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NEAR-INFRARED SECOND-HARMONIC AND DIFFERENCE-FREQUENCY GENERATION IN PERIODICALLY POLED Ti:LiNbO$_3$ WAVEGUIDES

Gerhard Schreiber, Raimund Ricken and Wolfgang Sohler
Angewandte Physik, Universität-GH Paderborn,
Warburger Str. 100,33098 Paderborn, Germany
Tel: +49-5251/60-2295 Fax: +49-5251/60-3422
E-Mail: g.schreiber@physik.uni-paderborn.de

Abstract

Efficient second-harmonic and difference-frequency generation in the 1.5 μm telecommunication window is reported. We achieved normalized efficiencies as high as 442 %W^{-1} for second harmonic generation and 318 %W^{-1} for difference-frequency generation in periodically poled Ti:LiNbO$_3$ waveguides of 50 mm interaction length.

Introduction

Nonlinear frequency conversion processes in the 1.5 μm wavelength range are of considerable interest in optical telecommunication. In particular, second-harmonic generation (SHG) and difference-frequency generation (DFG) in periodically poled waveguides in LiNbO$_3$ offer several advantages such as optical transparancy, large bandwidth and chirp reversal over other wavelength conversion technologies used in wavelength division multiplex systems [1]. Recently Xu et. al. [2] and Chou et. al. [3] demonstrated high efficiency difference-frequency generation in periodically poled proton exchanged waveguides in LiNbO$_3$. They achieved normalized efficiencies as high as 12.5 %W^{-1} resp. 260 %W^{-1} in 5.6 mm resp. 30 mm long structures. Only one result has been reported for SHG in electric field poled Ti:LiNbO$_3$ channel guides [4]. The measured efficiency of 0.35 %W^{-1} in a 5 mm long waveguide is more than an order of magnitude lower than predicted from theory.

In this contribution we report nonlinear wavelength conversion by SHG and DFG in the 1.5 μm wavelength range in 50 mm long periodically poled Ti:LiNbO$_3$ channel waveguides. The conversion efficiencies of 442 %W^{-1} and of 318 %W^{-1} are the best results ever reported. The good agreement of experimental and theoretical data demonstrates the excellent homogeneity of the waveguide and of the domain pattern resulting from an improved device fabrication technology.

Fabrication of periodically poled waveguides

98 nm thick and 7 μm wide titanium-stripes parallel to the crystal X-axis were deposited on the (-Z)-face of a 0.5 mm thick and 60 mm long LiNbO$_3$ substrate. Diffusion was performed at 1060 °C during 7.5 h. Simultaneously, a shallow domain inverted layer on the (+Z)-side of the substrate was generated, which prevents any electric field poling [4]. Therefore, we removed the domain inverted layer by a careful grinding of the (+Z)-face. As a periodic domain pattern made by electric field poling always has a better uniformity on the (+Z)-side than on the (-Z)-side [5] it is advantageous to have the waveguides on the (+Z)-face of the LiNbO$_3$ sample. For this reason we continued the fabrication process by

an electric field domain reversal of the whole substrate. Afterwards, the (+Z)-face with the optical waveguides was patternd over 6×50 mm^2 with a 17 μm period photoresist multigrating. Periodic poling was then accomplished by application of high voltage using liquid electrolyte electrodes. We controlled the poling process by monitoring the current flow through the crystal. Poling was stopped, when the charge Q corresponded to an empirically determined value to get a 50 % duty cycle of the domain pattern.

Second Harmonic Generation

After fabrication of the periodically poled waveguides they were characterized by measuring the phase match characteristics of second-harmonic generation and the normalized efficiencies. As light source of fundamental wavelength we used a fibre coupled tunable (1500 nm $< \lambda_f <$ 1580 nm) external cavity semiconductor laser. Its radiation was polarisation controlled and launched into the waveguide by butt-coupling. With 1.2 mW coupled fundamental power we achieved a maximum of 6.4 μW of generated second-harmonic power. This corresponds to a normalized efficiency of 442 %W^{-1}. The phase matching curve had only slight deviations from the ideal sinc^2 form with a full width at half maximum of 0.24 nm (see Fig. 1). These results demonstrate the very good homogeneity of the waveguide and of the microdomain pattern. Fig. 1 also presents a photograph of the etched surface of a periodically poled waveguide as inset.

