RTP Crystals for Electrooptic Q-switches

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Recent availability of a high quality of electro-optic materials has triggered an extensive use of Q-switching for generation of high peak-power pulses in solid state lasers based on the electro-optic effect. Initially, water soluble crystals of potassium dihydrogen phosphate (KDP) and its isomorphs [1] were widely used in the longitudinal mode, i.e. when the electric field is applied along the direction of the optical beam. They are hygroscopic and require hermetic housings with protective windows, but have high optical uniformity and are useful for large aperture applications. Higher transmission, or lower insertion losses, and high contrast ratio at average powers in the kW range [2] can be achieved with lithium niobate (LN, $LiNbO_3$) operating in a transverse electrode orientation with the light propagating along the optical axis. However, LN also has several limitations: low damage threshold (~ 10 MW/cm^2), piezoelectric ringing [3] and pyroelectric depolarization [4]. Lithium tantalate (LT, $LiTaO_3$), isomorphic with LN, exhibits no piezoelectric ringing, but its twice as large damage threshold is still not sufficient for use with high peak-power high repetition rate diode pumped solid state lasers (DPSSL). Therefore, high damage threshold BBO (BaB_2O_4) crystals are employed lately for small aperture DPSSL in spite of their low electro-optic coefficients, short length (high half-wave voltage, V_π) and high cost. Very good Q-switching properties have been demonstrated with KTP ($KTiOPO_4$) crystals. When operated in a thermally compensated mode the KTP device shows excellent resistance to thermal depolarization at high average power densities [5].

In the present work we have investigated for the first time the Q-switching properties of the KTP isomorph, namely the RTP ($RbTiOPO_4$) crystal. RTP has a several orders of magnitude higher electrical resistivity and, therefore, no signs of electrochromism as compared to KTP. A thermally compensated (double crystal) RTP Q-switch has been designed and tested for operation with high repetition rate DPSSL. Its performance has been compared with a commercial BBO Q-switch.

Large 65×65×65 mm^3 RTP crystals were grown by the top-seeded solution growth (TSSG) method with pulling on X-oriented seeds. Similarly to KTP, this method yielded single sector growth on the large flat X-facet and resulted in an extremely uniform distribution of refractive indices in the YZ plane necessary for improved contrast and extinction ratio of Q-switching elements cut in the X-direction. After electrical poling at elevated temperatures (monodomainization) a pair of such crystals with mutually perpendicular orientations of the Z-axis were fabricated into a Q-switch in a thermally compensated design [5] as shown in Fig. 1. The front and rear faces of each crystal were optically polished to flatness of $\lambda/10$ at 633 nm and parallelism less than 5 arc sec. Cr/Au electrodes were deposited onto the ZX faces. The RTP crystals were antireflection coated at 1064 nm with residual reflectivity of less than 0.1%. As a result, the one way insertion losses were < 0.8%.

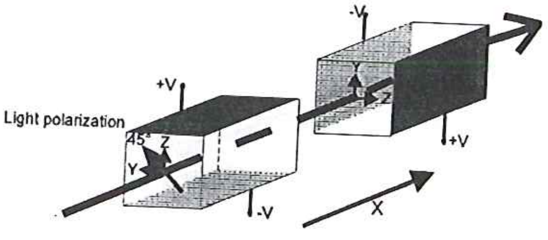

Fig. 1. Thermally compensated design of the double crystal RTP Q-switch.

In order to test the performances of the crystal as a Q-switch in high repetition rate lasers, a comparison between RTP and a commercial BBO Q-switch was made. They were placed inside a diode side-pumped Nd:YAG zig-zag slab laser working in the kHz region. The zig-zag geometry is well known to minimize thermal lensing and birefringence to first order. It also allows for more energy extraction of the TEM_{00} mode than with rod geometry while side-pumping. The Nd:YAG Brewster-cut zig-zag slab (2.5×2.5×47 mm^3) was pumped and cooled from the same faces. The laser head contained two opposite side-collimated QCW laser diodes with 200W output peak power and 20% duty cycle. The diode light passed through the cooling water before entering the slab. Unabsorbed pumped light was directed back from a mirror for additional pass through the slab. The 40 cm plano-concave laser cavity consisted of a 500 cm radius of curvature back mirror, and a flat output coupler. An Electro-Optic Q-switch based on either a BBO or a RTP crystal was mounted between the polarizer and the back mirror. We looked for piezoelectric ringing effects in RTP and BBO crystals as well. A beam from a CW Nd:YAG laser passed through the Pockels cell between two crossed polarizers. The Pockels cell was switched to quarter wavelength at 1064nm by applying 1.75kV on the RTP and 4.5kV on the BBO, with rise time of 10nsec of the electrical pulse.

With the setup describe above, i.e. light propagating along X and electric field applied along Z, $V_\pi = (\lambda / r_{c2} n_z^3)(d/l)$, where r_{c2} is the appropriate electro-optic coefficient, d – height and l – length of each crystal. We have determined experimentally the electro-optic coefficients and half-wave voltages (V_π (X) and V_π (Y) corresponding to the light propagation in X and Y directions respectively) of RTP, and the results are given in Table 1.

Although $V_\pi(Y) > V_\pi(X)$ we have used the setup of Fig. 1 in view of the better optical uniformity of the crystal in the YZ plane. However, small aperture devices with reasonable uniformity in the XZ plane may be fabricated for light propagation in the Y direction.

Table 1: Electro-optic coefficients and half-wave voltages of RTP for $d = l$ at $\lambda = 633$ nm.

