



HAL
open science

Third-Harmonic Generation at 1594 nm in a KTP Ridge Optical Waveguide

Augustin Vernay, Véronique Boutou, Corinne Félix, David Jegouso, Jérôme Debray, Sébastien Pairis, Florent Bassignot, Mathieu Chauvet, Benoit Boulanger

► **To cite this version:**

Augustin Vernay, Véronique Boutou, Corinne Félix, David Jegouso, Jérôme Debray, et al.. Third-Harmonic Generation at 1594 nm in a KTP Ridge Optical Waveguide. Proceedings Advanced Solid State Physics 2021, Oct 2021, Toronto, Canada. hal-03549432

HAL Id: hal-03549432

<https://hal.science/hal-03549432>

Submitted on 31 Jan 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Third-Harmonic Generation at 1594 nm in a KTP Ridge Optical Waveguide

Augustin Vernay¹, Véronique Boutou¹, Corinne Félix¹, David Jegouso¹, Jérôme Debray¹, Sébastien Pairis¹, Florent Bassignot², Mathieu Chauvet³, and Benoît Boulanger¹

¹Univ. Grenoble Alpes, CNRS, Institut Néel, 38000 Grenoble, France

²Femto-Engineering, 15B avenue des Lonbouçons, 25000 Besançon, France

³FEMTO-ST Institute, UMR CNRS 6174, Université de Franche-Comté, 15B avenue des Montbouçons, 25000 Besançon, France
benoit.boulanger@neel.cnrs.fr

Abstract: We achieved birefringence phase-matched Third-Harmonic Generation at 1594 nm in a KTiOPO₄ single crystal ridge optical waveguide. The energy conversion efficiency reached 3.4% for a pump energy as low as 2 μJ over a pulse duration of 15 ps. Strong agreements between theory and experiments for phase-matching and conversion efficiency were obtained.

1. Introduction

The achievement of the direct Third-Harmonic Generation (THG: $\omega + \omega + \omega \rightarrow 3\omega$) in the framework of guided optics is a current challenge of photonics, where the wavelength of the Fundamental beam must often range in the telecom domain. Ridges optical waveguides carved in quasi phase-matched (QPM) periodically-poled LiNbO₃ (PPLN) [1] and KTiOPO₄ (PPKTP) [2], or in birefringence phase-matched (BPM) KTiOPO₄ (KTP) single crystals [3] have shown strong potentialities in the case of Second-Harmonic Generation (SHG: $\omega + \omega \rightarrow 2\omega$). We report here on the first experiments where we show the ability of such a technology for performing direct THG in a KTP single crystal, with the target of reaching BPM for the conversion $\lambda_\omega = 1596 \text{ nm} \rightarrow \lambda_{3\omega} = 532 \text{ nm}$.

2. Design and fabrication of the optical waveguide

We considered ridges with squared-transverse-section, where d is the side of the square. Starting from the dispersion equations of the refractive indices of bulk KTP crystal, we were able to calculate the dispersion equations of the three principal effective indices of the waveguide as a function of d in any direction of propagation of the crystal. From these data, we found that it was possible to achieve BPM in the telecom range by propagating the waves in the y -axis of KTP, the Fundamental BPM wavelength λ_ω^{BPM} being given as a function of d by the following relation:

$$\lambda_\omega^{BPM}(d) = \lambda_\omega^{BPM}(\infty) + \rho d^{-\alpha} \quad (1)$$

with $\lambda_\omega^{BPM}(\infty) = 1476 \text{ nm}$, $\rho = 5945$ and $\alpha = 2.144$.

From Eqs. (1), it comes that the ridge transverse dimension has to be $d = 6.12 \mu\text{m}$ in order to get with $\lambda_\omega^{BPM} = 1596 \text{ nm}$. In a following step, the corresponding ridge waveguide has been elaborated using a diamond blade technic in a bulk crystal provided by Cristal Laser SA. The measured transverse section S is found to be non-constant over the 8.6 mm length along the propagation axis, as shown in Fig. 1.

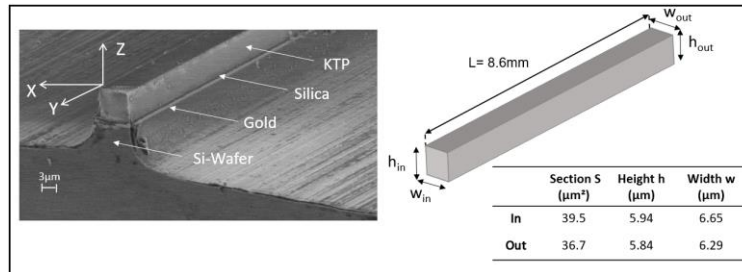


Fig. 1. Left: MEB image of the ridge waveguide. (x, y, z) is the dielectric frame of KTP. Right: Schematic view of the geometrical prismatic shape of the waveguide and dimensions of the in and out faces.

