of SiC as Brewster plate makes it easier to adjust the entire optical system. Moreover, the device works more stably, be much easier to achieve commercialization.

Key words laser optics; SiC; Brewster plate; single-frequency laser
OCIS codes 060.2430; 140.3380; 140.3570; 160.6030

SiC高折射率材料作为选频晶体单纵模激光器的研究

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摘要 采用高折射率的SiC晶体材料,作为布氏片的选频器件,实现了单纵模绿光激光器的稳定工作,输出功率达120 mW。通过理论分析和实验证明,相较于现有的采用K9玻璃,采用高折射率的SiC晶体作为选频器件,使整个光学系统更容易调节,且器件工作更加稳定,更易实现商品化。

关键词 激光光学,SiC,布鲁斯特片,单纵模
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1 Introdution

The green laser outputted through the frequency-multiplication of the semiconductor laser diode-pumped $Nd:YVO_4$ or Nd:YAG crystals has been widely used. However, the remaining many problems, such as the "green issue"[1] and instability, restrict the applications of this laser, such as in the biological analysis. A direct approach to this problem is to force the laser operating at a single-frequency[2]. For example, the ring cavity or wiggler cavity methods make the laser to reach a steady state by eliminating spatial hole burning effect, the birefringent filter cavity or the grating introduce the selective loss, while the micro-short cavity increases the spacing of the longitudinal mode, all the mentioned methods achieve a single longitudinal mode operation by the mode selection.

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However, these methods also have disadvantages: reducing the cavity length leads to very short working substance and is difficult to obtain high pump absorption efficiency, the mainly used ring cavity in the high-power single-frequency green laser exists the problems of low efficiency, complex structure and high cost, the loss introduced by birefringent filter is small, but the selected frequency is limited.[3-6]

Herein we propose a new structure, by using of the SiC crystal as Brewster plate, the stability of frequency-selection structure with the birefringent crystal and Brewster plate is greatly enhanced. This frequency-selection structure is simple and easy to commercialize. The output power of the resultant single-longitudinal-mode green laser with high stability reaches 120 mW.

2 Theoretical analysis

2.1 optical rotation

In the basic structure of the frequency selection using birefringent filter, the Brewster plate play the role of frequency-selective, while the KTP is optically active and disperses the light in the resonant cavity. In certain materials, the polarization plane of the linearly polarized light will rotate after traveling across the material along the optical axis direction, and the rotation angle is proportional to the thickness of the material, which is the optical phenomenon, as shown in Fig.1. These materials are called optically active. Linear polarized light is rotated through the angle of the optically active crystal, which is called optical rotation, indicated by θ. The vibration plane rotated angel θ is proportional to the distance L by the light within the optically active materials, can be expressed as: $\theta = \alpha L$.

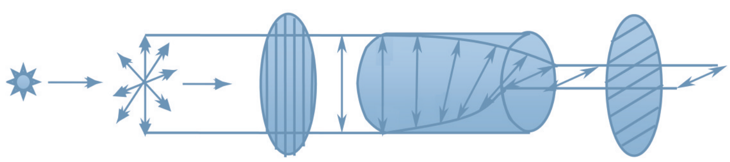

Fig.1 Schematic diagrams for the optical rotation.

2.2 KTP crystal

In the context of this paper, the main purpose of the using of the KTP crystal is its optical rotation and nonlinear optical multiplier effect properties. We use the dependence of the optical rotation characteristics with the wavelength to realize the crystal mode selection. As known from the above-mentioned analysis, with the increase of the crystal length, the same optical frequency interval will be separated more.

