Fabrication of quasi-phase-matched C/L inter-bands wavelength converter with LPE grown $LiNbO_3$ thin films

Hidekazu Seki, Takeshi Fukuda*, Satoshi Tanaka and Hirochika Nakajima

Department of Applied Physics, Waseda University

3-4-1 Okubo, Shinjuku-ku, Tokyo, 169-8555,JAPAN

(TEL / FAX) +81-3-5286-3155, mail to: hidekazu@pic.phys.waseda.ac.jp

**Recent affiliation: Fujikura Co.Ltd ., 1440 Mutsuzaki, Sakura, 285-0812, JAPAN*

Sunao Kurimura and Takunori Taira

Laser Research Center, Institute for Molecular Science

38 Nishigo-naka, Myodaiji, Okazaki, 444-8585, JAPAN

Abstract

Quasi-phase-matched (QPM) difference-frequency-generation (DFG) devices in liquid-phase-epitaxy grown $LiNbO_3$ (LN) waveguides are reported, designed for wavelength conversion in dense wavelength–division multiplexing （DWDM） optical communication. Periodically poled structures on a substrate were transferred to a ZnO-doped LN film, which was fabricated into a ridge-waveguide structure by dicing. DFG wavelength conversion was demonstrated in an 8mm-long device from C-band channels in 1530-1560 nm to L-band channels in 1580-1610 nm. The efficiency of -34 dB was obtained with flat wavelength dependence in this range.

DWDM expands its wavelength range from C-band (1530–1570nm) to L-Band (1570–1610nm) and the demand for the channel number is extensively increasing in recent years while multi-wavelength conversion becomes more attractive because of the reduced system complexity. Since quasi-phase matching enables to design conversion characteristics artificially [1], QPM-DFG devices have been attracting attention as a wavelength converter for the system and studied in LN waveguides formed by proton exchange with a periodically poled structure [2][3][4]. However, these waveguides suffer from degradation of nonlinear optical constant and the temporal change of waveguide property. This work reports composition-controllable waveguides grown by liquid-phase epitaxy (LPE) instead of proton exchange since it allows the control of optical quality (optical nonlinearity and photorefractive sensitivity) in core and the strong confinement of light due to sharp index profile.

Fig.1 illustrates an LN waveguide QPM-DFG device, consisting of a periodically poled structure in ZnO-doped LN (ZnO: LN) thin films grown on a z-cut LN crystal of 0.5mm thickness. A signal wave of wavelength λ_s and a pump wave of λ_p are coupled, generating a wave of $1/\lambda_d = 1/\lambda_p - 1/\lambda_s$ by QPM-DFG interaction through d_{33}, which is the largest nonlinear coefficient in LN. QPM period is determined by the effective indices and wavelengths for DFG, signal and pump waves.

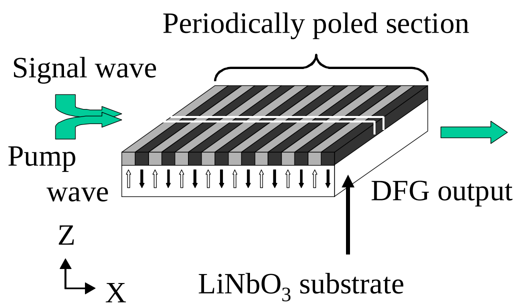

Fig.1 Quasi-phase-matched difference-frequency-generation device in liquid-phase-epitaxy grown $LiNbO_3$ waveguide.

We designed the QPM period as 19.5 μm, which was required for the wavelength conversion from λ_s= 1.53-1.57 μm to λ_s =1.57-1.61 μm at λ_p= 0.785 μm. Periodically poled section was fabricated by applying high voltage, after photoresist patterning on the +C face of a substrate. Fig. 2 shows the applied pulses and the observed poling currents, monitored with an oscilloscope. The numbers in fig. 2 represent the number for the applied the pluses. Typical poling field was 21.5 kV/mm and the number of pulses was 30 for a 5 mm circular area. LiCl saturated solution was used as liquid electrodes. The structure of the fabricated periodically poled section was observed with a microscope after etching with HF acid.

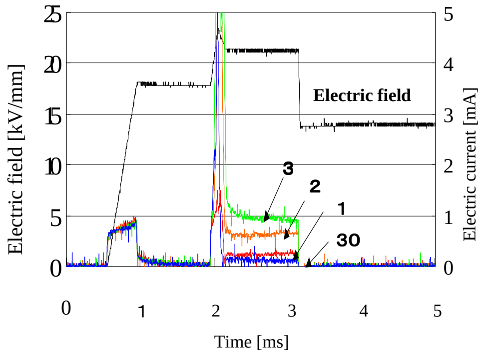

Fig.2 Pulse shape of applied electric field and polling current.

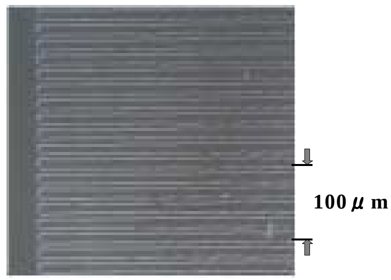

Fig.3 Photograph of the top surface of the periodically poled section after etching.

