



Performance optimization of the electro-optic Q-Switching for high power laser using RTP crystal

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Abstract

In order to study the performance of proposal model crystal constructed from (Rubidium Titanly Phosphate, RTP) the birefringence, electric field application, optical, Influences of the most parametric on the electro-optical Q-switching operated for high power lasers are accomplished. The voltage requirements for productions Q-switching operation with electro-optical pockels-cells by means of this proposal as transversal configuration cell crystal have been minimized from 1.900 kV to 1.808 kV for RTP cell these values were reduced in this work owing to the reduction of the thickness to length ratio of this crystal cell.

The RTP crystal can be used with longitudinal electric field which is more suitable for high electro-optical modulation of high power lasers, but with extreme half-wave voltage, which is measured in this work and found to be 9.143 kV and 6.363 kV for x and y direction respectively .

Also, in this work, interpolated treatments on the measurements were applied using quarter-wave plate ($V_{\lambda/4}$) arrangement, which offered high improvement for using the linear of the transmission-voltage schemes to select the suitable requirement voltage for any levels switching.

1. Introduction

Rubidium Titanly Phosphate, $RbTiOPO_4$ (RTP), is an orthorhombic crystal, iso-structural with the well-known potassium titanly phosphate $KTiOPO_4$ (KTP), non-linear optical crystal [1]. It is a particularly useful material for such electro-optic applications as high-frequency Q-switching and light modulation, due to its large electro-optic coefficients, chemical stability, high damage threshold, and the absence of piezoelectric ringing. These crystals are, among others, used for SHG (Second harmonic generation) of Nd-YAG laser frequency (1064 nm). RTP is a non-center symmetric crystal; [2-7]. This crystal is also of prime interest for quasi-phase-matched interactions, because thick samples of periodically poled RTP have been realized recently. Actually, the ionic conductivity of the compounds with isomorphic compound ($MTiOXO_4$) with $M=Rb$ is several orders of magnitude lower than the one of KTP itself. So, the associated coercive field is reduced, leading to thicker poled samples. Finally, RTP might also be an interesting alternative for phase-matched interactions, because its damage threshold has proved to be 1.8 times larger than the one of KTP while having similar nonlinear optical coefficients [8].

Crystal growth potassium titanly phosphate (KTP) is known as an outstanding nonlinear optical material. Numerous successful investigations of KTP properties and growth have provoked an interest in crystals which are iso-structural to KTP in particular (RTP), first grown by the hydrothermal method has demonstrated excellent nonlinear optical properties. We have determined that the growth of RTP crystals from tungstate and molybdate solvents leads to the inclusion of W and Mo in the crystal lattice, resulting in an enhancement of fragility, a reduction of the optical damage threshold, a decrease in the second harmonic generation efficiency and the appearance of off-color centers. Phosphate systems are the more preferable for the growth of optically pure $RbTiOPO_4$ crystals [9]. The saturation point at the beginning of crystal growth is set by using a seed-tentative method. The ranges of growth temperature from 950°C to 800°C [10]. Recently, Q-switching cells that made of linear electro-optical RTP crystals are most widely used as active devices for Q-switched Nd-YAG laser as mentioned earlier. They operate on the principle, that the applied electric field presents a change in optical anisotropy of a birefringence cell that characterized by two orthogonal directions, which are fast and slow axes, having different indices of refraction [11,12].

The RTP crystal is a most common crystal is, it can operate with transverse and longitudinal applied voltage. In the transverse geometry, the electric field is perpendicular to the laser beam direction, therefore the half-wave voltage $V_{\lambda/2}$ (voltage needed for $\lambda/2$ rotation of polarization plane), is linearly related with the ratio of thickness to the length of the electro optical crystal.

With regard to the plane of polarization, the configuration of RTP can be x-cut (where the propagation of light is parallel to x-axis, while the polarization is in the y-z plane), or y-cut cut (where the propagation of light is parallel to y-axis, while the polarization is in the x-z plane). In both cases, the linear polarization is rotated at 45° to the z- axis, as shown in figure(1) [13].

