Passive Q-switched laser—Initial transmittance T_0

1. What is the initial transmittance?

The initial transmittance is the specific transmittance of saturated absorber under the condition of initial absorptivity. For common artificial saturated absorbers, such as Cr: YAG crystal, the absorptivity will change with the light intensity of the pump laser. In the case of weak signal, that is, low optical power, the transmittance of Cr: YAG crystal to the laser is its initial transmittance, which is generally expressed by T_0. The change of transmittance can be regarded as the result of the change of internal transmittance of the material.

Fig. 1 common saturated absorber Cr: YAG Crystal

2. What is a saturated absorber?

To fully understand the initial transmittance, first introduce the saturated absorber.

Saturated absorber, also known as saturable absorber, is an optical element with certain absorption loss to light. Under high light intensity, the absorption loss will be reduced. When the incident light intensity exceeds the threshold of the saturable absorber, the optical loss decreases and the transmittance increases. The important parameters are wavelength range, modulation depth, recovery time, saturation flux, saturation intensity threshold and damage threshold.

The principle is: the saturated absorber is excited by light, and the carriers in the ground state are excited to the excited state. If the light intensity is large, the ground state ions are exhausted, and the excited state is occupied by some ions, so the absorption reaches saturation.

Its main function is to passively Q-switch or passively mode-lock the laser.

Generally, there are the following requirements for saturated absorbers:

(1) There is an absorption peak for the pump wavelength;

(2) The absorption cross section is much larger than that of the working material, which makes the saturated light intensity smaller and easy to "bleach";

(3) Excellent physical and chemical properties;

(4) Radiation stability.

Common saturated absorbers mainly include Co: spinel, Cr: YAG, V: YAG, Cr: YSO, Cr: GSGG, etc.

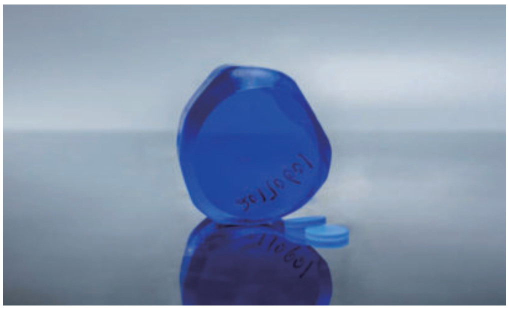

Fig. 2 common saturated absorber Co: spinel crystal

3. What is internal transmittance?

As mentioned earlier, the change of the transmittance of the material (saturated absorber) can be regarded as the result of the change of the internal transmittance of the material. Internal transmittance describes the energy loss caused by absorption, while (total) transmittance describes the energy loss caused by absorption, scattering, reflection, etc.

4. What is the difference between initial transmittance and transmittance?

What is the difference between the initial transmit-

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tance and what we often call transmittance or transmittance?

Taking Cr: YAG crystal as an example, the initial transmittance is low and the intracavity threshold is large. With the increase of intracavity light intensity, Cr: YAG is" bleached ", which means that the transmittance is close to 100%. At this time, the intracavity threshold becomes lower, so the pulsed laser is output. Generally speaking, the initial transmittance is the initial transmittance, and the transmittance should include the initial transmittance and the saturated transmittance. In actual measurement, the transmittance measured by ordinary spectrometer is generally the initial transmittance.

5. What factors affect the initial transmittance of materials?

The transmittance of the saturated absorber varies with the power density in the cavity. Take Cr: YAG crystal as an example. The following figure shows the change of its transmittance with the normalized excitation power density. It can be seen that the change trend of transmittance is the same, and the saturated transmittance increases with the increase of initial transmittance.

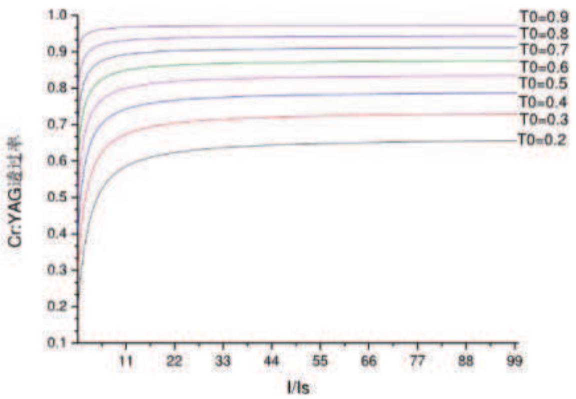

Fig. 3 change of Cr: YAG transmittance

The initial transmittance of the saturated absorber is mainly determined by the initial absorption coefficient and material thickness, and the absorption coefficient of the material is affected by the doping concentration of the material.

