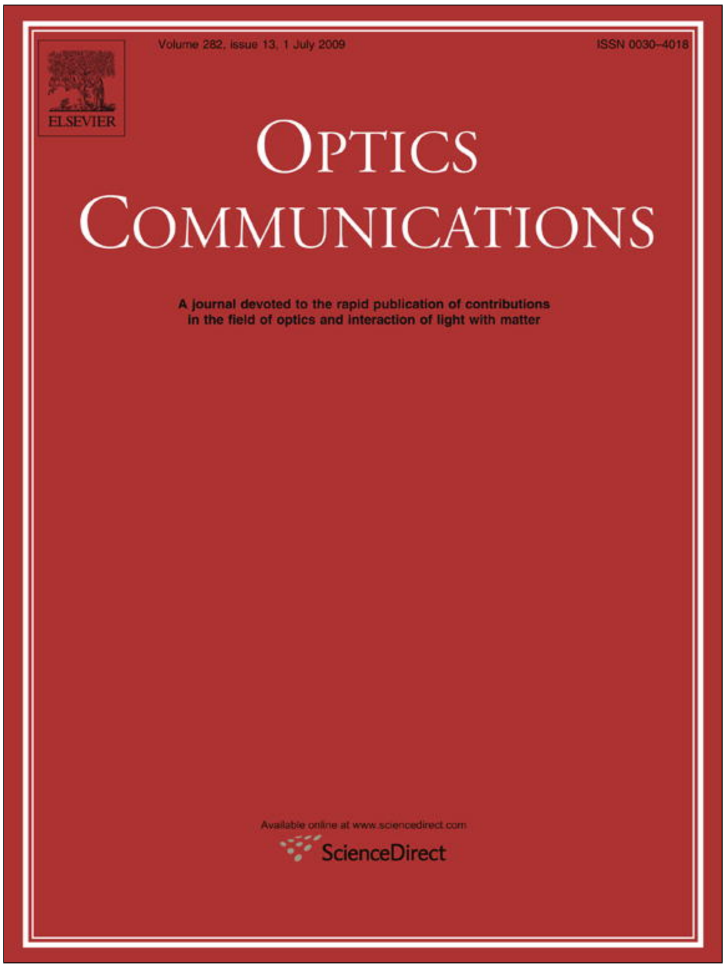
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Wavelength conversion in a Ti:PPSMgLN channel waveguide

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ABSTRACT

A periodically poled titanium (Ti)-diffusion waveguide in near-stoichiometric $MgO:LiNbO_3$ (SMgLN) was fabricated that exhibits a second harmonic generation (SHG) efficiency of 63%. The device shows very high resistance to photorefractive damage at room temperature. All optical wavelength conversion by difference frequency generation (DFG) has been demonstrated in a periodically poled SMgLN (PPSMgLN) with Ti-diffusion channel waveguides. The wavelength conversion efficiency was measured to be −7.3 dB with the pump power of 150 mW and the signal power of 50 mW at room temperature.

1. Introduction

Wavelength converters using quasi-phase-matched (QPM) $LiNbO_3$ waveguides are recognized as key devices for future wavelength division multiplexing (WDM) systems. These converters offer several distinct advantages such as the simultaneous conversion of WDM channels, a large signal bandwidth and transparency as regards modulation format. However, congruent $LiNbO_3$ (LN) is known to be exhibit photorefractive damage in the presence of radiation at wavelengths below 100 nm [1]. To suppress photorefractive damage effect, congruent $LiNbO_3$ is typically operated at temperatures around 120 °C [2], making this material impractical for telecom products.

Highly Mg-doped $LiNbO_3$ is known to be more resistance to photorefractive damage than congruent $LiNbO_3$. However, unexpected leakage current and the strong effect of domain widening out of the electrode area impose limitations on the period of short-pitch domain inversion patterns [3]. Near-stoichiometric $LiNbO_3$ crystals doped with MgO at lower concentration show better photorefractive damage resistance than congruent $LiNbO_3$ and conventionally highly MgO doped congruent $LiNbO_3$ [4], and poling field for ferroelectric domain inversion can be decreased significantly as well [5]. Therefore, PPSMgLN has been anticipated as the most practical QPM material.