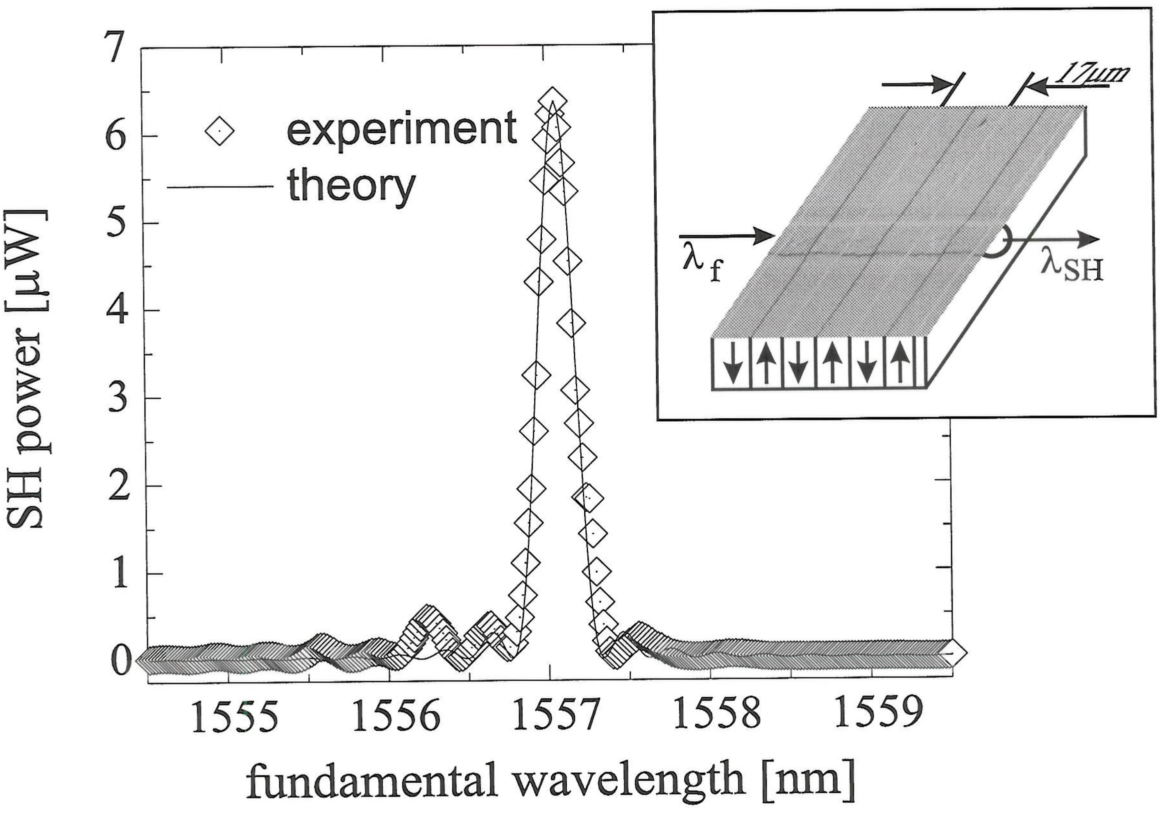

Figure 1: Generated second-harmonic power versus the fundamental wavelength. The width of the curve is 0.24 nm. A normalized conversion efficiency of the device of 442 %W^{-1} was evaluated. The inset shows the etched surface of the periodically poled Ti:$LiNbO_3$ waveguide with a total length of 50 mm.

Difference Frequency Generation

A cw Titan-Sapphir laser at 779.5 nm wavelength was used as pump laser in a DFG experiment. Photorefractive effects were avoided by performing the experiment at 90 °C. The signal laser was again a fibre coupled external cavity semiconductor laser tunable from 1500 to 1580 nm. A special wavelength division multiplexer has been used to couple pump and signal beams into a single mode fibre of 780 nm second order mode cutoff; it was butt-coupled to the waveguide end face. In this way mainly the fundamental modes were excited (Higher order pump modes would lead to weak DFG at other wavelengths due to the altered phase-match condition). The coupling was mechanically optimized by observing the second-harmonic power generated by the tunable laser.
We used 260 μW of coupled pump power and 1.1 mW of coupled signal power. Fig. 2 shows the optical output spectrum for a signal of 1551 nm wavelength, leading to an idler wave (at the difference frequency) at 1568 nm. The conversion efficiency was 318 % W^{-1}