According to the frequency-doubling properties of crystal, in the ideal case, the longer the crystal, the higher harmonic conversion efficiency of light is. However, the actual pump light has a certain width and divergence angle, which will cause the phase mismatch of part of the light. Due to the influence of the divergence angle and line width, frequency conversion efficiency of light is no longer monotonous increase with the length of the crystal, but cyclical changes. The greater the divergence angle and line width, the shorter the period of harmonic light changes. In this condition the harmonic conversion efficiency of light has the largest value, with the corresponding length of the crystal length known as the best crystal length. When the crystal length is not equal to the optimum crystal length, the frequency-doubling intensity and conversion efficiency will decline, and when the crystal length is constant, the pump intensity has one best value, when the harmonic conversion efficiency is highest. When pump

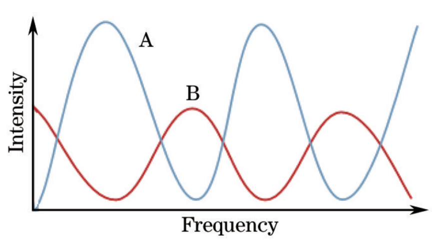

Fig.2 Schematic diagrams for the corresponding periodical intensity of the fundamental light A and harmonic light B

strength exceeds or be less than the optimum value, harmonic conversion efficiency will decline[7], the corresponding periodical intensity of fundamental periodic light A and harmonic periodic light B are shown in Fig.2.

2.3 Mode selection with Brewster plate

When light travels from one medium into another one, the reflectivity depends on the electric field vector direction of the incident light, the incident angle and the relative refractive index of the two media. According to Fresnel's law, the electric vector of the incident light can be decomposed into the p-wave and s-wave, which are parallel and perpendicular to the plane of incidence, respectively. The reflectivity R_p and R_s are

$$R_p = \tan^2(\alpha - \beta)/\tan^2(\alpha + \beta)$$

$$R_s = \sin^2(\alpha - \beta)/\sin^2(\alpha + \beta)$$

in which the α and β are the angle of incidence and reflection, respectively. We compare the frequency selection effect of the laser cavity, using the 4H-SiC and K9 glass as Brewster plate, respectively. Figure 3 (a) shows the reflectance curves of the two polarization directions when the light is incident from the air to the 4H-SiC crystal (the refractive index of the air and 4H-SiC are taken as 1 and 2.56). R_p shows the change in reflectivity of p-polarized light with the incident angle, it can be seen in the 68.8° position there is a zero point, the light with this polarization direction is completely transmitted, without any loss. R_s shows the curve of its reflectivity changing with the angle of incidence of s-polarized light, as can be seen, in the 68.8° position, the reflectance is of 76%. Figure 3 (b) shows the reflectance curves of the two polarization directions when the light is incident from the air to the K9 glass (the refractive index of the air and 4H-SiC are taken as 1 and 1.52). $P_p^{'}$ shows the change in reflectivity of p-polarized light with the incident angle, it can be seen the zero point is in the 57° position. $P_s^{'}$ shows the curve of its reflectivity changing with the angle of incidence of s-polarized light, as can be seen, in the 57° position, the reflectance is 15%. In the above-mentioned comparison, 4H-SiC shows a significantly greater reflection of s-polarized than K9 glass.

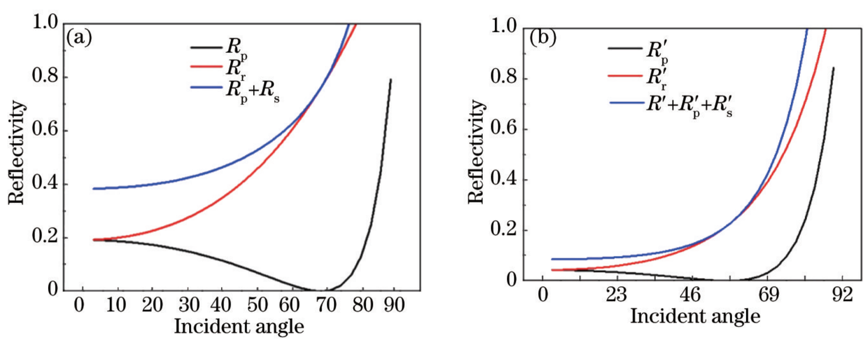

Fig.3 Relationship between incident angle and reflectance of (a) 4H-SiC crystal and (b) K9 glass

