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Near-Infrared Cascaded Difference Frequency Generation in Periodically Poled Ti:LiNbO$_3$ Waveguides

G. Schreiber, D. Hofmann, W. Grundkötter, R. Ricken, and W. Sohler

Angewandte Physik, Universität Paderborn
Warburger Str. 100, D-33098 Paderborn, Germany
Tel: +49-5251-60-2295, Fax: +49-5251-60-3422
E-Mail: g.schreiber@physik.uni-paderborn.de

With 155 mW coupled pump power (λ_p = 1.556 μm) a DFG efficiency of -14 dB has been achieved in a 80 mm long periodically poled Ti:LiNbO$_3$ for signals in the 1.5 μm telecommunication band

Introduction

Recently Brener et al. [1] demonstrated highly efficient difference frequency generation in the 1.5 μm telecommunication band by using a cascaded second order nonlinear process in a periodically poled, proton exchanged waveguide in LiNbO$_3$. In such a $\chi^{(2)} : \chi^{(2)}$ based wavelength converter a strong fundamental wave in the 1.5 μm band is used to generate a pump wave at $\omega_p = 2\omega_f$ which interacts with a signal wave at ω_s to generate an idler wave at $\omega_i = \omega_f - \omega_s$. The major advantage of using a cascaded process in comparison with a conventional DFG with a pump of about 780 nm wavelength is that no selective mode excitation is necessary. The idler output power in a $\chi^{(2)} : \chi^{(2)}$ process can be written as $P_i \propto L^4 P_f^2 P_s$ (low fundamental power regime). As it scales with fourth power of the interaction length it is a great challenge to develop low loss nonlinear converters of maximum length. Periodically poled Ti:LiNbO$_3$ waveguides are ideal candidates. Based on equations from [2] we calculated the efficiency of an cascaded difference frequency generator for an ideal and lossless periodically poled Ti:LiNbO$_3$ waveguide of 80 mm length. Fig. 1 shows the results for two different nonlinear coefficients $d_{33} = 27$ pmV^{-1} and $d_{33} = 18.7$ pmV^{-1}, both taken from literature [3]. In this contribution we demonstrate for the first time an efficient near infrared "cascaded" DFG wavelength converter using a periodically poled Ti:LiNbO$_3$ waveguide.

Device Fabrication and Experiment

The periodically poled waveguide was fabricated by indiffusion (1060°C, 7.5h) of 7 μm wide and 98 nm high Ti-stripes into the (-Z)-face of a 0.5 mm thick LiNbO$_3$ substrate. A subsequent electric field poling was not possible due to a shallow domain inverted layer on the (+Z)-face. Therefore, we had to remove that layer by careful grinding. As domain inversion always starts on the (+Z)-face it is advantageous to have the waveguides on the preferred side of the sample. Taking these considerations into account we performed as next fabrication step a homogeneous polarisation reversal of the whole sample. Thereafter, the periodic microdomain structure ($\Lambda = 17\mu$m) was fabricated by using the electric field poling method with the structured photoresist on the (+Z)-side. The length of the periodically poled waveguide was 80 mm. Due to inhomogeneities of the waveguides the effective nonlinear interaction length - measured by SHG - was reduced to 50 mm. The corresponding conversion efficiency was 200 %W^{-1} considerably lower than previously observed in other waveguides [4].

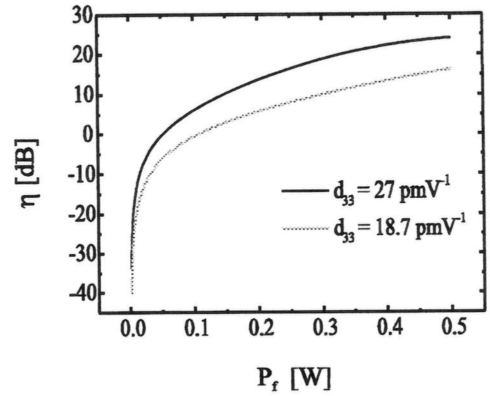

Figure 1: Calculated device efficiency for an ideal, lossless periodically poled Ti:LiNbO$_3$ waveguide of 80 mm length and two different values for d_{33}.

