Design of Optical Path Switching Device Based on Electro-Optical Crystal

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Abstract: Optical switch devices are mostly used in laser systems with multiband or multioutlet outputs. The existing optical pathswitching modes are mostly mechanical ones, which are complex in structure and low in precision, and cannot meet the high-precision application requirements. In this paper, the electro-optical effect of electro-optical crystal is used to study its application in optical switch. An optical circuit switching device based on electro-optical crystal is designed, which has the features of simple structure, high accuracy and fast response. Tested, the output energy of the device is 1.6%~2% lower than the input energy, and the difference between the two energy outputs of the device is 0.3%.

Keywords: electro-optical effect; electro-optical crystal; polarizer; optical pathswitching

1. Introduction

The existing optical pathswitching mode is mostly mechanical switching mode, which uses the motor or electromagnet to change the state or position of the optical components in the optical path to realize the change of the optical path [1,2]. This method has complex structure and low precision, which can not meet the application requirements of high precision. In this paper, the electro-optic effect of electro-optic crystal is used to study its application in optical pathswitching. A device based on electro-optic crystal is designed to switch the optical path by changing the polarization direction of polarized light under certain conditions. After first debugging, it can realize the optical pathswitching without changing the device and position in the optical path.

2. Theoretical Basis

2.1. Electro Optic Effect

Electric field, magnetic field, stress field and temperature field will affect the optical properties of crystal, resulting in some interactive effects that can be used by people, such as electro-optic effect, magneto-optic effect, piezoelectric effect, elasto-optic (or piezoelectric) effect, thermo optic effect or photorefractive effect [3]. The phenomenon that the refractive index of electro-optic crystal changes due to the action of external electric field is called electro-optic effect [3]. The relationship between refractive index and electric field is as follows

$$n=n_0+aE+bE^2+ \quad (1)$$

Where: n_0 is the refractive index of the crystal without external electric field; a and b represent the primary and secondary electro-optic coefficients respectively. The change of refractive index in direct proportion to the external electric field is called linear electro-optic effect or Pockels effect; the change in direct proportion to the second power of the external electric field is called quadratic electro-optic effect or Kerr effect [4].

The electro-optic effect can make the electro-optic crystal form different polarized light according to the applied voltage, such as elliptical polarized light, circular polarized light and linear polarized light. The electro-optic crystal can be used as the electro-optic Q-switch in the laser by applying pulse type λ/4 voltage or λ/2 voltage at both ends of the crystal to generate narrow pulse width and high peak power laser [5,6], as shown in Figure 1.

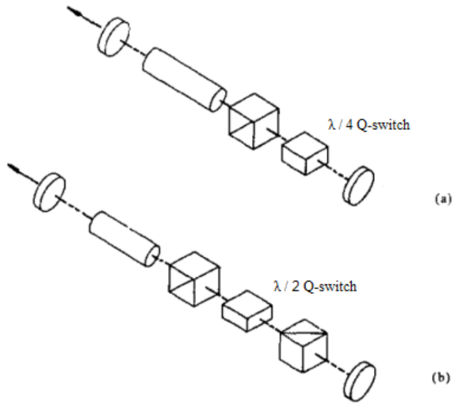


Figure 1. Application of linear electro-optic effect in laser q-switching (a) λ/4 q-switch, (b) λ/2 q-switch

In this paper, the pulse voltage applied to both ends of the electro-optic crystal is changed to constant DC λ/2 voltage, so that the polarization plane of the laser output from the output mirror can be rotated by 90 degrees.

2.2. Marius Law

According to Marius law [7], when a light beam propagates in an isotropic homogeneous medium, it always maintains the orthogonality with the wave surface, and the optical path between the corresponding points of the incident wave surface and the outgoing wave surface is constant. When the linearly polarized light with intensity I_o passes through the polarizer, the transmitted light intensity (regardless of absorption) is as follows:

$$I=I_o cos^2\theta \quad (2)$$

Where: θ is the angle between the light vibration direction of the incident polarized light and the polarization direction of the polarizer [7].

It can be seen from formula (2) that when θ is taken as 0, the polarized light of the incoming ray can be completely transmitted; when θ is taken as 90, the polarized light of the incoming ray is completely reflected.