QPM-LN waveguides are usually fabricated by the annealed proton exchange (APE) technique but they only allow the propagation of TM mode light [6]. In contrast, waveguides made of Ti-diffusion can propagate both TM and TE mode lights and are effective for polarization-independent operation [7]. In this work, we report the first preparation of a QPM titanium-diffusion waveguide in PPSMgLN, and we demonstrate SHG and wavelength conversion properties based on the QPM difference frequency generation using PPSMgLN waveguides at room temperature. In addition, photorefractive damage effect cannot be observed when a high power 780 nm pump light was lunched into the waveguide at room temperature.

2. Device fabrication

We prepared a Z-cut $40 \times 6 \times 0.5\ mm^3$ near-stoichiometric $LiNbO_3$ doping 2 mol% MgO wafer as a substrate. The wafers were photolithographically patterned with a periodic stripe Al metal electrode pattern deposited on the $+Z$ surface and oriented along the Y-axis. The uniform metal film is deposited as a ground electrode on the $-Z$ face. To reduce the coercive field, the high temperature poling was also important. To heat up the samples from 25 to 100 °C, the coercive field could be reduced from 5 kV/mm to 3 kV/mm. The current in the external circuit indicates the domain evolution during poling. PPSMgLN was performed on the substrates using the conventional method of the voltage pulse application technique [3]. Domain grating period of 16–18 μm in PPSMgLN permitted QPM of DFG having signal wavelengths around 1.5 μm and pump wavelengths around 7.5 μm at operating room temperature. Fabricating Ti-diffused waveguide is more important to achieve wavelength conversion. The Ti film of ∼0.1 μm thickness was deposited on $+Z$ surface of the wafer by RF sputtering, and patterned into channels with 6.5 μm width by a conventional

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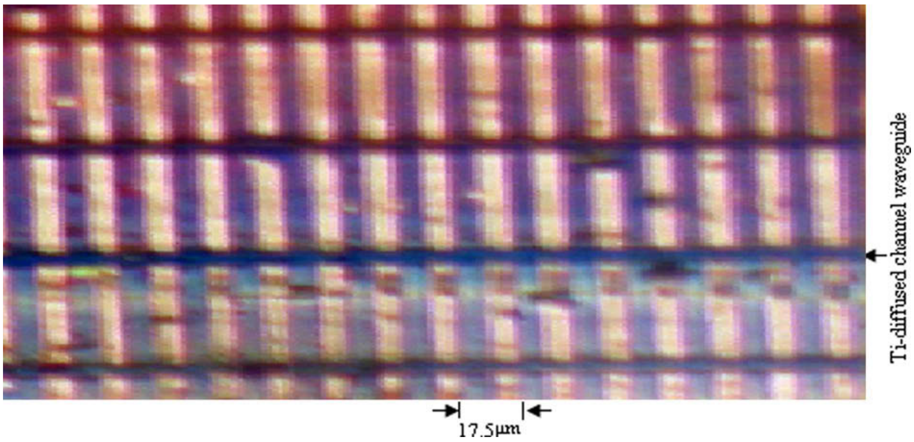

Fig. 1. PPSMgLN with 17.5 μm period after Ti-diffusion waveguide of 6.5 μm width.

photolithography technique. Ti-diffusion was carried out at 1049 °C in an O_2–H_2O gas mixture. The flow of oxygen was 2.4 l/min, the total gas pressure was 1 atm. The wafers were placed on a support made of platinum. The duration of annealing was 8–10 h. Fig. 1 shows the SEM image of the fabricated Ti-diffused PPSMgLN (Ti:PPSMgLN) waveguide following 5 min etching.

3. Experimental and results

As a preliminary test, we measured SHG characteristics of the device by CW operation. The experiment was carried out at room temperature and a fundamental wave from a Nd:YAG laser pumped Gr:YAG with 100 mW output at 1530 nm [8]. The mode size was adjusted with a telescope to provide an appropriate mode match to the waveguide. A SH wave for input of 1530 nm was obtained in a channel with period is 17.3 μm. The result is shown in Fig. 2. The measured FWHM wavelength bandwidth, 0.5 nm, was close to the theoretical value, 0.48 nm. It suggests good uniformity of the waveguide and the QPM grating. Fig. 3 shows the SHG output power dependence on the fundamental power. The powers were measured directly at the output side of the waveguide. The SHG power increased in proportion to the square of the fundamental power. We achieved an output power 63 mW with a pump power of 100 mW, which corresponds to approximately a 63% conversion of the pump light into SHG light.

