Nonlinear Processes in Periodically Polled KTP Waveguides

Radek Machulka⋆, Jiří Svozilík, Jan Soubusta and Ondřej Haderka

Joint Laboratory of Optics UP and Institute of Physics of AS ČR,
17. listopadu 50A, 779 07 Olomouc, Czech Republic

radek.machulka@slo.upol.cz

1. Introduction

Motivation:

- The process of second harmonic generation (**SHG**) is used to study **periodically polled KTP** waveguides (PP-KTP-WG) [1]
- PP-KTP-WGs are used as an efficient **source of entangled photon pairs** [2]
- Pumping PP-KTP-WG with femtosecond Ti:Sa laser one can generate short pulses in blue spectral region [3]

The main adventages of waveguides:

- High power concentration inside the structure
- High optical damage threshold
- High overlap of interacting fields
- Potential for integration into more complex structures
- Generation to colinear spatial modes is helpful in many applications
- Anisotropic ionic conductivity in KTP is useful for WG formation

2. Theory

Periodic polling

Periodical polling of nonlinear materials is a way how to fulfil phase matching condition in collinear regime. This condition is replaced in this case by so called **quasi-phase matching** condition:

$$\Delta k = k_{sh} - k_1 - k_2 - \frac{2\pi}{\Lambda}$$

Due to this new condition a higher nonlinear coefficients in the material can be utilized ($d_{33} = 10.7\,\mathrm{pm{\cdot}V^{-1}}$) [4].

Spatial modes

The mode structure is essential parameter for the nonlinear processes in the waveguides. Since there are more excitable modes in the WG, the phase matching condition gets different form:

$$(\omega_A + \omega_B)n^C_{mn}(\omega_A + \omega_B) = \omega_A n^A_{ij}(\omega_A) + \omega_B n^B_{kl}(\omega_B) + \frac{2\pi c}{\Lambda}$$

Due to this phenomena, one can control spatial properties of generated light with spectral filtering and vice versa [5, 6].

3. PP-KTP-WGs parameters

The experiments were accomplished using following structure (see Fig. 1):

Parametres of used PP-KTP

- AdvR manufacturer
- Optimized for Type II nonlinear process at 800 ↔ 400 nm wavelength
- 7.62 μm polling period
- KTP substrate with dimensions: 10.5×2×1 mm (l×h×w)

Parametres of integrated guides

- Cross-section dimensions: about 5×8 μm
- Rb^+ ion diffusion fabrication technique

We assume that, bacause of the fabrication method, the refractive index is almost constant in horizontal direction (x axis) and in vertical direction (y axis) the shape coresponds to error function.

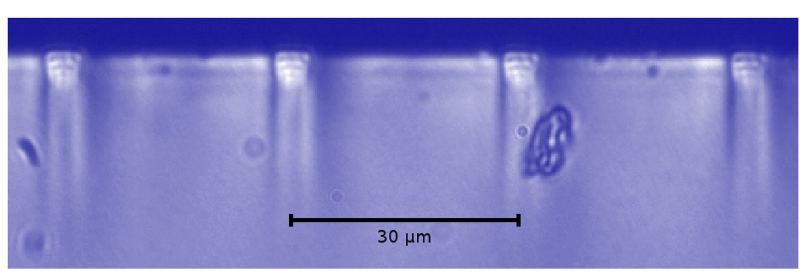
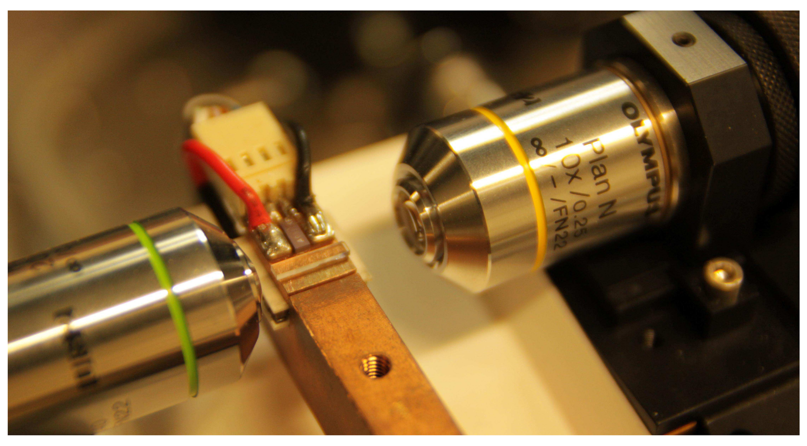


Figure 1: Facet of the PP-KTP chip with 4 waveguides and litle defect in the substrate. Particular waveguides are about 5 μm width, separated by 30 μm .

