Locally Poled Ridge Waveguide on X-cut $LiNbO_3$ for Nonlinear Wavelength Conversion

Li Gui, Hui Hu, Rahman Nouroozi and Wolfgang Sohler
Angewandte Physik, Department Physik
Universität Paderborn
Paderborn, Germany
lgui@mail.upb.de

Abstract—**Fabrication of a periodically poled Ti in-diffused ridge waveguide on X-cut $LiNbO_3$ using local poling and doping techniques is reported. Stable second harmonic generation of 50 mW at λ=775 nm was achieved at room temperature. Wavelength conversion in the C-band of optical communication was also demonstrated using cascaded nonlinear interaction.**

Keywords-ridge waveguide; periodic poling; second harmonic generation; wavelength conversion

I. INTRODUCTION

To enhance the efficiency of nonlinear interactions in optical waveguides, smaller cross section and higher index contrast are required leading to a strong enhancement of the guided mode intensity. Therefore, $LiNbO_3$ (LN) ridge waveguides are of increasing interest. Nishida et al. reported highly efficient wavelength conversion using a Z-cut direct-bonded PPLN ridge waveguide [1, 2]. Iwai et al. reported high power blue generation from an X-cut adhered MgO:LN ridge waveguide by frequency doubling [3]; Sugita et al. also demonstrated efficient second harmonic generation (SHG) in a Y-cut direct-bonded MgO:LN ridge waveguide [4]. The fabrication of the PPLN ridge waveguide in all existing work is based on adhering or direct-bonding a periodically poled bulk substrate to another substrate followed by lapping, polishing and either sawing or dry etching in order to shape the ridge. We have recently reported novel local poling and doping techniques to fabricate a periodically poled Ti in-diffused ridge waveguide on X-cut LN [5]. In this work, we improved the fabrication techniques and thus enhanced the efficiency of second harmonic generation (SHG) by a factor of two. Moreover, for the first time we demonstrated wavelength conversion using a cascaded scheme of SHG and difference frequency generation (DFG).

II. WAVEGUIDE FABRICATION AND LOCAL POLING

A. *Fabrication of Ridge Waveguide*

The ridge was fabricated using ICP etching in a mixture of C_4F_8 and He. The etching process was repeated several times until the ridge height was 3.5 µm. A Ti layer of 80 nm was then deposited only on the top of the ridge as the doping source. Ti in-diffusion was done at 1060 °C for 8.5 hours. A fabricated ridge waveguide is shown in Fig. 1(a). The propagation loss of such a ridge waveguide at λ=1550 nm is around 1 dB/cm for TE and 0.8 dB/cm for TM polarization.

B. *Local Periodic Poling*

Local periodic poling was performed as depicted in Fig. 1(b). Comb-like electrodes were deposited on the sides of the ridge using a lift-off technique. Since the ridge is typically 7 - 9 µm wide, a low voltage of a few hundred volts was sufficient to overcome the coercive field of ~ 21 KV/mm. Generally, a voltage pulse of 400 Volts and 30 ms duration was used. By cutting through the ridge (Fig. 1(c)) and using selective chemical etching in HF:HNO_3 solution, the inverted domains are revealed as shown in Fig. 1(d). However, the quality of the poling, especially the domain shape and the duty cycle, could be further improved.

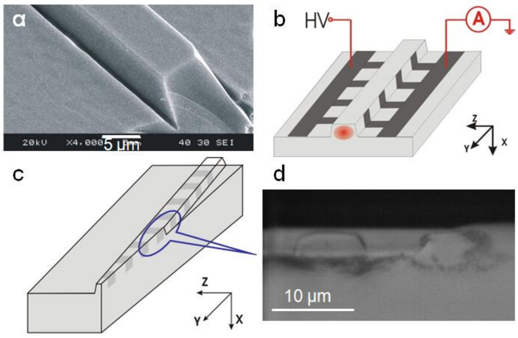

Figure 1. (a) SEM micrograph of a Ti in-diffused ridge waveguide; (b) Scheme of local periodic poling; (c) Sketch of cutting a ridge; (d) selectively chemical etched periodic domains in the ridge waveguide.

III. WAVELENGTH CONVERSION

Nonlinear interactions were investigated using a 13 mm long locally poled ridge guide on X-cut LN at room temperature. The height and width of the ridge guide are 3.5 µm and 7 µm respectively. The domain period is 16.6 µm throughout the waveguide. The end faces of the waveguide have been carefully polished and an anti-reflection coating at λ=1550 nm was deposited.

