High Fidelity Large Aperture Periodically Poled Rb:$KTiOPO_4$ for High Energy Frequency Conversion

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Abstract: We demonstrate periodic poling of 5 mm thick Rb-doped $KTiOPO_4$ crystals at room temperature. The ferroelectric domain grating is shown to be uniform and homogeneous across the whole crystal aperture.
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1. Introduction

Materials of the $KTiOPO_4$ (KTP) group are known to be excellent nonlinear gain media for various frequency conversion applications used in spectroscopy, sensing and defense systems. KTP has good mechanical properties as well as a high nonlinearity and a high damage threshold. Its wide transparency range covers 0.35-4.5 μm wavelengths [1] and coupled with low thermooptic coefficients makes this material an ideal choice for 1 μm pumped optical parametric oscillators (OPOs). The advantages of quasi-phase matching (QPM) in KTP can be employed by using the electric field poling technique to fabricate a periodic structure in the crystals. Such periodically poled KTP (PPKTP) crystals are commercially available [2] with a thickness of only up to 1 mm and are therefore limited to relatively low output energies applications.

Periodical poling of 3 mm thick KTP and $RbTiOAsO_4$ (PPRTA) crystals and even 5 mm thick MgO:$LiNbO_3$ (PPMgOLN) and MgO:$LiTaO_3$ (PPMgOLT) crystals have been demonstrated previously [3, 4]. However, in order to obtain a high and homogeneous conversion efficiency over the whole optical aperture, the periodicity and the duty cycle of the ferroelectric domains needs to be maintained throughout the volume of the crystal. The periodic ferroelectric domain grating quality in such crystals often suffers from domain broadening, domain merging and irregularity of the poling period leading to a low yield and poor reproducibility of the overall fabrication process. Ferroelectric domain growth morphology in MgOLN and MgOLT is also prone to substantially varying domain duty cycle for sample thicknesses larger than 2 mm [3, 5]. Although larger anisotropy of the domain growth velocities allows for better fidelity of the domain pattern in KTP, the high inhomogeneous and nonlinear conductivity prevented so far from poling crystals thicker than 3 mm.

To address these we chose bulk Rb-doped KTP (RKTP) as the starting material. The RKTP crystals were flux-grown from the melt containing 1.4 mol % Rb, resulting in a final Rb concentration of less than 1%. The low Rb concentration suggests no significant difference in transmission or the nonlinear properties compared to undoped KTP. However about two orders of magnitude lower ionic conductivity makes it an ideal candidate for large aperture QPM crystals [6]. Additionally, this material shows substantially lower induced absorption as compared to KTP making it an ideal candidate for high-energy OPO applications [7].

In this work we demonstrate periodic poling of crystals up to 5 mm thick RKTP crystals at room temperature. High fidelity of the QPM grating is maintained due to absence of domain merging and very small domain broadening. The ferroelectric domain grating shows high quality and uniformity throughout the whole crystal thickness.

2. Experiments

The samples we used for our experiments were commercial, single domain, c-cut, flux-grown RKTP crystals with a Rb concentration of about 1%. The crystals were of dimensions 12 mm, 7 mm, 5 mm along the a-,b-,c-crystallographic axes, respectively. A periodic aluminum electrode with a period of Λ = 38.86 μm and a duty cycle of 50% was created on the c^- faces of the samples employing standard photolithography. The photoresist was left as an insulator while the c^+ faces of the crystals were left pattern-free. Liquid electrodes were used to contact the crystals to the external electric circuit. The poling area was 8 x 4 mm^2 and was only limited in size by the available photolithography mask and the need of proper crystal surface isolation owing to the high poling fields.

Due to the relatively long grating period and the large sample aperture we chose 5 ms long square pulses to pole our RKTP crystals. The best results were obtained by applying two electric field pulses of a magnitude of 3.2

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kV/mm. We believe that the ability to provide higher electric fields would allow designing optimal poling pulse shapes and gaining more control over the periodic domain inversion in this material.