4. Experiment



Experimental setup

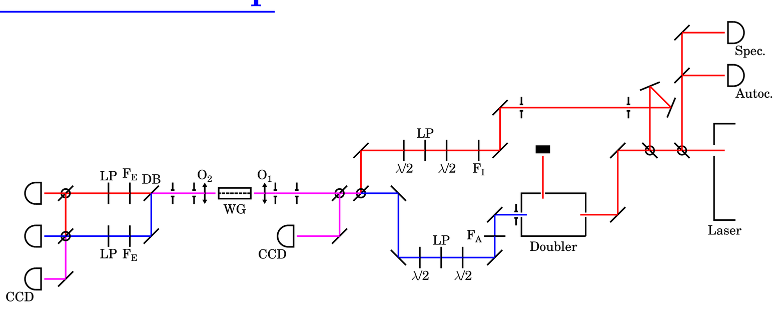
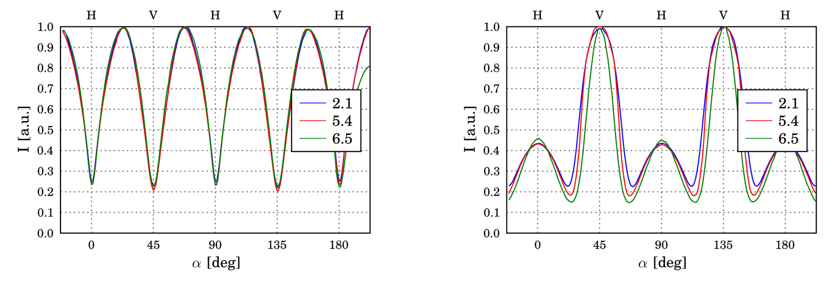


Figure 2: Experimantal setup: F_I - Interference filter, F_A - Neutral density filter, F_E - Edgepass filter, $\lambda/2$ - Half-wave plate, LP - Linear polarizer, O - Microscope objective, DB - Dichroic beamsplitter, CCD - CCD camera.

Processes

- Three different processes: Type 0, I and II (acording to the non-zero nonlinear coeficients)
- Polling period optimized for Type II process
- Processes can be switched on and off by proper polarization setting at the input of the WG in combination with polarization analysis at the output

Existance of those processes can be verified with polarization analysis of second harmonic generation (see Fig. 3), the Tab. 1 then summarises all of them with corresponding nonlinear coeficients and conversion efficiencies as well.



(a) Horizontal (b) Vertical

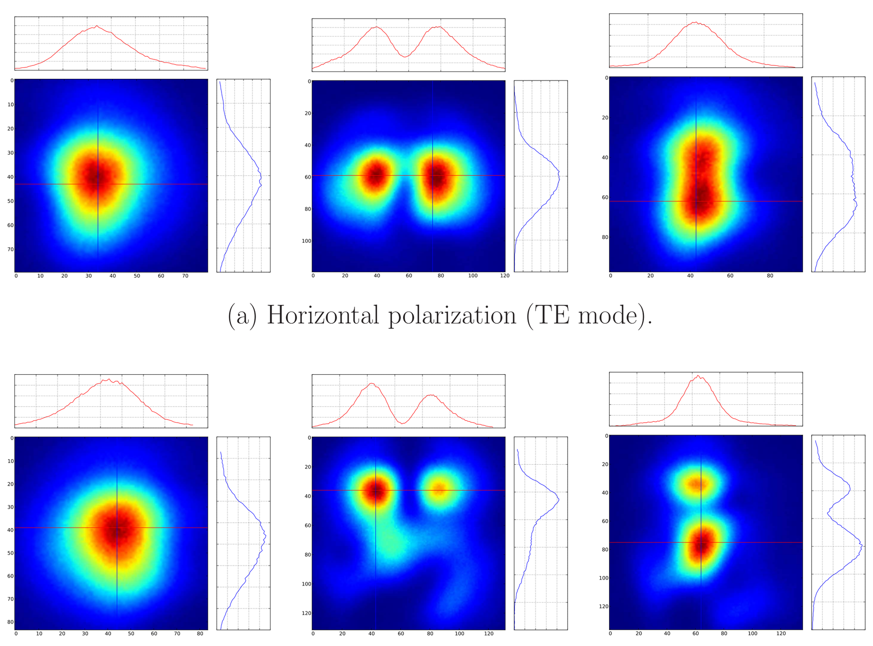
Figure 3: Intenzity of the second-harmonic field as a function of input polarization for two ortogonal orientation of output analyzer.