Fig.3 is a photograph of the top surface of etched periodically poled section. We achieved an ideal 0.5 duty ratio, which is the ratio of the polarization-reversed area to the period. After the poling process, we grew a ZnO: LN thin films by LPE on the periodically poled LN wafer using a Li_2O-V_2O_5 flux system. It is known that the periodically poled structure is transferred to the films by LPE by choosing appropriate growth condition [5]. The starting melt composition was 20 mol% LN –80 mol% $LiVO_3$, and ZnO was added into the melt. As a growth method, we adopted the solid-liquid -coexisting method, which has advantages of high transfer fidelity of a periodically poled structure and high crystalline quality [6]. Although V^{3+} is believed to cause photorefractive damage for visible blue light, we here used V_2O_5 since operating wavelengths are much longer than in the previous report. The experimental setup for LPE growth is illustrated in Fig.4. The melt includes 40 mol% ZnO and a film was grown at 900℃ for 10 min immersion with a rotation speed of 50 rpm. [6].

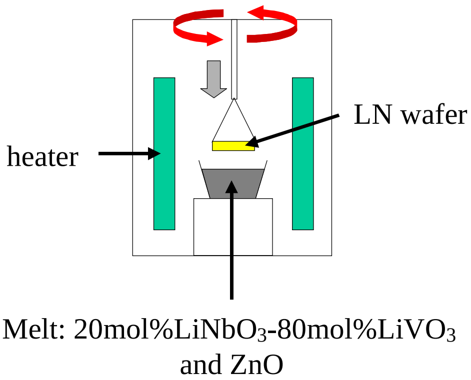

Fig.4 Experimental setup for LPE.

By choosing an appropriate blade and cutting parameters in our dicing saw, optical-quality surfaces were obtained without polishing on the input and output endfaces of the device. Then, we fabricated 8 μm-wide ridge waveguides of 5 mm length by making trenches parallel to the propagation direction as illustrated in Fig.5. Fig 6 shows the experimental setup for wavelength conversion, where DFG experiments were performed using a tunable laser diode as a signal light source and a Ti: sapphire laser as a pump light source. The signal beam was coupled by an objective lens and launched in TM mode. An optical spectrum analyzer monitored DFG light as the output light from the device.

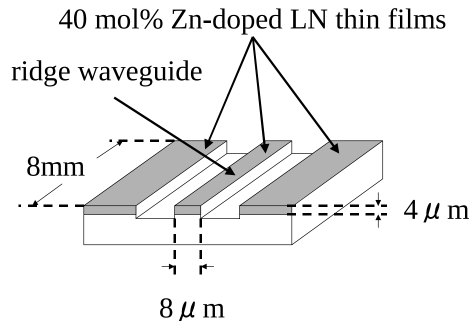

Fig.5 Fabricated ridge waveguide with a dicing saw.

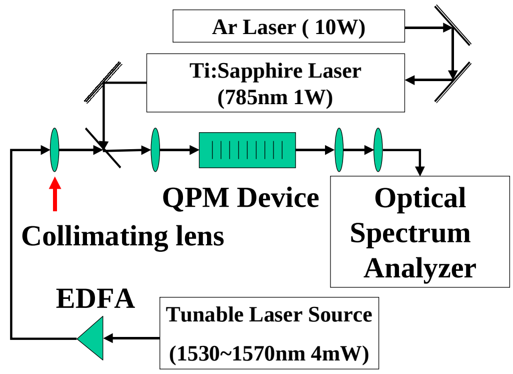

Fig.6 Experimental setup for wavelength conversion.

Channel conversion was achieved in an 8 mm-long device from C-band channels in 1520-1560 nm to L-band channels in 1570-1610 nm with the efficiency of -34 dB, which shows flat dependence on wavelength as shown in Fig.7.

In conclusion, we fabricated the QPM-DFG device with LPE growth of ZnO-doped LN thin films, and realized flatly –34 dB in wavelength conversion between C-L bands. Optimized waveguide geometry and effective pumping of TEM_{00} mode at 785 nm will increase conversion efficiency of the device.

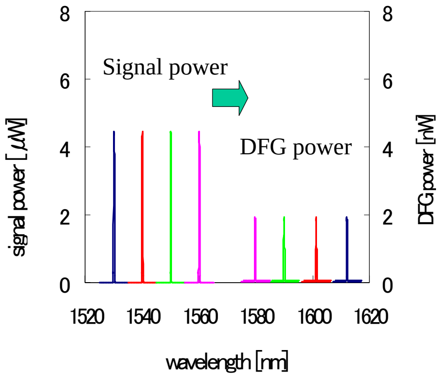

Fig.7 DFG wavelength conversion between C-band and L-band channels: pumped by a Ti: Sapphire laser.

The authors would like to thank Dr. Kawaguchi of NGK Insulators, Ltd. for fruitful discussions and Dr. Chikuma of Pioneer Electronic Corp. for the use of the Ti: sapphire laser.

References:

[1] S.Kurimura, Nonlinear Optics, **8**, pp. 191-204(1994)

[2] M.H.Chou, J.Hauden, M.A.Arbore, and M.M.Fejer, Opt.Lett., **23**, pp1004–1006 (1998)

[3] M.Fujimura, A.Shiratsuki, T.Suhara and H. Nishihara, Jpn. J. Appl. Phys., **37**, pp.659-662 (1998)

[4] C.Q.Xu, H.Okayama and M.Kawanaka, Appl.Phys.Lett., **63**, pp.3559-3561 (1993)

[5] T.Kawaguchi, H.Kitayama, M.Imaeda and T.Fukuda, J. of Crystal Growth, **178**, pp. 524-528 (1997)

[6] T.Kawaguchi, Doctorial dissertation (1999)

[7] T.Kawaguchi, K.Mizuuchi, T.Yoshino, M.Imaeda, K.Yamamoto and T.Fukuda, J.of Crystal Growth, **203**, pp. 173-178 (1999)