Performance of Nd:YLF laser by using $La_3Ga_5SiO_{14}$ crystal electrooptic Q-switch

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Abstract

The polarization rotating coefficient and the laser-damage threshold of $La_3Ga_5SiO_{14}$ crystal at 1064 nm are measured, which are 1.1 deg/mm and 900 MW/cm^2, respectively. The working principle and the design method of electrooptic Q-switch based on $La_3Ga_5SiO_{14}$ crystal, which has the optical activity, are reported. The performance of Nd:YLF laser with the electrooptic Q-switch of $La_3Ga_5SiO_{14}$ crystal was studied. The output pulses with an energy of 379 mJ, a duration of 8.7 ns and repetition of 10 Hz are achieved.
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1. Introduction

An Nd:YLF laser is usually used as the source laser in a system of amplifiers, in which Nd-doped phosphatic glass is used as the gain medium, because the wavelength of 1053 nm from Nd:YLF laser matches with the gain peak of the glass very well. The other wavelength of 1047 nm from Nd:YLF laser is in the range of pump wavelength of Pr-doped fiber amplifiers. So researchers have paid attention to the study on Nd:YLF lasers. The electrooptic Q-switch is an important optical element used in laser technology. An excellent Q-switch may make the laser systems more efficient and more reliable, as well as generating pulses of higher energy. Although $La_3Ga_5SiO_{14}$ crystal has the property of electrooptic effect, few studies have been focused on this property,

for it is an optically active crystal [1]. In general, the electrooptic application of a crystal with optical activity could be very complicated when the crystal is used as an electrooptic Q-switch [2]. This is the reason why even though $La_3Ga_5SiO_{14}$ crystal has been known for a long time, it is still today used as a laser crystal or a piezoelectric material. In our laboratory, the use of $La_3Ga_5SiO_{14}$ crystal as an electrooptic Q-switch [3–6] has been studied. In this paper, we present the application of the $La_3Ga_5SiO_{14}$ Q-switch on a Nd:YLF laser.

2. The properties of electrooptic effect and optical activity in $La_3Ga_5s_{14}$ crystal

Crystalline Nd-doped $La_3Ga_5SiO_{14}$ was first reported by Kaminsky [1,7] as a laser crystal in 1982. $La_3Ga_5SiO_{14}$ crystal belongs to the trigonal system with point group 32 and has the properties of piezoelectricity, electrooptic effect, and optical activity. $La_3Ga_5SiO_{14}$

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crystal is optically active along its optical axis (Z-axis) direction. When a linearly polarized light propagates through the crystal along the optical axis, its polarization plane will rotate for an angle of α around the wave vector **K**. The rotated angles of polarization plane at the wavelength of 1064 nm versus difference lengths of $La_3Ga_5SiO_{14}$ crystal were measured. The result is shown in Table 1. According to the measured data, the coefficient of the rotated angle of polarization plane of $La_3Ga_5SiO_{14}$ crystal is obtained which is 1.1 deg/mm at 1064 nm.

In a cavity, when the linearly polarized light emitted from the laser rod propagates through a $La_3Ga_5SiO_{14}$ crystal along its optical axis, the polarization plane will rotate for an angle of α around the wave vector **K**. After it is reflected by the full-reflection mirror of the cavity and propagates back through the crystal, the polarized plane rotates by angle −α around the wave vector −**K**. Thus, the rotated angle of the polarization plane is zero while the polarized light travels through the optically active crystal forth and back twice. Thus the $La_3Ga_5SiO_{14}$ crystal can be placed in the laser cavity as an electrooptic Q-switch, as well as that of crystals which have no optical activity.

When light propagates along the optical axis and an electric field is applied parallel to the X-axis, the transverse electrooptic effect of $La_3Ga_5SiO_{14}$ crystal is used. As a Q-switch, the half-wave voltage V_π can be expressed as follows:

$$V_\pi = \frac{\lambda}{2n_0^3 \gamma_{11}(l/d)}, \tag{1}$$

where λ, n_0, l and d are the laser wavelength, the refractive index of $La_3Ga_5SiO_{14}$ crystal for the ordinary light, the optical path length and the thickness along the

Table 1
The rotating angles of polarization plane vs. difference lengths of $La_3Ga_5SiO_{14}$ crystal

Sample	1#	2#	3#	4#
Length (mm)	7.20	21.0	40.3	55.0
Rotating angle (deg.)	8.0	23.5	46.5	58

applied electric field direction of $La_3Ga_5SiO_{14}$ crystal, respectively. γ_{11} is the electro-optic coefficient.