Simply expressed by the formula:

$$T = e^{-a \cdot L} = \begin{cases} \lim\limits_{I \to 0} a = \alpha_0, T = T_0 = e^{-\alpha_0 \cdot L} \\ \lim\limits_{I \to \infty} a = 0, T = 1 \end{cases}$$

T is the transmittance of the material, α Is the material absorption coefficient, I is the pump light intensity, and L is the material thickness.

6. What effect does the initial transmittance of the material have on the laser output?

The initial transmittance has a significant effect on the output performance of passively Q-switched laser. Generally speaking, it affects the slope efficiency, pulse width, repetition rate, far-field spot, average power, single pulse energy and peak power of passively Q-switched laser. Here are detailed examples.

6.1 Relationship between laser output pulse width and initial transmittance of saturated absorber Cr: YAG

The following figure shows the relationship between the experimentally measured laser output pulse width and the initial transmittance of the saturated absorber Cr: YAG.

As can be seen from Fig. 4, the pulse width of the output laser increases with the increase of the initial transmittance of Cr: YAG. When the initial transmittance is small, the pulse width increases slowly; When the initial transmittance is large, the pulse width increases rapidly.

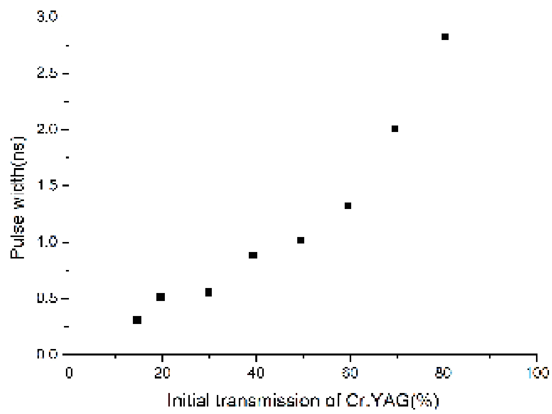

Fig. 4 spectral curve with obvious peak value in large fluctuation

6.2 Relationship between laser output energy and initial transmittance of saturated absorber Cr: YAG

The following figure shows the relationship between the total laser output energy and single pulse energy measured experimentally and the initial transmittance of the saturated absorber Cr: YAG.

As can be seen from Fig. 5, the total output energy increases with the increase of the initial transmittance, while the single pulse energy decreases with the increase of the initial transmittance.

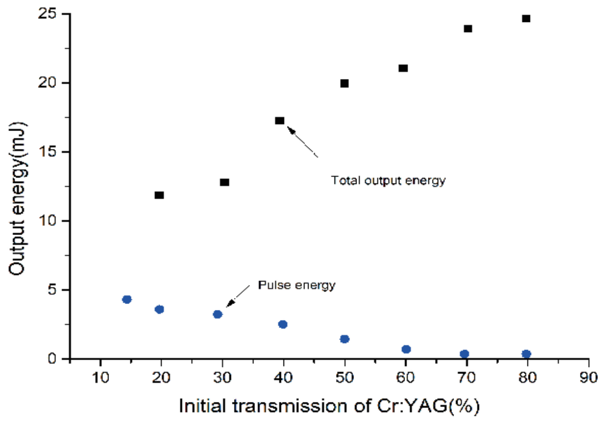

Fig. 5 Variation of total output energy and single pulse energy with initial transmittance of Cr: YAG

6.3 Other effects

The following figure shows the relationship between the anisotropy of saturated absorber Cr: YAG and its initial transmittance.

As can be seen from Fig. 6, the anisotropy of Cr: YAG crystal becomes less and less obvious with the increase of its initial transmittance. The more obvious anisotropy can obtain a relatively stable polarization output laser.

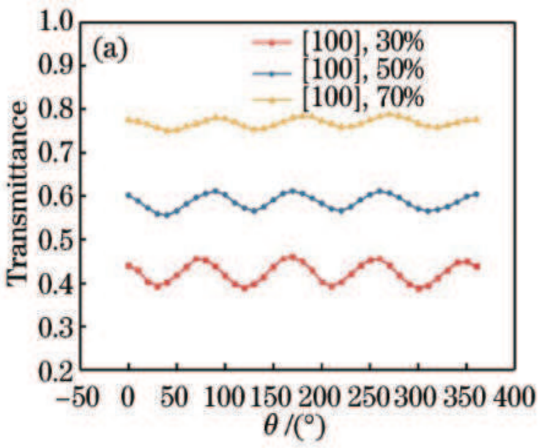

Fig. 5 Variation of total output energy and single pulse energy with initial transmittance of Cr: YAG

7. Why measure and select the initial transmittance of materials?

From the above relationship between the initial transmittance and the laser output characteristics, it is not difficult to see that the selection of the initial transmittance has a significant impact on the output performance of the passively Q-switched laser. Therefore, it is very important to measure the initial transmittance of materials and select an appropriate initial transmittance.