Therefore, as shown in Figure 2, combined with the electro-optic effect and Marius law, the polarization plane of the laser can be rotated 90° after the electro-optic crystal is electrified, and then the laser can be reflected to other optical paths by the polarization splitter. When the voltage is not added at both ends of the electro-optic crystal, the polarization plane of the laser does not change, and the laser can directly pass through the polarization splitter and output from the original outlet. So as to realize the optical path switching. As shown in the figure below.

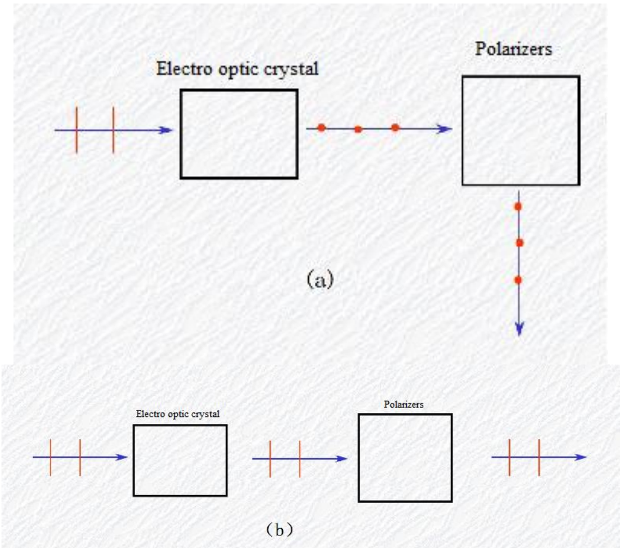


Figure 2. Schematic diagram of optical path switching principle (a) power on crystal (b) no power on crystal

3. Device Selection

3.1. Electro Optic Crystal

Linear electro-optical effect occurs in crystals with no point symmetry, while secondary electro-optical effect occurs in some liquids. The voltage required for linear electro-optical effect is 1/10-1/5 of the secondary electro-optical effect, so the linear electro-optical effect is widely used [5].

At present, 20 kinds of crystals with asymmetric points have electro-optical effect, but due to the influence of optical, physical, chemical and processing difficulties, there are few kinds of crystals used in practice. Among them, lithium niobate (LN) crystal and potassium dihydrogen phosphate (DKDP) crystal are mature and widely used. With the development of technology, rubidium titanate (RTP) crystal, low temperature phase barium metaborate (β -bbo) crystal, gallium lanthanum silicate (LGS) crystal, lithium tantalate (LT) crystal and potassium titanopodium phosphate (KTP) crystal have also been applied. The application parameters of the above seven crystals are listed in Table 1.

Table 1. Application parameters of various crystals [6]

Crystal type	λ/2 voltage (kV)	Damage threshold (GW/cm2)	Transmission band (μm)	Resistivity (Ω/cm)
LN	3.76	0.1	0.4~5.0	2.0×10^{13}
DKDP	4	5	0.2~2.15	1.3×10^{11}
β-BBO	7.7	50	0.189~3.5	10^{8}~10^{14}
RTP	2.37	1.8	0.35~2.5	10^{8}
LGS	3~4	0.95	0.19~2.4	4×10^{12}
LT	56	0.46	0.45~1.0	4.25×10^{14}
KTP	3.2	2.2	0.35~4.5	10^{11}~10^{12}

At present, there are still different shortcomings in rubidium titanate (RTP), barium metaborate (β -bbo) crystal, LGS crystal, lithium tantalate (LT) crystal and KTP crystal, which are not widely used. DKDP crystal is a deuterized potassium dihydrogen phosphate (KDP) crystal, with relatively high damage threshold, which is widely used in electro-optical Q-switched laser system. However, the crystal has a long growth period and its easy to deliquescence characteristics lead to its sealing in a container, which leads to the decrease of transmittance, which limits its application to a certain extent. LN crystal is mainly used in low power lasers because of its low damage threshold. Because of no need for sealing, the transmittance of LN crystal coated with antireflection film can reach 98%; meanwhile, the piezoelectric constant of LN crystal changes little, which requires low temperature and wide range of use. Considering the low peak power in the applied optical path, LN crystal is chosen as the electro-optical crystal with the polarization surface rotating.

3.2. Polarizers

The existing polarization splitting devices can be divided into two categories: prism polarizers and thin film polarizers.

Prism polarizers are prism which cut two crystals according to certain rules and then bond them. It includes birefringence prism and PBS reflection prism, in which PBS reflector can all pass through parallel polarized light (p-light) and all reflect vertical polarized light (s-light). In fact, the perspective of PBS to s-light is >0, and the reflectivity of p-ray is more than 0, which will have a certain impact on optical system [8].