2.4 Frequency-selective laser cavity

Frequency-selective structure is shown in Fig.4, the Nd∶YVO_4 crystal is 3 mm×3 mm×1 mm, the doping concentration is 3%. The 'a' side is coated as 808 AR, 1064 and 532 high reflectivity (HR), with the 'b' side 1064 and 532 anti-reflectivity (AR). The Brewster plate is an undoped SiC crystal with both sides polished. This Brewster plate is of the thickness of 0.4 mm and highly transparent to visible light. The KTP is prepared using Π-class cutting, with the size of 2 mm×2 mm×5 mm, and be of 1064 and 532 AR. In this structure, the pump source, Nd∶YVO_4 and KTP are all strict

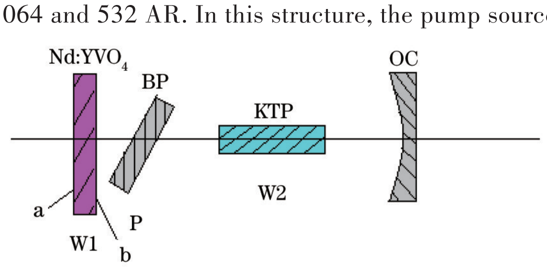

Fig.4 Schematic diagrams for the frequency selection structure

temperature-controlled, to provide the necessary conditions for the single longitudinal mode laser.

The Nd∶YVO_4 absorbs the 808 nm laser diode laser, then form the fundamental 1064 nm light output through the laser resonant cavity. Determined from the nature of the laser-emitting crystals and mechanism of the output laser, the output light is linearly polarized. As the Brewster plate, the SiC crystal need to be placed following the Brewster angle, that is, the optical axis between the incident plane and the laser axis direction is 68.8°. When the fundamental frequency light is decomposed into o-light and e-light through KTP, the phase difference is: $\delta = 2\pi d(n_o - n_e)/\lambda$. Where d is the length of KTP, n_o and n_e are the refractive index of the o-light and e-light, corresponding to the different longitudinal modes, separately; λ is the wavelength in vacuum, also corresponding to different longitudinal modes. According to the analysis of optical crystal, only when $\delta = 2m\pi$, that is, the light with a longitudinal mode which maintains the same polarization direction after returning from the Brewster plate, its loss could be zero. Other longitudinal modes have different degrees of loss, the larger the deviation angle of rotation, the more serious loss.

As can be seen from the above analysis, the roles of the Brewster plate in laser cavity are: Firstly, as to the longitudinal modes with different frequencies, the Brewster angle is slightly different. When the output light is in its Brewster angle, the other longitudinal modes will suffer loss. Thus, the larger interval of the Brewster angle of different longitudinal modes, the better effect on the selection of the longitudinal mode is. Secondly, the polarization direction of longitudinal modes at different frequencies will deflect while traveling through the KTP, Brewster plate results in reflection losses to the longitudinal modes with the s-component generated due to the rotation, which means that the greater loss of s-component, the better selection effect of the longitudinal mode. Obviously the latter is the predominant factor.

With this configuration to select frequency, the best condition for the selected longitudinal mode is the one at the center of the gain curve. Brewster plate is just placed at the Brewster angle of that longitudinal mode. KTP is prepared using 45° phase-matching Π-class cutting. KTP's length meets the optimal value of the frequency and optically active. A shorter laser cavity is preferred to reduce the number of longitudinal modes and increase their spacing, which is benefit for the frequency-selection by the Brewster plate.

3　Experimental results

The entire devices are mounted on an aluminum plate, which is cooled using the TEC, to reach a constant temperature of 25 ℃. We use the collimated light alignment methods to ensure a good laser cavity composed with the highly reflective mirror, the Nd∶YVO_4 crystal and the output mirror. Pump sources the pump light is focused onto the Nd∶YVO_4 via the coupling lens. Turn on the power, then adjust the various devices to reach the maximum output 1064 nm light. The light spot is observed by an infrared observation instrument, which is working at the fundamental transverse mode. Turn off the power, insert the KTP, then adjust the optical axis perpendicular to the pass plane. Then turn on the power, trimming KTP, to the highest power of the output green light with a fundamental transverse mode. Turn off the power, and then insert the SiC Brewster plate at the 68.8°. Adjust the output mirror and Brewster plate, as the light has a small lateral displacement at this time. At the same time observe the single longitudinal mode characteristic of the output green laser using a 24000 grating spectrometer. Figure 5 shows two typical spectral curves appear in the mediation process, showing the adjustment of the lasing peak from multiple peaks to a single one.