Process		coeff. [pm·V^{-1}]	η [W^{-1}·cm^{-2}]
Type 0	VV→V	$d_{33} = 10.7$	1.25
Type I	HH→V	$d_{32} = 2.65$	0.45
Type II	HV→H	$d_{23} = 2.65$	13.48

Table 1: Sumarization of all achievable nonlinear processes in the PP-KTP-WG with corresponding nonlinear coefficients and conversion efficiencies.

Spatial modes

Experimental mode profiles are monitored using CCD camera. The mode profile is very sensitive to proper alignment.



(a) Horizontal polarization (TE mode).

(b) Vertical polarization (TM mode).

Figure 4: Intenzity profiles of some excitable modes in the waveguide at 800 nm (pump wavelength).

5. Theoretical model

Spatial modes

The transverzal distribution $\vec{h}(x, y)$ of magnetic field intensity (magnetic component is continuous) $\vec{H}(x, y, z, t) = \vec{h}(x, y)e^{i\beta z - i\omega t}$ can be expressed using Maxwell equations in the following form

$$\frac{\partial^2 h_x}{\partial x^2} + \frac{\epsilon_y}{\epsilon_z}\frac{\partial^2 h_x}{\partial y^2} = (\beta^2 - \epsilon_y k_0^2)h_x$$

$$\frac{\epsilon_x}{\epsilon_z}\frac{\partial^2 h_y}{\partial x^2} + \frac{\partial^2 h_y}{\partial y^2} = (\beta^2 - \epsilon_x k_0^2)h_y.$$

Although for some special cases the solution can be found analytically, for a general transversal profile, the numerical approximation method has to be used.

The most effectine method for the calculations appeared the scalar finite element method (SC-FEM) called the weight residual method.

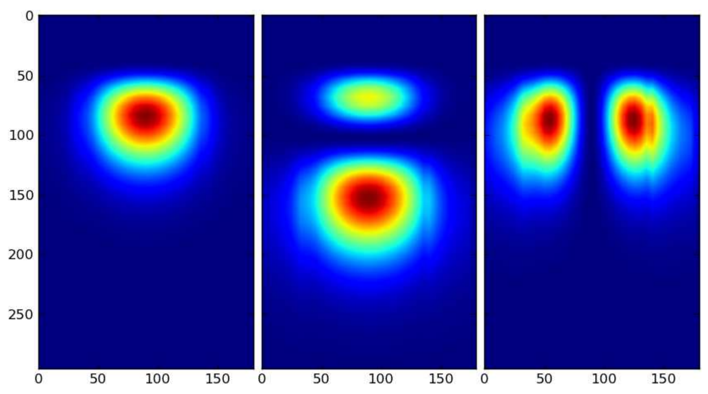


Figure 5: Theoreticaly calculated intensity profiles of three spatial TE modes as 800 nm.

Spatial-Spectral properties

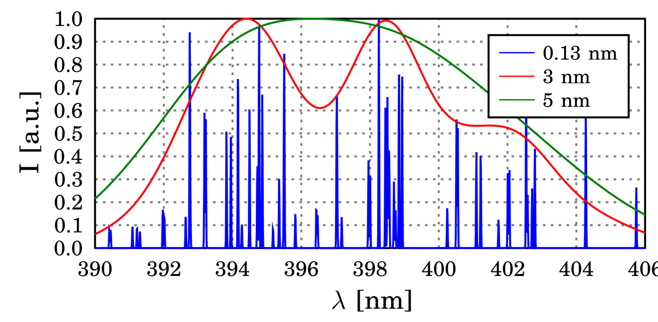


Figure 6: Particular sub-processes varying in combination of interacting spatial modes.

6. Results

Modes	λ (exp.) [nm]	λ (theor.) [nm]
10+00→10	400	401
01+01→01	397	399
01+01→02	394	396

Table 2: Some sub-processes identificated in the waveguides with theoreticaly calculated wavelengths.

7. Conclusion

Efficiency of the SHG process in PP-KTP-WG is affected by several parameters. Among them the overlap of the transverse modes of the interacting fields is very important. Good agreement of the theoretical calculations with experiment is achievable only after carefull inspection of the individual waveguide parameters.

8. Acknowledgments

This research was supported by the projects IAA100100713 of GA AS ČR and by the projects 1M06002 of the Ministry of Education of ČR.

9. References

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