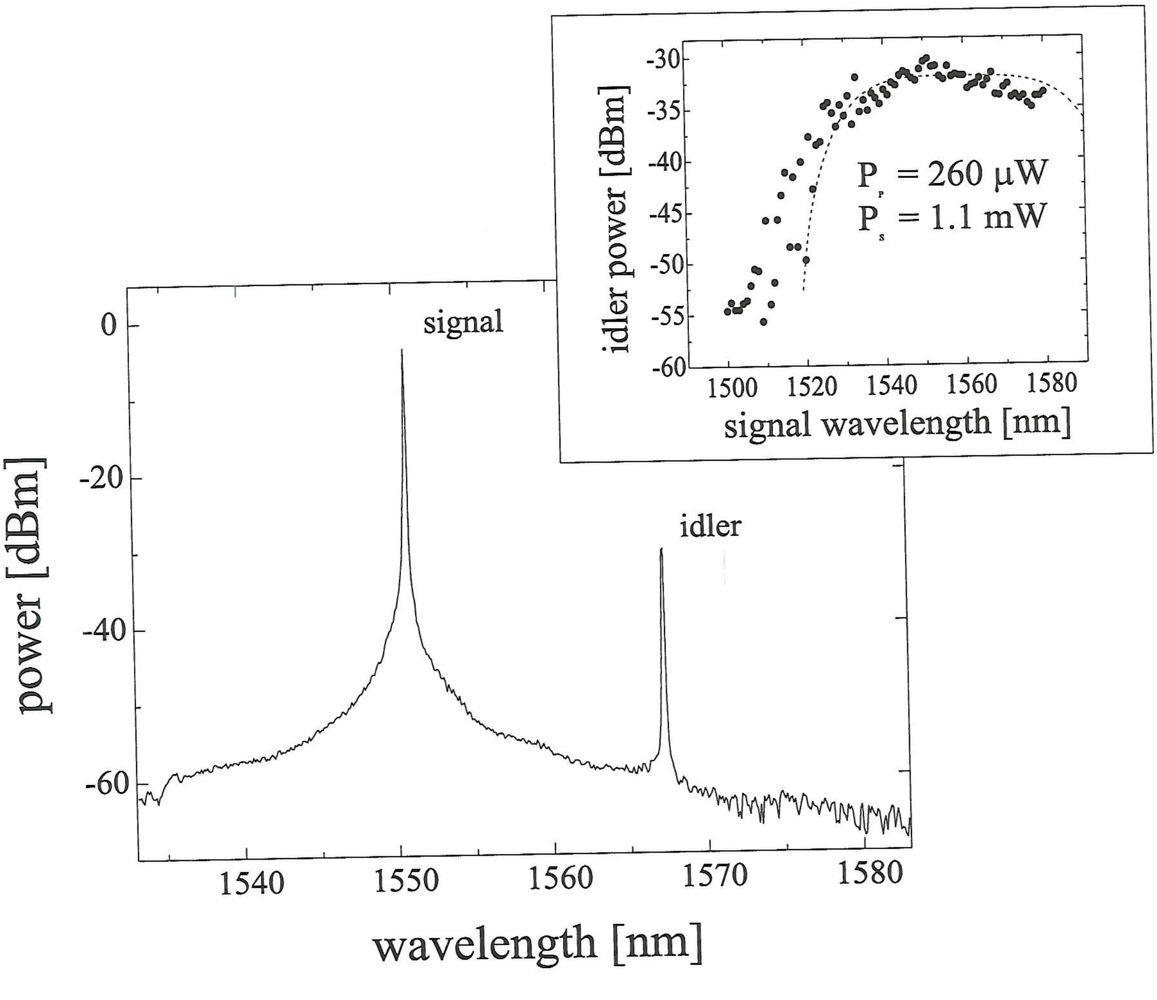

Figure 2: Optical power of signal and idler versus wavelength (resolution 0.1 nm). The wavelength of the pump was 779.5 nm; the periodicity of the periodically poled Ti:$LiNbO_3$ waveguide was 17μm. The inset shows the idler power as function of the signal wavelength. Closed circles are measured results, the dashed line is calculated for an ideal device of 50 mm interaction length.

resp. 12.7 % $W^{-1}cm^{-2}$; the generated idler power was 930 nW. We attribute the difference to the SHG efficiency mainly to a nonideal coupling efficiency to the fundamental mode of the waveguide. The DFG conversion bandwidth was measured by tuning the external cavity laser from 1500 nm to 1580 nm (inset at Fig. 2). The 3 dB bandwidth for this device was 55 $\pm$ 5 nm. This bandwidth agrees well with the 56 nm bandwidth predicted from theory.

Conclusion and Outlook

In summary, we demonstrated for the first time high efficiency SHG and DFG in quasi-phasematched Ti-diffused waveguides. We achieved an efficiency of 442 $\%W^{-1}$ for second-harmonic generation and of 318 $\%W^{-1}$ for difference-frequency generation in the 1.5 μm band. We expect that the device efficiency can be improved by a factor of up to 3 mainly by increasing the length of the device up to 80 mm. The resulting wavelength converter of an efficiency of about 1000 $\%W^{-1}$ would be an attractive device for wavelength-division multiplex systems of future optical communications.

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