The wavelength and spectral width of the output light are measured using the spectrometer, which is shown in Fig.6. It presents a stable spectral with a width of less than 0.3 pm, the linewidth is greater than 1 MHz. Under a 2.5 W pump power, the output power of a single longitudinal mode green laser at 532 nm is more than 120 mW, with an optical conversion efficiency of up to 5%. The equal inclination interference fringes on the screen formed by the coherent superposition are obtained by the Fabry -Pablo coherence interferometer, which is shown in Fig.7.

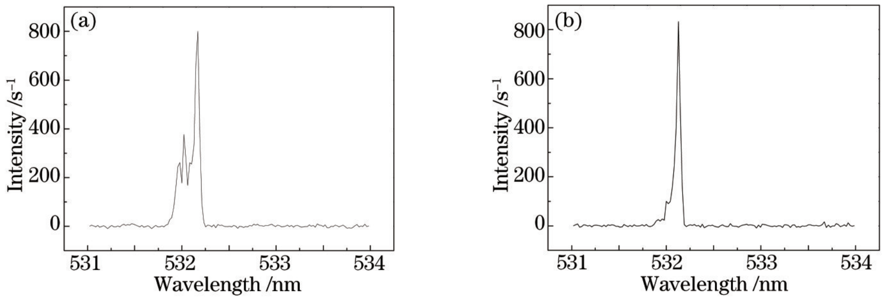

Fig.5 Two typical spectral curves appear in the mediation process

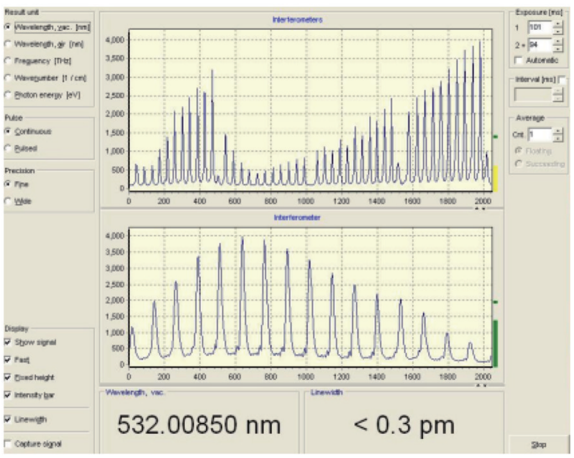

Fig.6 Spectral width and wavelength measured by spectrometer

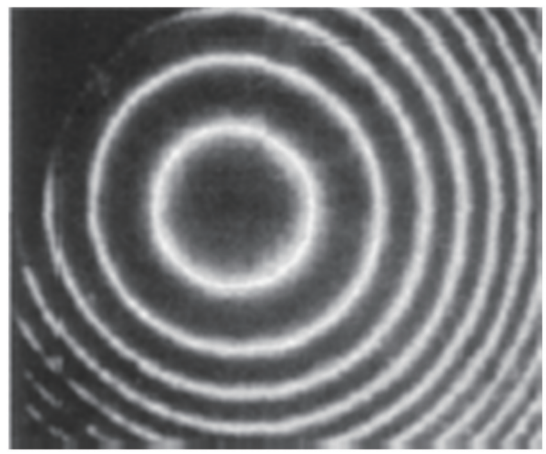

Fig.7 Schematic diagrams for optical rotation

4 Conclusion

We use the high refractive crystal SiC as the Brewster plate to select the mode in laser cavity, which achieves a single-longitudinal-mode green laser with an output power of 120 mW. Compared to the common K9 glass as the Brewster plate, both the theoretical calculation and experiments show that the use of SiC crystal is easy to adjust and shows good stability. After fixation, the resultant green laser shows low possibility of mode-hopping. Moreover, the structure has a small size, low cost, which should have large market potential.

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