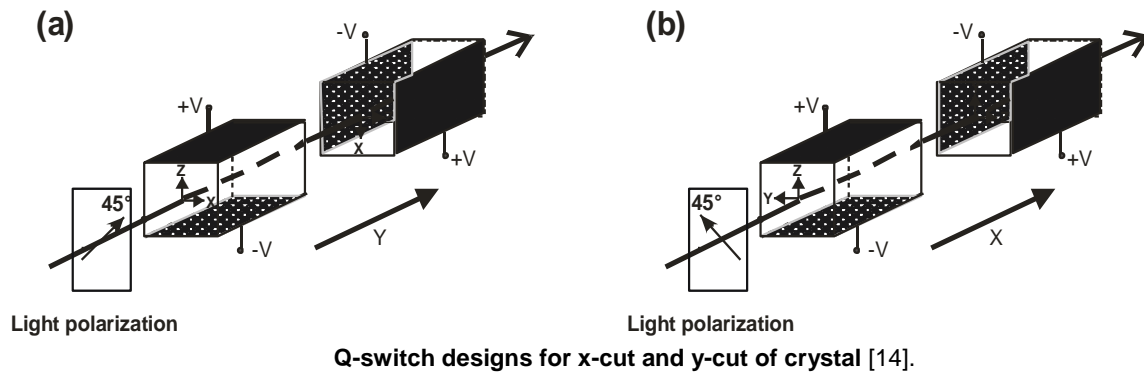


Fig. (1):

Q-switch designs for x-cut and y-cut of crystal [14].

2. Results

We studied in this research RTP pockel's cell, in order to optimize the performance of the electro-optic Q-switching cells for high power Nd:YAG laser. This cell has dimensions (4×4×20 mm³). Analysis for this study was done by applying transverse and longitudinal electric fields. To have the best performance, it must be looked for best design, arrangement, constructions, and configurations, for getting the most effective parameters of the two models that influence on their operations as transverse and longitudinal cells.

In this research, the configuration shown in figure (2) is used for the measurement of the voltage requirement. A simple polarization-optical configuration was used with the electrode modulator crystal situated between crossed (or parallel) polarizers. The modulator crystals were driven with a.c high voltage pulse generator according to the crystal type requirement to measure half-wave voltage.

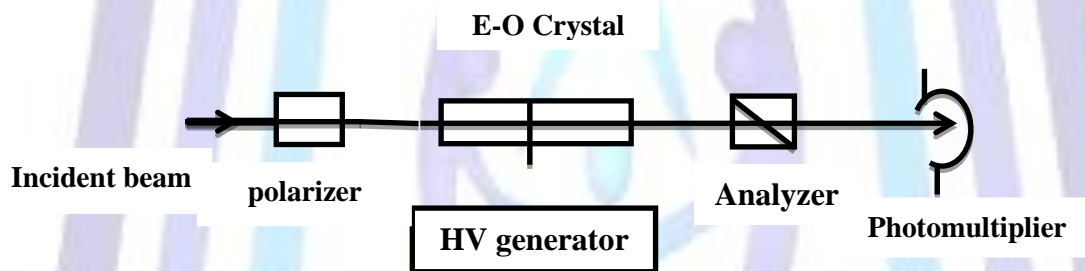


Fig. (2): Experimental design for measuring the transmission-voltage characteristics.

The static half-wave voltage $V_{\pi/2}$ was determined by taking the intensity voltage characteristics of the modulator crystal placed between the two polarizers, driving the crystal with a high voltage generator of voltage variable between 0 to 2.5 kV. The obtained results, which shows the normalized intensity–voltage characteristics for RTP, is drawn in figure (3). And it found that the value of voltage for maximum intensity or half wave voltage equal 1770 kV for RTP.