A. *Second Harmonic Generation*

The fundamental wave was provided by a tunable extended cavity semiconductor laser (ECL) with the wavelength λ_f tuned in steps of 1pm around 1548 nm. The light was coupled into the waveguide by fiber butt coupling. Fig. 2 presents the SHG tuning characteristic as generated SH power versus λ_f. The measured bandwidth of 0.8 nm agrees with the calculated result. This indicates the excellent homogeneity of the periodically poled ridge guide along the interaction length.

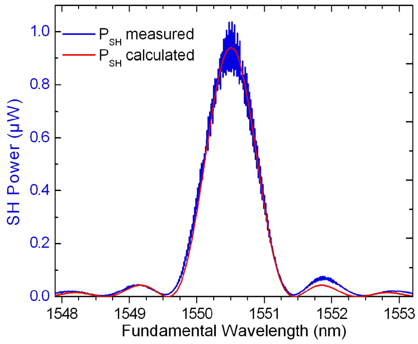

Figure 2. Generated SH power as function of the fundamental wavelength.

SHG was also investigated as function of the fundamental power as shown in Fig. 3. A parabolic dependence between the SH power and the fundamental power was observed, well described by a power normalized efficiency of 28 % W^{-1} (or 16.5 % $W^{-1}\,cm^{-2}$). It is calculated as the ratio of out-coupled SH power and the square of in-coupled fundamental power. The normalized efficiency was improved by a factor of two compared to [5] mainly due to the reduced cross sectional area of the ridge guide. It is important to note that the ridge guide shows a higher resistance to the photorefractive damage at room temperature compared to a conventional Ti:PPLN channel waveguide. A stable SH power up to 50 mW was measured at the fundamental power of 700 mW as a function of time as shown in the inset of Fig. 3. A similar phenomenon was reported in [1] but on a Z-cut direct-bonded LN ridge guide.

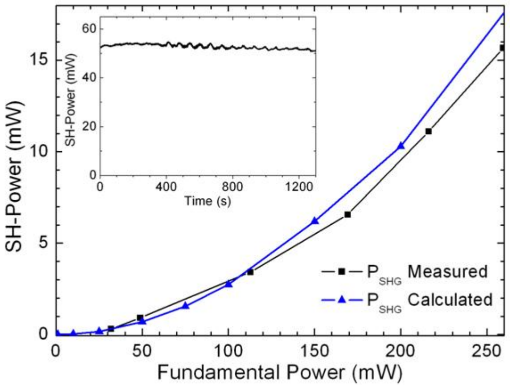

Figure 3. Generated SH power as function of coupled fundamental power. Inset: Measured SH power as function of time.

B. *Cascaded SHG/DFG*

Wavelength conversion based on a cascaded scheme as shown in Inset 1 of Fig. 4, was demonstrated using the ridge guide. The fundamental wave from the ECL at λ_f =1548.5 nm and the signal wave at λ=1555.5 nm from a DFB laser diode were both coupled into the ridge guide. The generated SH wave at λ=774.25 nm served as the pump of the successive DFG. In this first experiment, we observed a conversion efficiency from the signal to the idler of -29 dB when the coupled fundamental power was around 200 mW. The idler power is relatively stable as shown in Inset 2 of Fig. 4.

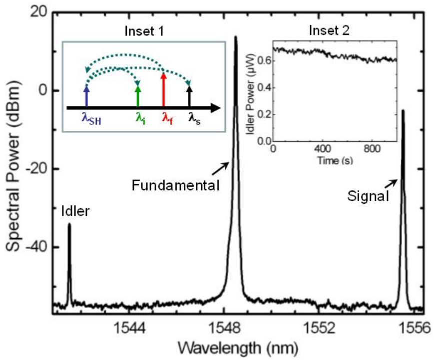

Figure 4. Wavelength conversion by cascaded SHG/DFG at a coupled pump power of ~200 mW (Resolution: 0.1 nm). Inset 1: Scheme of the wavelength conversion. Inset 2: Measured idler power as function of time.

IV. CONCLUSION

We demonstrated SHG and cascaded SHG/DFG using a locally poled Ti in-diffused ridge waveguide on X-cut LN. Such a ridge guide shows a high resistance to the photorefractive damage at room temperature. There is a large potential to improve the conversion efficiency by using a longer waveguide with smaller cross section and further optimizing the domain shape and the duty cycle.

ACKNOWLEDGMENT

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