Fig. 7 Cr: YAG crystal with different initial transmittance (T_0)

8. How to measure and calculate the initial transmittance of materials?

Here, we give an approximate formula for calculating the initial transmittance of the saturated absorber, as follows:

As shown in equation (2), the total transmittance T_{total} transmitted by the first and second sides of the material is:

$$T_{total} = \frac{T^2 e^{-\alpha l}}{1 - R^2 e^{-2\alpha l}} \qquad \text{Equation (2)}$$

As shown in equation (3), the total reflectance Rtotal reflected by the first and second surfaces of the material is:

$$R_{total} = R + \frac{RT^2 e^{-\alpha l}}{1 - R^2 e^{-2\alpha l}} \qquad \text{Equation (3)}$$

As shown in equation (4), the initial transmittance T_0 of the material is the addition of equation (2) and equation (3):

$$T_0 = T_{total} + R_{total} = \frac{T^2 e^{-\alpha l}}{1-R^2 e^{-2\alpha l}} + R + \frac{RT^2 e^{-\alpha l}}{1-R^2 e^{-2\alpha l}} \quad \text{Equation (4)}$$

As shown in equation (5), the absorption coefficient α of the material is:

$$\alpha = -\frac{\ln\left(\frac{-T^2+\sqrt{T^4+4T_{total}^2 R^2}}{2T_{total}R^2}\right)}{l} \quad \text{Equation (5)}$$

Where, l is the thickness of the material, T and R are the transmittance and reflectivity of the material end face respectively.

9. What is the initial transmittance of the material?

By changing the doping concentration and material thickness, materials with different initial transmittance can be produced, which is mainly limited by the process difficulty and cost. Generally speaking, for common saturated absorbers, such as Cr: YAG crystals, the initial transmittance T_0 ranges from 20% to 95%; For example, V: YAG crystal, the initial transmittance T_0 ranges from 30% - 97%; the initial transmittance T_0 of Co: Spinel crystal is in the range of 30% - 90%.

10. How can users match application requirements and select materials with appropriate coefficients?

Above, we analyzed how the initial transmittance of the saturated absorber affects the output of the passive Q-switched laser, and which parameters determine the initial transmittance of the material. It can be seen that how to match the application requirements and select the material with appropriate correlation coefficient is very important.

For example, in order to reduce the pulse width and increase the single pulse energy, we often choose to reduce the initial transmittance by changing the length or doping concentration of the material. However, when the initial transmittance is low, the total output energy of the laser will be reduced and the pulse waveform of the output laser will deteriorate rapidly. In order to obtain an excellent output waveform, the repetition frequency of the output can only be limited. Therefore, in practical application, it is necessary to select materials with appropriate coefficients to match the demand. For example, for 1064nm Nd: YAG laser used in laser drilling, laser marking, laser welding, etc., the initial transmittance of saturated absorber Cr: YAG should be selected within a reasonable range, and cooperate with the reasonable selection of other components of the laser, such as excitation light source, resonator, output mirror, etc., in order to achieve the ideal output.

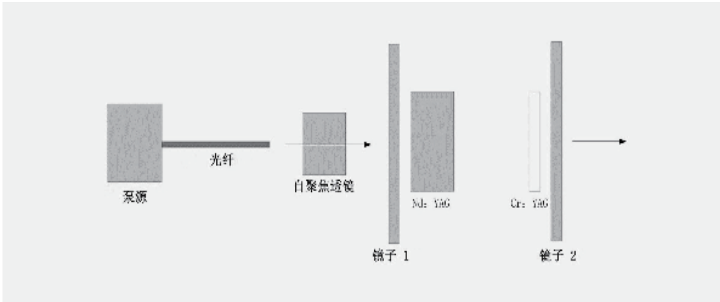

Fig. 8 1064nm Nd: YAG laser

Reference

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[2] https://www.rp-photonics.com/saturable_absorbers.html

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[4] 张思, et al. "利用 Cr 4+： YAG 晶体的各向异性提高输出激光消光比的实验研究." 激光与光电子学进展 56.16 (2019): 161401.