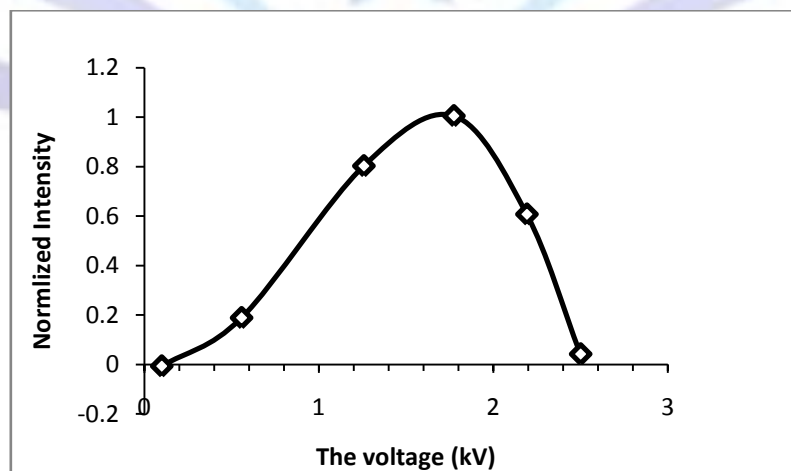


Fig.(3): Dependence of output intensities on the half-wave voltage voltage for RTP.

While the dependence of output intensities on the quarter-wave voltage is found by means of quarter-wave voltage retarder plate, set-up configuration is as shown in figure (4).

Retarder-plate

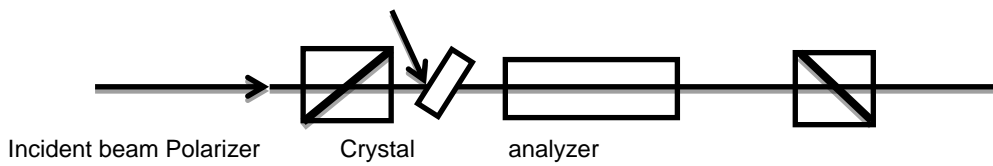


Fig.(4):a birefringent modulator with retarder plate.

Also the normalized intensities were used to fit the quarter-wave voltages as shown in figure (5):

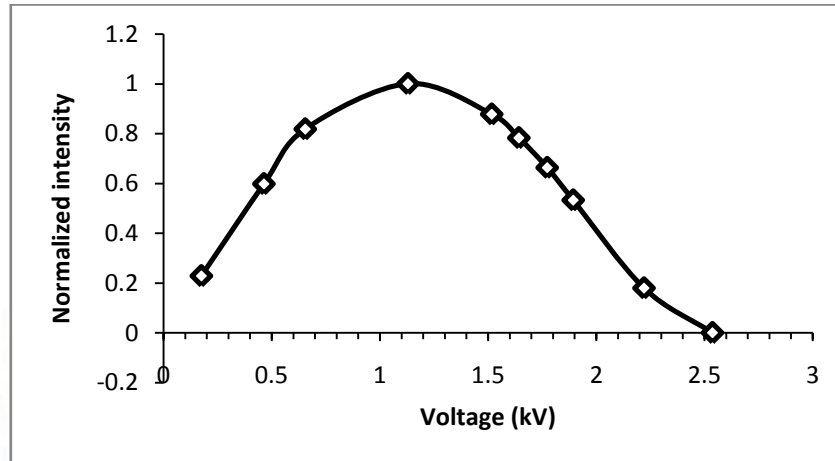


Fig. (5): Dependence of output intensities on the quarter-wave voltage for RTP.

The half-wave voltage can be calculated from the following expression:

For transverse electric field configuration [15]

$$V_{\lambda/2} = \frac{\lambda d}{2n^3 r_l} \dots \dots (1)$$

$V_{\lambda/2}$ =half-wave voltage, λ = wavelength, n =refractive index, r =effective electro-optic coefficient, d = thickness of crystal, l = length of crystal

For longitudinal electric field configuration [15]

$$V_{\lambda/2} = \frac{\lambda}{2n^3 r} \dots \dots (2)$$

And the calculated values, of x-cut and y-cut half wave voltage, for the crystal, were written in tables (1) and (2) for the transverse and longitudinal configuration respectively.