Fig. 2 shows the experimental setup to investigate "cascaded" DFG. A high power erbium doped fibre amplifier (up to 27 dBm) was used to amplify the output of two tunable external cavity lasers. One was used as the fundamental source to generate by SHG the pump for DFG; the other one was the signal source. Both waves were polarisation controlled and launched into the waveguide by butt-coupling. The coupled fundamental power was 155 mW and the coupled signal power was 54 mW. The generated idler radiation was measured using an optical spectrum analyzer. Fig. 3 shows on the left a corresponding result with an idler power of 2.1 mW. Therefore, the conversion efficiency was -14 dB. By tuning the signal wavelength we measured the conversion bandwidth in the low power regime. The measured figure (see Fig 3. on the right) of 55 nm agrees exactly with the bandwidth calculated for a 50 mm long device.

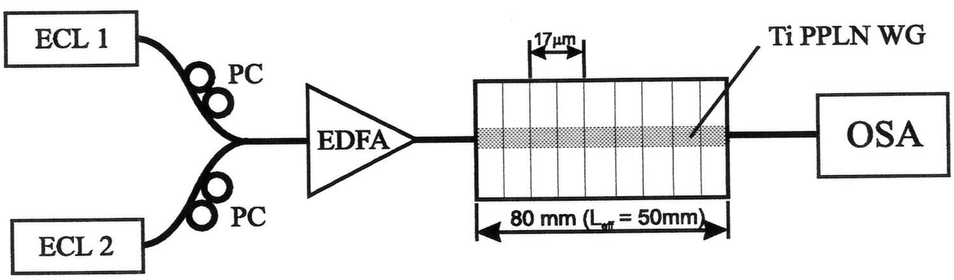

Figure 2: Experimental setup to investigate "cascaded" difference frequency generation; ECL: external cavity laser; PC polarisation controller; EDFA: erbium doped fibre amplifier; OSA: optical spectrum analyzer.

Conclusion and Outlook

We demonstrated "cascaded" difference frequency generation in 80 mm long periodically poled Ti:LiNbO$_3$ waveguides. The maximum efficiency was -14 dB achieved with 155 mW coupled

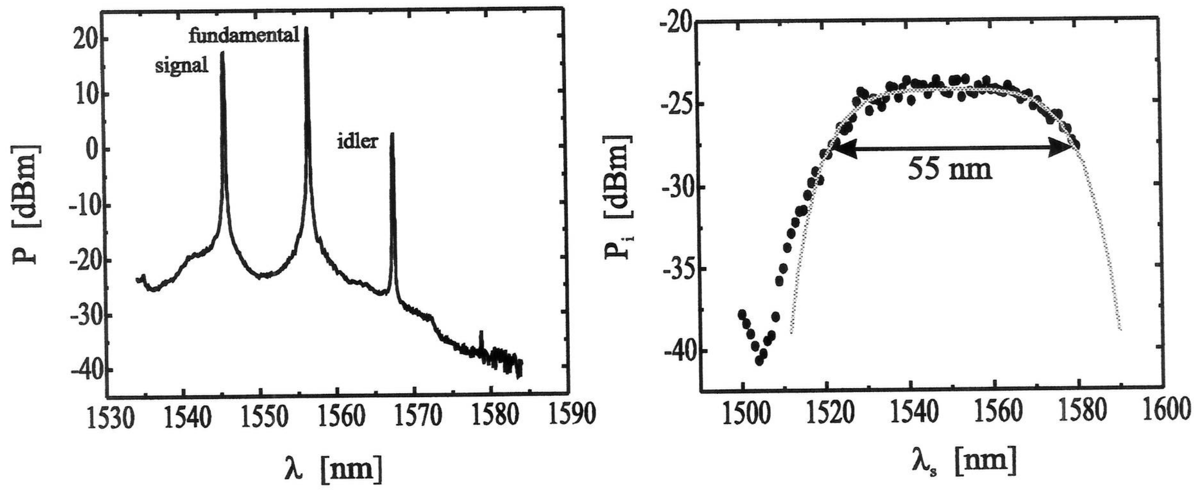

Figure 3: Left: Transmitted optical power of fundamental, signal and idler versus wavelength measured with a spectral resolution of 0.1 nm. The coupled fundamental power was 155 mW. Right: Measured (dots) and calculated (solid line) (spectral resolution 0.1 nm) idler power versus signal wavelength in the low power regime.

pump power. The device efficiency was mainly limited by the effective nonlinear interaction length. It is expected that by further improvements of our waveguide fabrication technology a device of 0 dB conversion efficiency at fundamental power levels of about 100 mW can be developed.

Acknowledgement

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