The optical damage threshold is an important parameter for a crystal to be used in a laser system. This parameter of $La_3Ga_5SiO_{14}$ crystal has been determined by using a pulse Nd:YAG laser (PIA-NO2000, a product of Beamtech Co.) with a duration of 10 ns. The laser beam was focused on the surface of $La_3Ga_5SiO_{14}$ crystal. When the power density of the laser output is higher than 900 M W/cm^2, about 10 times that of $LiNbO_3$, optical damage appears on the surface of the crystal. Thus, a $La_3Ga_5SiO_{14}$ crystal is particularly suitable for an electrooptic Q-switch application in lasers.

3. Performance of Nd:YLF laser by using $La_3Ga_5SiO_{14}$ electrooptic Q-switch

The Q-switched Nd:YLF laser in our experiment is designed to a Cassegrain unstable cavity employing a variable reflectivity mirror (VRM) and $La_3Ga_5SiO_{14}$ crystal electrooptic Q-switch. High efficiency and good beam quality at high output energy were obtained by using the cavity [8]. When the laser operates under the Q-switched or mode-locked condition, the well distributed laser beam can keep the self-focus inside the laser rod in check. The schematic diagram of Nd:YLF laser cavity is shown in Fig. 1.

The size of the Nd:YLF rod used in our experimental research is ⌀ 6 × 80 mm, a-cut and coated with anti-reflection at 1047 nm. The laser rod is pumped by two flashlamps with a repetition of 10 Hz. The curvatures of the full-reflection mirror and VRM are 1.5 m and 10 m, respectively. The cavity length of the laser is 0.7 m. Although the a-cut Nd:YLF rod can simultaneously emit two wavelengths of 1047 and 1053 nm which have the vertical polarization planes with each other, the laser only operates on the 1047 nm which has the higher gain cross section. A block of $La_3Ga_5SiO_{14}$ crystal was cut and polished to form a Pockels cell with the dimension of 8 × 8 × 38 mm^3 (X, Y, Z). The light propagates in the crystal along the Z-axis and an electric field is applied at the X-axis direction of the crystal. According to Eq. (1),
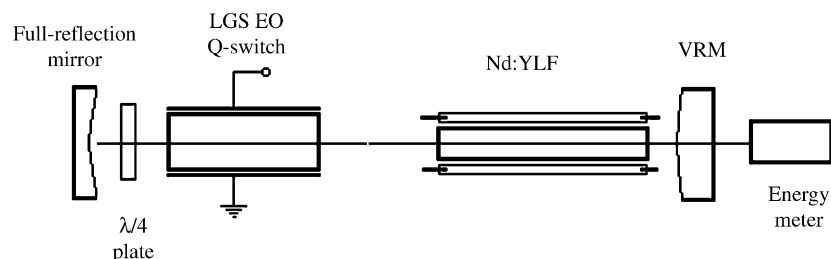

Fig. 1. Schematic diagram of Nd:YLF laser cavity with the electrooptic Q-switch of LGS crystal.
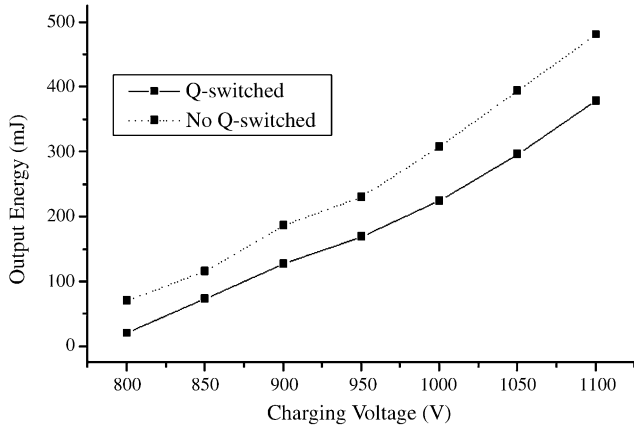
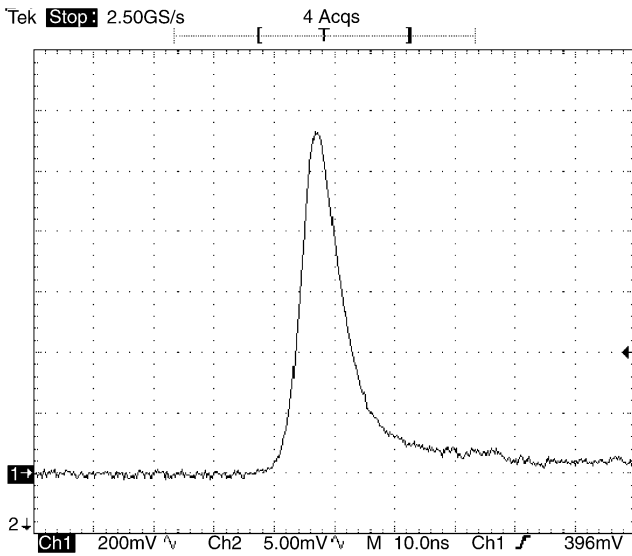Fig. 2. Output energy vs. charging voltage of the capacitor.