Polarization film is a kind of reflection band bandwidth of two polarization components (p-light and s-light) when light is incident into the dielectric film at Brewster angle.

As shown in Fig. 3 [9], between 1044 nm and 1084 nm, the film is highly reflective of s-light, equivalent to a high reflection film; high transmission of p-light is equivalent to a high projection film. The thin film polarizer is formed by coating the polarization film on the surface of the optical lens, which can play the polarization splitting role.

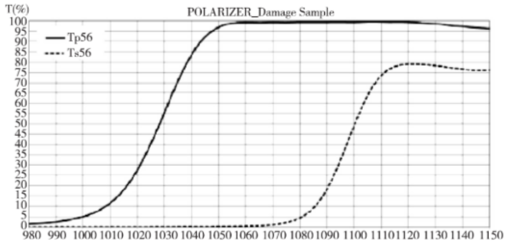


Figure 3. Spectrogram of polarizing film (solid line represents P light, dotted line represents s light) [9]

Compared with PBS prism, thin film polarizer has the advantages of small volume, low loss and high degree of polarization [9]. In this design, a thin film polarizer is selected as the polarization splitter.

4. Design of Switching Device

4.1. Selection of Electro Optic Crystal

Because the P-light needs to pass through the electro-optic crystal and change into S-light, it will be reflected by the polarizer. In the switching setting, the electro-optic crystal should be placed in front of the polarizer. In the switching device, the electro-optic crystal changes the power on mode, but the principle is the same. The electro-optic crystal changes the power on mode in the switching device, but the principle is the same, so it can use the same power on mode as the Q-switch - transverse electric field, as shown in Figure 4. In this way, the original electro-optic crystal structure can be used as much as possible.

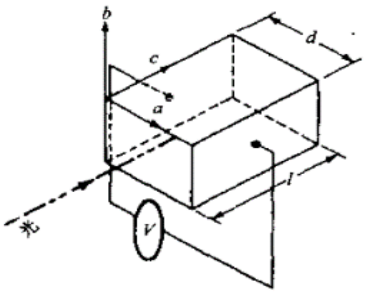


Figure 4. Schematic diagram of LN crystal power on

When there is electrostatic field, the electro-optical effect of crystal is equal to the sum of electro-optical effect and piezoelectric effect. According to the formula of λ/2 voltage of LN crystal [5]

$$V_{\lambda/2} = \frac{\lambda d}{2 r_{22} n_0^3 l} \quad (4)$$

Where, $r_{22} = r_{22}' + p_{2k} d_{2k}$ is the electro-optic coefficient, where, r_{22}''is the electro-optic constant of the crystal, p_{2k} is the elastic optical constant of the crystal, d_{2k} is the piezoelectric constant of the crystal [5]. When LN crystal is used as Q-switch, it is not necessary to consider $p_{2k} d_{2k}$ When the DC voltage is applied, P should be considered $p_{2k} d_{2k}$. Therefore, the DC voltage of LN crystal is lower than that of Q-switch. The results show that the P-light can be converted to S-light when 3750V voltage is applied at both ends of 9x9x20 mm3 LN crystal at 1.06 μM wave band.

4.2. Selection of Polarizer

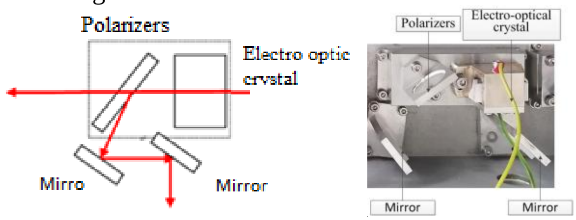
The polarizer is placed at the back of the electro-optic crystal and should be placed according to a certain angle. According to Brewster angle calculation formula

$$\theta_B = \tanh \frac{n_2}{n_1} \quad (3)$$

Where θ_B is Brewster angle, only when the angle between the polarizer and the light path is maintained, can s light be totally reflected; n_1, n_2 is the refractive index of the two media [10]. The Brewster angle of air glass is between 56 °and 58 ° according to the different materials. The Brewster angle is 56.3 °in this system.

4.3. Optical Path Collimator Group

The angle between incidence and exit of the polarizer is not 90 degrees. Therefore, the laser light path emitted by the polarizer is not perpendicular to the original light path, so a set of 45 degrees mirrors is needed to collimate the output light path. The optical path switching device is shown in Figure 5.