We carried out a DFG measurement in the 1550 nm band. The experimental setup is shown schematically in Fig. 4. The pump laser was a cw Ti:Sapphire laser that was tunable from 700 to 870 nm with an output power of several hundreds of milliwatts.

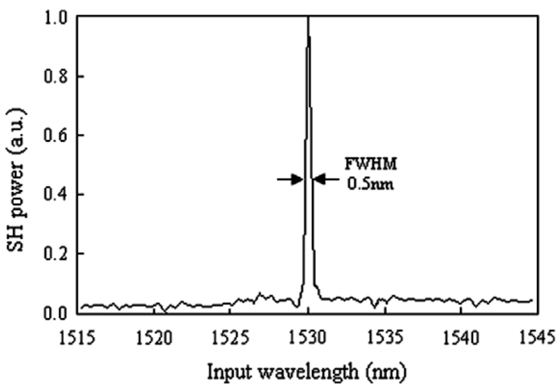

Fig. 2. SHG power dependent on input fundamental wavelength.

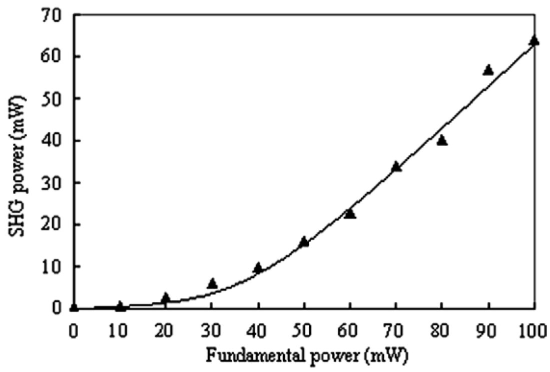

Fig. 3. SHG output power dependent on input fundamental power.

The signal laser was a Nd:YAG laser pumped Gr:YAG that was tunable from 1400 to 1700 nm with an maximum output power of more than one hundred milliwatts. The two laser beams, after being combined by a dichroic mirror (transmission near 1550 nm, and reflection near 800 nm), were then focused by a microscope objective, and then lunched into end-polished QPM Ti:PPSMgLN waveguide. The output spectrum from the waveguide was analyzed in an optical spectrum analyzer. To obtain high frequency conversion efficiency, the pump and signal laser beams have to be spatially overlapped within Ti:PPSMgLN waveguide. Two apertures were placed along the laser beam to make the two beam spots as equal as possible.

We performed multichannel wavelength conversion with coupled pump and signal power is 150 mW and 50 mW, respectively. The optical spectrum at the Ti:PPSMgLN waveguide out put is shown in Fig. 5. The signal wavelength is tuned at 1550 nm. The pump wavelength is chosen at 770 nm to meet the QPM condition for the DFG process. As shown in Fig. 5, the DF wave $\lambda = 1530$ nm was obtained. The QPM period of the Ti:PPSMgLN was 17.5 μm, and the waveguide loss was determined to be 0.12 dB/cm at a 1550 nm wavelength. The power difference between the 1550 nm signal and the 1530 conversion signal at the output of the Ti:PPSMgLN waveguide is the conversion efficiency. For a 770 nm input pump power of ~50 mW, a conversion efficiency of −7.3 dB is achieved. According to Ref. [9], the theoretically predicted conversion efficiency is 0-dB, and our experimental conversion efficiency was relatively low in comparison with the optimized one. The difference between the calculated and the experimental conversion efficiencies might be caused by such factors as propagation loss and spatial overlap between the wave-