Fig. 3. Pulse shape of the laser output.

Fig. 4. Light spot of Nd:YLF laser using the LGS Q-switch: (A) near field; (B) far field.

when the parameters are: $\lambda = 1047$ nm, $n_0 = 1.8845$, $l = 38$ mm, $d = 8$ mm and $\gamma_{11} = 2.3 \times 10^{-12}$ m/V, the calculated $\frac{1}{4}\lambda$ voltage is 3600 V. A $\frac{1}{4}\lambda$ plate is used for the Pockels cell working in the case of no bias electric field. A photodiode (MRD500) and oscilloscope (TEK TDS620B) are used for receiving and recording the laser pulse and an energy meter (EPM-1000, made by Molectron Co.) for energy measurement.

Fig. 2 shows the relation of the output energy and charging voltage of the capacitor. When the charging voltage of the capacitor is 1200 V, the output energy of the laser at 1047 nm is 379 mJ with a duration of 8.7 ns. Pulse shape of the laser output and light spot are shown in Figs. 3 and 4. In order to evaluate precisely the potential of the Pockels cell for use in Q-switched laser, we have studied further the insertion loss in the cavity and the rate of output energy with Q-switched and without Q-switched. 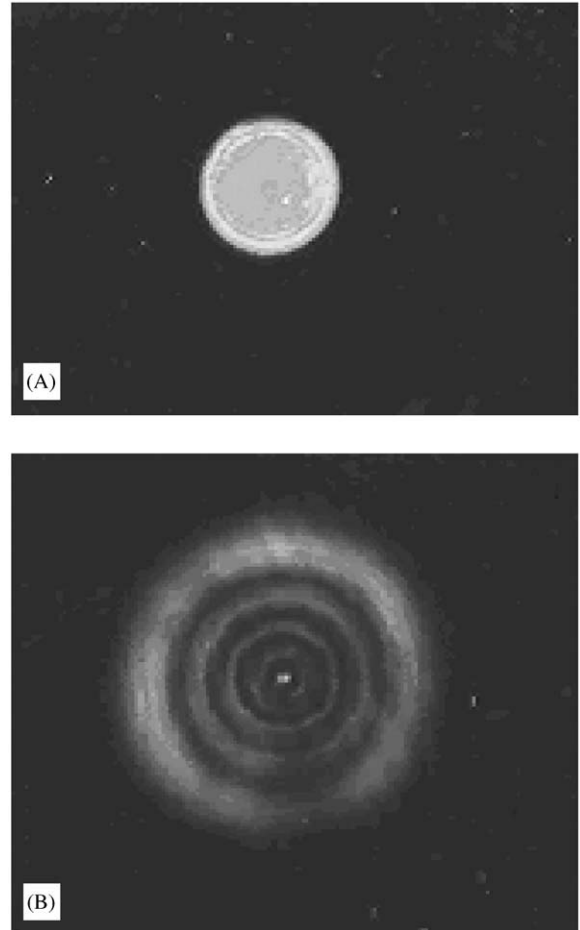First, the $\frac{1}{4}\lambda$ plate and the Pockels cell are not placed in the cavity shown in Fig. 1, and a output energy of $E_1 = 510$ mJ is measured. Then, only the Pockels cell is placed in the cavity, but does not work. The output energy of $E_2 = 499$ mJ is measured. The insertion loss is defined as $\delta = 1 - E_2/E_1 = 2.1\%$. Finally, both the $\frac{1}{4}\lambda$ plate and the Pockels cell are placed in the cavity and the electric pulse of higher than 3600 V is applied to Pockels cell. The output energy of $E_3 = 379$ mJ is measured. The rate of output energy with Q-switched and without Q-switched is defined as $G = E_3/E_2 = 75.9\%$.

4. Conclusion

An advanced version of Q-switched Nd:YLF laser has been built by using $La_3Ga_5SiO_{14}$ crystal electrooptic Q-switch. It has been designed to a Cassegrain unstable cavity with a variable reflectivity mirror (VRM). Efficiency and good beam quality at high output energy at 1047 nm are obtained. The results show that the $La_3Ga_5SiO_{14}$ crystal works properly as an electrooptic

Q-switch. Compared with the Q-switch made of $LiNbO_3$ and DKDP crystals, the $La_3Ga_5SiO_{14}$ crystal grown by the Czochralski method cannot be hygroscopic in the air, which is the advantage of $LiNbO_3$ crystal, and has higher laser damage threshold, which is the advantage of DKDP crystal. The measurements of the thermal properties, resistivity, dielectric constants, transmission spectrum also show that $La_3Ga_5SiO_{14}$ crystal is suitable for electro-optic applications. In conclusion, $La_3Ga_5SiO_{14}$ crystal electro-optic Q-switch is a promising device for applications in solid-state lasers.

Acknowledgements

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