New design of the temperature controlled pockels cell for IFE driver

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Abstract. We have observed the temperature dependence of the electro-optic coefficients of the DKDP crystal from 298K to the 231K. The half-wave retardation voltage was decreased proportionally with the crystal temperature at the rate of 55.1 V/K. The lowest half-wave voltage was 551 V at the crystal temperature of 231K, which corresponded to 1/8 of that at the room temperature. Note that the low operation voltage of 511 V may permit the use of semiconductor electrical switches instead of the thyratron.

1. Introduction

The electro-optic modulators are one of the indispensable optics for laser systems. Various nonlinear crystals are used such as LiNbO3, BaB2O4, and NH4H2PO4 for the electro-optic modulators. In particular, the KD2PO4 crystal (DKDP) is often used in the high power, high energy lasers such as inertial fusion driver because of its material growth capability and relatively high electro-optic coefficient of 25 pm/V. Nevertheless, the half-wave retardation voltage of DKDP for 1µm wavelength needs a high voltage supply of 6.5 kV. A thyratron switch has been generally used in a pockels cell driver especially for a large aperture laser system due to its high current capability. To realize the inertial fusion driver laser, its instability and short lifetime are considerable for highly repeatable operation. If the electro-optic coefficient has been improved, the electric power of the pockels cell driver will reduce and semiconductors may be used instead of the thyratron. Another use is for ultra-short pulse laser system. Shortening the length of the pockels crystal leads to lower dispersion.

The increase of the electro-optic coefficient of the DKDP crystal at low temperature has been reported [1]. Cooling the material may be easier than producing a new material. Some material coefficients should be measured at low temperature to evaluate characteristics for an electro-optics modulator. In this work, we have measured the temperature dependence of half-wave voltage quantitatively at first.
2. Experimental setup

The temperature of the DKDP crystal was controlled by a cryostat using adiabatic expansion of helium gas. Figure 1 shows the experimental setup for the measurement of the half-wave voltage of cooled DKDP crystal.

![Experimental setup diagram](image)

Fig. 1: The experimental setup. G.P.: the Glan Thompson prism, probe: 1/100 probe for high voltage measuring, and DMM: digital multi meter

The crystal had diameter \( \phi = 10 \text{ mm} \), length \( L = 18 \text{ mm} \), crystal optic axis \( \theta = 0 \text{ deg.} \) cut and put in a vacuum chamber. The electrodes were made with silver paste. To add the electric field in parallel to the transmitted beam direction, electrode was set up at the both ends of the crystal. The crystal was conductively cooled. The temperature deference in the crystal along the Z-axis was smaller than 0.7 K which was measured using the thermocouples. The temperature controlled crystal was set between the crosse-polarized Glan-Thompson prisms. The probe laser for the measurement of the polarization rotation was the He-Ne laser whose wavelength was 633 nm. The high voltage was continuously applied to the crystal. The added voltage was measured by the digital multi meter with a 1/100 probe. The transmitted laser intensity of the probe laser was measured by a PIN-photo diode.

3. Results

We measured the transmitted intensity of the probe laser as a function of the applied voltage to the crystal with changing the crystal temperature from room temperature of 298K to the 231K. At first, we measured the transmitted intensity at room temperature. The evaluated half-wave voltage of 4.1kV is in good agreement to the calculated value of 3.9kV derived from the electro-optic coefficient in the literature. The measured intensity at the crystal temperatures of 298K and 231K as a function of the adding voltage was shown in Fig.2.

![Graph 1: Detected voltage vs added voltage](image)

![Graph 2: Half-wave voltage vs crystal temperature](image)

Fig. 2: the detected voltage of PIN-photo diode versus added voltage. The closed circle shows the results at room temperature and open circle shows one at 236K.

Fig.3: calculated half-wave voltage versus the crystal temperature.
It shows the reduction of periodic constant clearly. In all temperature, the extraction ratio, which is determined by the ratio between the transmitted intensity when the Glan Thompson prisms (G.P.s) are crossed each other and when G.P.s are parallel is up to 1:1400. It means that there is not affection by the stress birefringence caused by the crystal cooling.

The calculated half-wave voltage as a function of the crystal temperature is shown in Fig.3. It shows that the half-wave voltage at the room temperature was 4.12 kV and the one at the 231K that is the lowest temperature in this experiment was 511V. The half-wave voltage was decreased proportionally to the temperature of DKDP crystal. It is considered that this decrease of the half-wave voltage is mainly due to the increase of the electro-optic coefficient, which is reported in [1].

4. Discussion

Here, we discuss about the other affects caused by the crystal cooling. At first, we considered about the changing of the relative dielectric constant. It was reported that the relative electric constant increases in the cooled DKDP crystal [2]. It means the increasing of the electric charge to the electrode to realize the half wave voltage.

![Graph showing the required relative electric charge and relative dielectric constant vs. crystal temperature.](image)

Fig. 5: the required relative electric charge. The dashed curve shows the literature value of the relative dielectric constant and the solid curve shows the required relative electric charge to realize the half wave voltage in each temperature.

Figure 5 shows literature value of the relative dielectric constant and the required electric charge to realize the half wave voltage in each temperature. The required electric charge is reduced with crystal cooling on the contrary of increasing the relative dielectric constant. It shows that the affection of the reducing of half-wave voltage is more effective than the affection of increasing of the relative dielectric constant. And it means that the required electric charge will be smaller and smaller with crystal cooling. On the other hand, the reduction of the half wave voltage may occur to the instability of polarization rotation with temperature changing. For example, in using cooled pockels cell as an optical isolator, that instability makes the low transmittance from the output polarizer. The fluctuation is larger in the low crystal temperature due to its low half-wave voltage. To suppress this fluctuation to 5% or less, crystal temperature should be over 230K. In that temperature, the required electric charge will be reduced to 3/5 comparison to it at room temperature.

5. conclusion

We investigated the temperature dependence of the electro-optic coefficients of the DKDP crystal at low temperature. The half-wave retardation voltage was decreased with the rate of about 55.1 V/K in the experimental temperature range. In the experiments, the lowest half-wave voltage was 551 V at the
crystal temperature of 231K, which corresponded to 1/8 of the half-wave voltage at the room temperature. The sufficiently low voltage of 511 V may permits the use of semiconductor electrical switches instead of the thyratron. On the other hand, the shorter crystal length of 1/8 comparison to the one at the room temperature showed the possibility of inserting cooled DKDP pockels cell in the ultra-short pulse laser system with low dispersion. In addition, the relatively high temperature of 231K can be easily realized using the vacuum chamber and the peltier module.

References
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