Table (1): Data $V_{\lambda/2}$ for Transverse configuration

Type Crystal	V_x	V_y	$L(mm)$	$d(mm)$	$\lambda (nm)$
RbTiOPO ₄	1828.V	1800. V	20	4	1064

Table (2): Data $V_{\lambda/2}$ for Longitudinal configuration

Type Crystal	V_x	V_y	$\lambda (nm)$
RbTiOPO ₄	9143 V	6363 V	1064

These values were compared with empirical values [16], which is 1.8 kV for the transverse configuration.

Theoretically, the output intensity is changed with the increasing applied voltage, depending on the state of polarizers, as follows [17]:

$$I = I_0 \sin^2 \left(\pi / 2 \frac{V}{V_{\lambda/2}} \right) \text{crossed polarizer} \dots \dots (3)$$

$$I = I_0 \cos^2 \left(\pi / 2 \frac{V}{V_{\lambda/2}} \right) \text{parallel polarizer} \dots \dots (4)$$



These equations were drawn in figure (6). This figure shows that at $V=V_{\lambda/2}$ for RTP (1800) the value of the intensity is equal to its minimum value when the two polarizers are parallel, and it is equal to its maximum value when the polarizers are crossed.

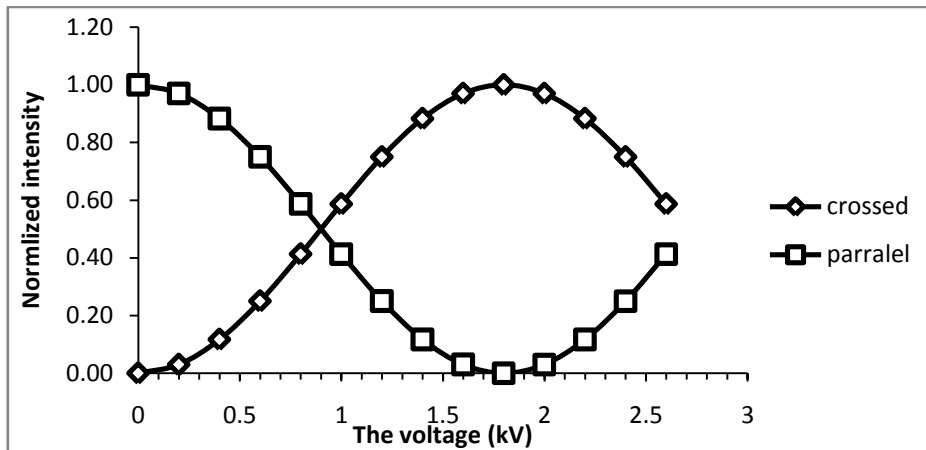


Fig.(6): Normalized intensity as a function of voltage for crossed polarizers and parallel polarizers for RTP.

When a longitudinal electric field is applied to the crystal, $V_{\lambda/2}$ does not depend on (the thickness (d) and length of the crystal (l)) or on the ratio d/l ,

$$V_{\lambda/2} = \frac{\lambda}{2n^3r} \dots\dots\dots (5)$$

In this case the crystal needs a large voltage for the purpose of electro-optical Q-switching.

In order to reduce this large value of voltage, the electric field is applied transversely, because the applied electric field depends on both the (thickness (d) and length of the crystal (l)).

$$V_{\lambda/2} = \frac{\lambda d}{2n^3rl} \dots\dots\dots (6)$$

To illustrate the dependence on $V_{\lambda/2}$ with the length of the crystal l , and make d constant, then figure (7) for RTP is the result, and it's obvious that the relation is inversely proportional.

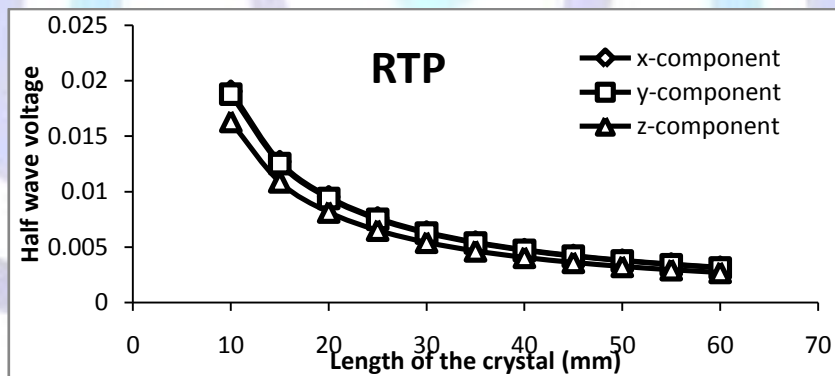


Fig. (7): The dependence of $V_{\lambda/2}$ on crystal length (y-axis multiplied by $\lambda d/(2r)$)