The average transverse dimension of the fabricated waveguide is very close to the $6.12 \mu\text{m}$ that was targeted, *i.e.*: $d_{avg} = \sqrt{(S_{in} + S_{out}) / 2} = 6.17 \mu\text{m}$. The corresponding BPM Fundamental wavelength calculated from Eq. (1) is $\lambda_{\omega}^{BPM} = 1594.2 \text{nm}$, which is very close to the 1596nm that are targeted.

3. Optical measurements

We used a tunable Optical Parametric Generator as the fundamental beam, with a pulse duration of 15ps and a repetition rate of 10Hz . It is injected in the waveguide using a $\times 20$ microscope objective (MO). The generated Third-Harmonic (TH) beam is collected by a $\times 40$ MO placed at the exit of the waveguide.

The TH energy measured as a function of the fundamental wavelength allowed us to determine that $\lambda_{\omega}^{BPM} = 1594 \text{nm}$, which is very close to the 1594.2nm predicted by our model.

Figure 2 shows the generated TH energy measured as a function of the fundamental incident energy. The energy conversion efficiency reaches up to 3.4% for a fundamental energy as low as $2 \mu\text{J}$. We compared these experimental data with a calculation performed in the undepleted pump approximation. We considered evanescent wave losses calculated at $10\% \text{cm}^{-1}$ and $30\% \text{cm}^{-1}$ for the fundamental and TH wavelengths respectively, and an effective interaction length of 2.7mm measured from the spectral acceptance and allowed us to take into account the gradient of the transverse section of the waveguide along its axis. Figure 2 shows the perfect agreement between measurements and calculations, and that without any fitting parameters.

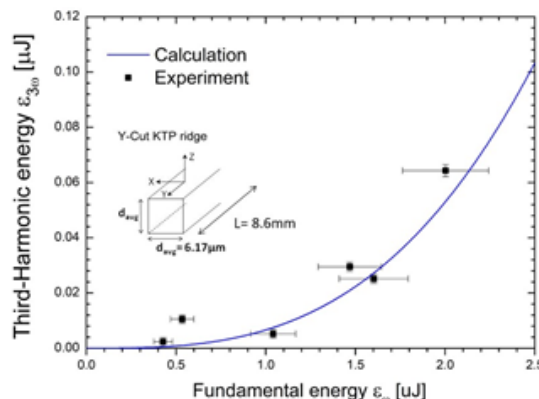


Fig. 2. Measured Third-Harmonic energy (in black) at the exit of the crystal as a function of the Fundamental energy at the entrance. Calculated energy (in blue) without any adjusting parameter.

4. Conclusion

In summary, we fabricated a 8.6-mm -long ridge waveguide based on a single KTP crystal allowing THG to be phase-matched at 1594nm . We obtained an energy conversion efficiency of 3.4% for a fundamental energy of $2 \mu\text{J}$ in the picosecond regime. The THG conversion efficiency can be mostly optimized by decreasing the losses, which will be done by increasing the thickness of the silica layer between the gold film and the KTP crystal.

The full agreement between calculation and measurement validates our calculation of effective indices as well as the notion of effective interaction length for the modeling of the effect of the prismatic shape of the ridge.

The fabrication of samples with a $2\text{-}\mu\text{m}$ -thick Silica layer is in progress with the target to decrease the propagation losses so that it is expected to reach a THG energy conversion efficiency up to 50% from our calculations.

5. References

- [1] M. Chauvet, F. Henrot, F. Bassignot, F. Devaux, L. Gauthier-Manuel, V. Pecheur, H. Maillotte, and B. Dahmani, "High efficiency frequency doubling in fully diced LiNbO_3 ridge waveguides on silicon," *J. Opt. (United Kingdom)*, 18(5), 085503 (2016).
- [2] C. C. Kores, P. Mutter, H. Kianirad, C. Canalias, and F. Laurell, "Quasi-phase matched second harmonic generation in periodically poled Rb-doped KTiOPO_4 ridge waveguide," *Opt. Express* 26(25), 33142-33147 (2018).
- [3] V. Boutou, A. Vernay, C. Felix, F. Bassignot, M. Chauvet, D. Lupinski, and B. Boulanger, "Phase-matched second-harmonic generation in a flux grown KTP crystal ridge optical waveguide," *Opt. Lett.* 43(15), 3770-3773 (2018).