(a) Light path map (b) physical map

Figure 5. Optical path switching device

4.4. Design of Test Optical System

The design of switching optical path laser needs three transmitting windows, so two sets of switching equipment are needed. The optical path diagram is shown in Figure 6.

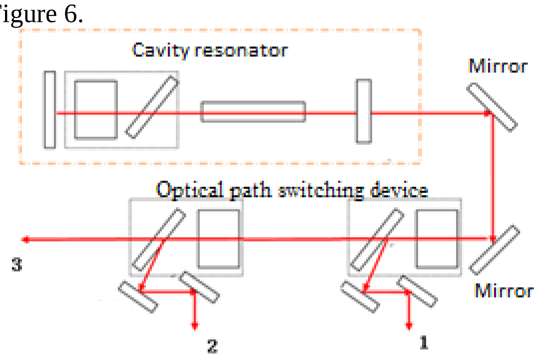


Figure 6. Optical path diagram of test system switching optical path

The output P-light from the resonator cavity of the laser enters into the electro-optic crystal. By applying a voltage of λ/2 to the electro-optic crystal, the P-light is transformed into S-light, which is reflected after passing through the thin film polarizer (Polarizer). The output direction of the beam is changed through a group of mirrors and is output from window 1. When the output of window 2 is needed, the λ/2 voltage on the electro-optic switch is removed. At this time, the laser is still p-light. It smoothly passes through the polarizer and enters the second electro-optic crystal. Similarly, the switch is added with λ/2 voltage to change the polarization direction of the laser into S-light. After being reflected by the polarizer, the output direction of the beam is changed through a group of mirrors and the laser is output from window 2. When the output of window 2 is needed, the λ/2 voltage on the electro-optic switch light is removed, and the output light is directly output from window 3 through two groups of switching devices in horizontal polarization state.

5. Test Results

In this paper, an optical path switching laser is designed for performance test. Its structure is shown in Figure 7.

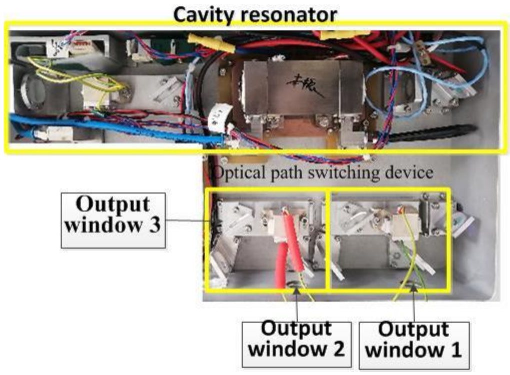


Figure 7. Test system

In this test, monitoring points are set in three windows of the equipment to detect the energy at the exit of the transmitter. Considering the single pulse energy pulsation error, 100 pulses are sampled at 80 mJ, 90 mJ and 100 mJ repetition rates of 1 Hz, 5 Hz and 10 Hz to calculate the average value. The test results under different parameters are listed in Table 2.

Table 2. Energy test results of each output window

Frequency (Hz)	Output window 1 energy (mJ)	Output window 2 energy (mJ)	Output window 3 energy (mJ)
1	82.04	80.47	80.66
5	82.26	80.64	80.86
10	81.87	80.32	80.51
1	91.18	89.45	89.63
5	92.25	90.46	90.66
10	92.01	90.27	90.48
1	103.43	101.43	101.66
5	104.02	102.06	102.26
10	103.89	101.92	102.18

According to the above table, the energy of outlet 2 is 1.9% ~ 2% lower than that of outlet 1, and the energy of outlet 3 is 1.6% ~ 1.7% lower than that of outlet 1. It can be seen that the energy loss of the laser through the electro-optic crystal is 1.6% ~ 1.7% without changing the polarization plane. When the polarization plane is rotated 90 degrees and reflected by the polarizer, the energy loss is more than 0.3%.

6. Conclusion

In this paper, according to the electro-optic effect, an optical path switching device based on electro-optic crystal is designed. The device realizes the optical path switching by changing the polarization direction of the laser. Compared with mechanical switching mode, it has the advantages of simple structure, high precision and fast response. The test results show that the output energy of the device is reduced by 1.6% ~ 2% compared with the input energy, and the energy gap between the two output channels is 0.3%.

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