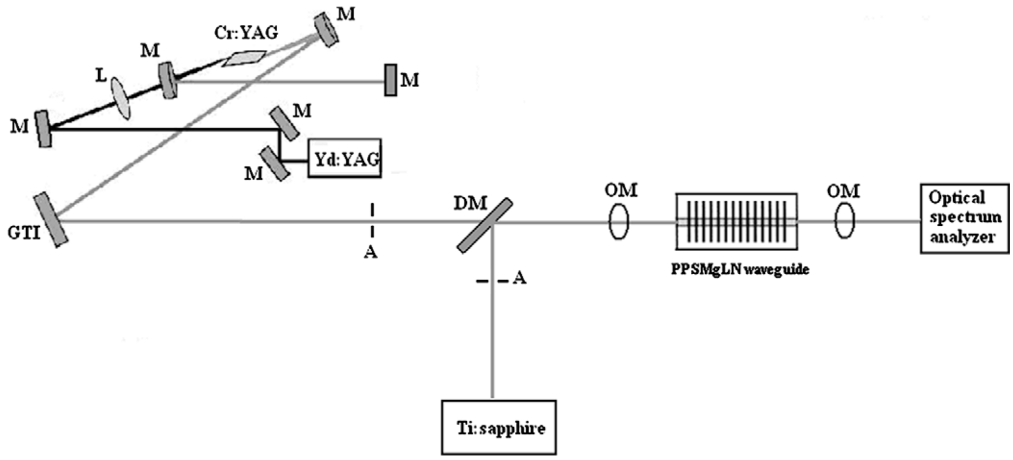

Fig. 4. Experimental setup for DFG wavelength conversion.

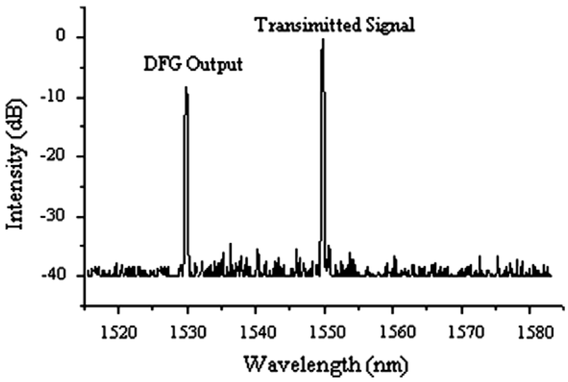

Fig. 5. Spectrum of the output waves for a DFG experiment with 770 nm pump light of 150 mW.

guide modes of the waves involved in the nonlinear interaction. We believe that the conversion efficiency could be further increased by using a pump and signal laser fiber combiner, optimizing the waveguide design and fabrication conditions, and minimizing the propagation loss.

The photorefractive damage characteristics of the fabricated device was examined by observing the second harmonic generation spectra when a high power 780 nm pump light was lunched into the waveguide. To monitor the output wavelength shift caused by the photorefractive damage, we used a high power signal light at 1560 nm and measured the generated SHG spectra with the spectrum analyzer. Fig. 6 shows the wavelength shift against the pump wave irradiation time. These experiments were carried out at room temperature and a 780 nm light with a power of 200 mW was launched into the waveguide. Fig. 6 also shows the result for the device made of congruent $LiNbO_3$ for comparison. The wavelength shift of the QPM-LN device shows an increase at the beginning of the irradiation and stabilizes at 4 nm after 10 min. In contrast, the QPM-SMgLN device shows no wavelength shift even after 10 min irradiation.

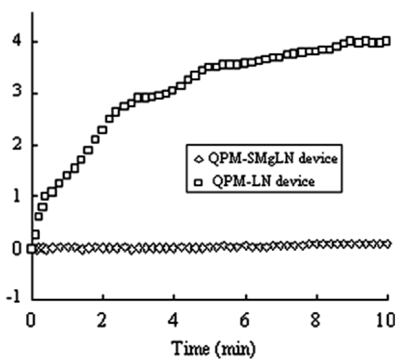

Fig. 6. SHG wavelength shift against 780 nm wave irradiation time.

4. Conclusion

Wavelength conversion of QPM DFG in the Ti:PPSMgLN waveguides has been demonstrated for the first time. The conversion efficiency of the signal to the DF wave was approximately −7.3 dB with the pump power of 150 mW and the signal power of 50 mW at room temperature. The characteristics of the Ti:PPSMgLN waveguide was tested by second harmonic generation, and we obtained an SHG efficiency of 63% in the 1530 nm band. The SHG spectrum shift against irradiation time was measured using a 780 nm pump light of 200 mW, and it revealed the device has a very high resistance to photorefractive damage even at room temperature. These results indicate that the use of Ti:PPSMgLN waveguide may contribute appreciably to the development of practical wavelength converter devices suitable for telecom applications.

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