Property	Literature data [6]	**Our results**
r_{13} (pm/V)	10.9	**12.5**
r_{23} (pm/V)	15.0	**17.1**
r_{33} (pm/V)	33.0	**39.6**
r_{c1} (pm/V)	23.6	**30.2**
r_{c2} (pm/V)	20.3	**23.6**
V_π (X), V	4560	**3920**
V_π (Y), V	3900	**3080**

$\boxed{\frac{r_{33}}{r_{c1}} = 1,3}$

The insensitivity of transmission of a compensated RTP Q-switch (with two 11 mm long crystals) to average temperature changes was evaluated by placing it in a thermally regulated mount between crossed polarizers (45° to the Z-axis). The signal transmitted through the system was measured as a function of the mount temperature. No transmission changes have been observed in the 25 – 125 °C temperature range. For comparison, a single RTP crystal of equivalent length (22 mm) showed a well defined periodic retadation with a period of about 2.5 °C as shown in Fig. 2.

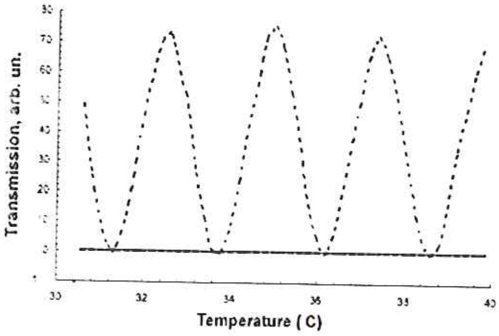

Fig. 3. Transmission versus temperature of an RTP Pockels cell (solid line) and a 22 mm long RTP crystal (dotted curve) see text for details.

The half-wave voltage of the compensated Q-switch did not vary in this temperature interval either. The angular alignment sensitivity of the Q-switch was about 12 arc min. It was measured under a condition for the extinction ratio not to diminish below 100:1.

When subjected to high voltage pulses, piezoelectric effects can give rise to acoustic waves in nonlinear crystals which impair the performance of them as Pockels cell by continuing to modulate the crystal birefringence through the elasto-optic effect long after the high voltage pulses is applied. Effective Q-switching of lasers at high repetition rate implies that the crystal is relatively free from piezoelectric ringing. We have operated the RTP Q-switch at repetition rates up to 50kHz. The ratio of the electrically switched pulse to noise was > 35:1. This oise was still present when the laser beam was cked. Any piezoelectric effects which may had rred were less then 3% (noise level). In contrast, mmercial BBO Q-switch operated at repetition f 30kHz showed piezoelectric effects on the order of 10%. The comparative results at 30 kHz are shown in Fig. 3.

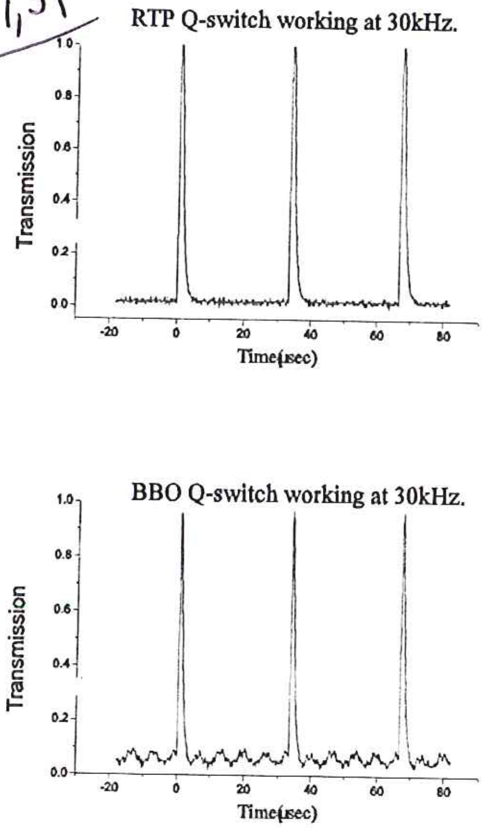

Fig. 3. Comparison of piezoelectric ringing effect.

We have measured the average Q-switched output power and the pulse duration with a 40% reflectivity output mirror for both RTP and BBO devices. Both Pockels cells give similar performances. The zig-zag laser produced up to 5mJ per pulse at repetition rates of 1kHz, with 16 ns pulse width and a beam quality of 1.5 time diffraction limit. Average power density of 2.3 kW/cm^2 and peak power of 150 MW/cm^2 were developed on the crystals. However, the advantage of the RTP crystal as a Pockels cell lies in the fact that in order to achieve hold off, less then 1kV had to be applied as compared to 4kV in BBO. Moreover, due to the differences in their electro optical properties the RTP aperture was 6x6mm^2 while that of the BBO was just 2.5mm in diameter.

References:

[1] W. Koechner, *Solid State Laser Engineering* (Springer-Verlag, 4th edition, Berlin, 1996), p. 468.
[2]. S.P. Velsko, C.A. Ebbers, B. Comaskey, G.F. Albrecht and S.C. Mitchell, Appl. Phys. Lett. 64 (1994)1.
[3] W. D. Fountain, Appl. Opt. 10 (1971) 972.
[4] P. Adsett, M. Croteau, F. Hovis, G. Grabon, S. Guch, G. Morse, R. Selleck, B. Shepard, D. Stanley, C. Tanner, D. Williams and B. Wilson, CLEO, Vol. 11of 1993 OSA Technical Digest Series (Optical Society of America, Washington, DC. 1993), p. 436.
[5] C.A. Ebbers and S. P. Velsko, Appl. Phys. Lett. 67 (1995) 593.
[6] L.K. Cheng, L.T. Cheng, J. Galperin, P.A. Morris and J.D. Bierlein, J. Crystal Growth 137 (1994) 107.