Also the dependence of $V_{\lambda/2}$ on wavelength λ is studied with making d/l constant, and figure (8) for RTP is the result, and it's obvious that the relation is linearly proportional.

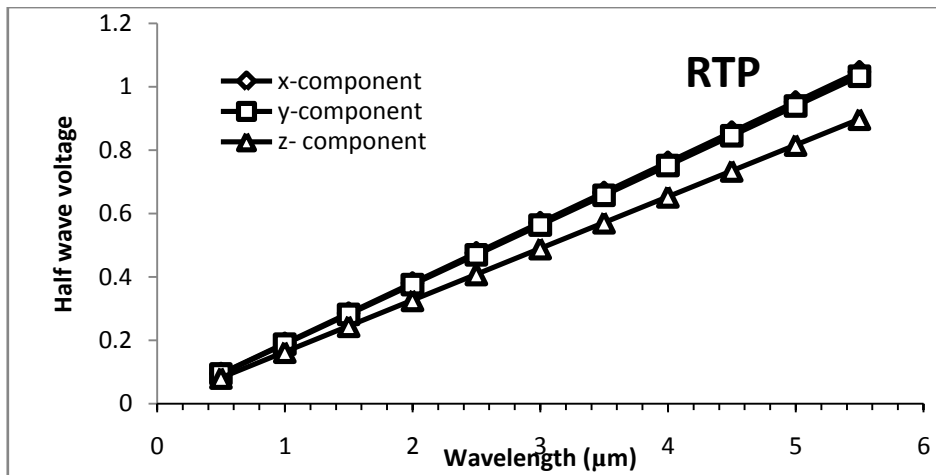


Fig. (8): The dependence of $V_{\lambda/2}$ on λ (y-axis multiplied by $d/(2rl)$)

Figure (9) shows a three dimensional plots illustrating the dependence of the half wave voltage on both the wavelength and length of the crystal for RTP :

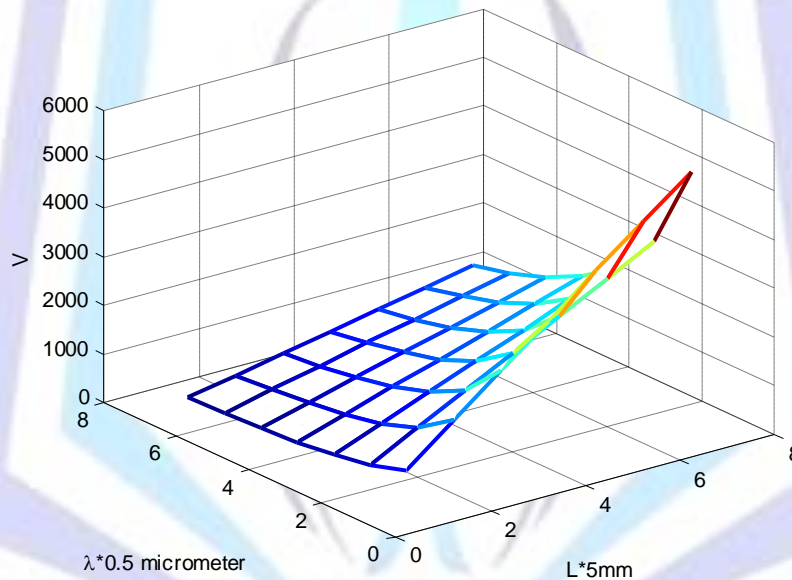


Fig. (9): 3-D figure shows the dependence of $V_{\lambda/2}$ on λ and L for RTP.