The quality of the fabricated ferroelectric domain grating was revealed by selective chemically etching in a KOH and KNO_3 solution. Fig. 1 shows the domain structure at (a) the former c^- face and (b) the former c^+ face of a 5 mm thick PPRKTP crystal. We did not see any significant variations of the ferroelectric grating uniformity on both sides of our crystal and therefore we assume that such uniformity is also maintained in the bulk. This was corroborated by the frequency conversion efficiency scans across the crystal aperture. The duty cycle of the periodic structure was 51% on the patterned face and 57% on the non patterned face. Hence, no significant domain broadening was observed, which can be attributed to a much lower ionic conductivity in RKTP compared to that of undoped KTP. Furthermore, it has to be noted that the homogeneity of the electrical properties of RKTP wafers is substantially higher than in commercial KTP material, resulting in good reproducibility of the poling process and thus much higher yields. At present these samples are evaluated in high energy OPO experiments. These results will be reported at the conference.

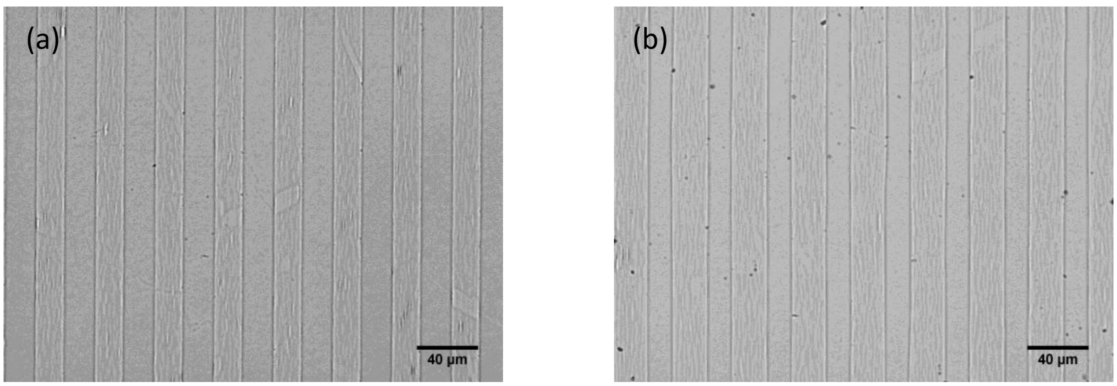

Fig. 1. Photographs of the domain structure after poling revealed by chemical etching on (a) the patterned face and (b) the non patterned face of a typical 5mm thick PPRKTP sample.

3. Conclusions

We demonstrated successful fabrication of a high-quality ferroelectric domain gratings with a period of Λ = 38.86 µm in 5 mm thick RKTP crystals at room temperature. To the best of our knowledge these are the thickest periodically poled crystals from the KTP family to date. Domain broadening and duty cycle variation in the fabricated structures was remarkably small and domain merging was not observed at all. The periodic domain grating was of high quality, making the produced QPM devices suitable for high-energy OPO applications.

4. References

[1] G. Hansson, H. Karlsson, S. Wang, F. Laurell, "Transmission measurements in KTP and isomorphic compounds," Appl. Opt. **39**, 5058-5069 (2000).
[2] Raicol Crystals Ltd., http://www.raicol.com
[3] M. Peltz, U. Bäder,A. Borsutzky, R. Wallenstein, J. Hellström, H. Karlsson, V. Pasiskevicius, and F. Laurell, Optical parametric oscillators for high pulse energy and high average power operation based on large aperture periodically poled KTP and RTA Appl. Phys. B, **73**, 663-670 (2001).
[4] H. Ishizuki and T. Taira, "High-energy quasi-phase-matched optical parametric oscillation in a periodically poled MgO:$LiNbO_3$ device with a 5 mm x5 mm aperture," Optics Lett., **30**, 2918 (2005).
[5] H. Ishizuki and T. Taira, "Mg-doped congruent $LiTaO_3$ crystal for largeaperture quasi-phase matching device," Opt. Express, **16**, 16963 (2008).
[6] S. Wang, V. Pasiskevicius, F. Laurell, "High efficiency frequency converters with periodically poled Rb-doped $KTiOPO_4$," Opt. Mater. **30**, 594-599 (2007).
[7] A. Zukauskas, V. Pasiskevicius, F. Laurell, C. Canalias, M. Safinas, A. Michailovas, "High-Performance Periodically Poled Rb-doped KTP For Frequency Conversion in Blue/Green region", Europhoton 2010, Europhysics Conference Abstract Volume 34C, ISBN 2-914771-64-9, Hamburg, Germany, 29 August – 3 September 2010, Paper No. FrA4.