In this study, crystal was studied; it belongs to phosphate group, which is RTP. This crystal its dimensions ($4 \times 4 \times 20 \text{ mm}^2$) so as to be able of comparing work in different steps of the Q-switching operation studied such as the operation as longitudinal and transversal with both switch-off and switch-on configurations.

This work is also concentrated on the most affective parameters that effect on the crystals performing as Q-switches lasers, working in field of infrared region, around the $1064 \mu\text{m}$.

The ability for using the RTP crystal in a transverse electric field, can be reduces the requirement voltage, while when using the longitudinal electric field it needs much high voltage, because of this configuration the voltage, absolutely, did not depend on the crystal dimensions, but depends only on getting the best state of double refraction. The required half wave voltage for obtaining the photoelectric process will depend on the crystal dimensions of aperture and crystal length, as ratio of the thickness to length of d/l .

3. Discussion

The parameters that affect the required half wave voltage can be summarized as:

- 1- The optical properties of photoelectric crystal.
- 2- Crystal dimension (only for transverse configuration).
- 3- Incidence angle of laser light on the crystal, or the coincidence of laser beam with the optical axis.



From number two, it is obvious that the half wave voltage can be reduced with applying transverse electric field by reducing the value of the thickness (d) and increasing the length (l) of the crystal minimized the ratio d/l .

There were many problems and difficulties accompanied with the work of electro-optics Q-switching that using the double refraction crystals, like the two proposal crystals in the present work, which is RTP. The most important problems are the problems accompanied the applying required voltage to achieve the process of electro-optics modulation for laser beam, because there is a probability of crashing or crackling the crystal, and thus damaging it. So, the applied half wave voltage must be lowered by using appropriate ways and designing, like applying the transverse electric field instead of the longitudinal electric field so as to make the half wave voltage do depends on the ratio of thickness to length d/l , as(6) equation:

Where the half wave voltage depends linearly with the ratio d/l , so to minimize the voltage requirement this ratio must be reduced. This reduction method has some limitations, and the most important limitation is: coming from

- the angle of incidence, where the cross section area can't be so small or less than 2.5 for RTP crystal, because it will be difficult to get perfect angle of incidence, Brewster angle, which are limited by 60.99° for RTP crystal.
- Also the ratio d/l can also be reduced by increasing the length of the crystal, but here a new limitations appear concerned with the increasing of optical length of the crystal, which is increased the problems of ray-wall-off for the crystal optic axis, this increase the probability of scattering which reduces the electro-optical modulation process.

Another problem arises from increasing the length of optical path length inside the crystal represented by increasing of the inside crystal temperature, which are removed the benefit of good optical properties of this materials. The voltage requirements for productions Q-switching operation with electro-optical pockels-cells by means of these two proposals as transversal configuration cell crystal have been minimized for 1.900 kV to 1.808 kV for RTP cell these values practical were reduced in this work owing to the redaction the thickness to length ratios of both crystals cells.

Also, the RTP crystal can be used with longitudinal electric field which is more suitable for high electro-optical modulation for high power lasers but with extreme half-wave voltage, which are measured in this work by as function with normalized intensities in the range of 9.143 kV to 6.363 kV for x and y direction respectively .

By the rough estimated treatments on the linear part of the empirical transmission –voltage characteristics by 1.8kV were used for RTP model, this work also prove that the switch-off and switch-on are operated reversible with each other, this proposal model is very satisfied for these, to apply as element for Q-switching operation with high efficiency and reliability tests.

Also, interpolated treatments on the measurements were applied in this work on the quarter-wave plate ($V_{\lambda/4}$) arrangement were offered high improvement to use the linear of the transmission-voltage schemes to select the suitable requirement voltage for any levels switching .

The results wave-length as a function with half wave voltage application for ordinary and extraordinary(RTP crystal have two extraordinary rays because it has two refraction index) with this cell was linear dependent is encourage for higher frequencies lasers generation such as, second-harmonics (SHG), third harmonics (THG) and more higher harmonics generation (HHG).

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