P2-23 Optical Parametric Oscillator Based on Periodically Poled MgO-Doped $LiNbO_3$

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Abstract

We report the fabrication of 0.5-mm-thick periodically poled MgO-doped $LiNbO_3$ (PPMgLN) with domain-inverted periods of ~30.0 μm and an interaction length of 30 mm, and the demonstration of quasi-phase-matching optical parametric oscillator (QPM-OPO) using PPMgLN.

1. Introduction

Periodically poled $LiNbO_3$ (PPLN) with domain-inverted periods of a quasi-phase-matching optical parametric oscillator (QPM-OPO) have been extensively studied on account of its large nonlinear optical coefficient, d_{33} [1]. Recently, PPLN QPM-OPO has attracted special interest as a mid-IR source for remote sensing of trace gases in the atmosphere by the use of the differential absorption lidar technique. However, PPLN irradiated with a high-power laser beam is known to experience photorefractive damage. To prevent such photorefractive damage, QPM devices using PPLN require high-temperature operation (~200 °C) [1,2], thus limiting the extent of miniaturization.

In contrast, MgO (~5 mol%)-doped $LiNbO_3$ (MgO: LN) is an important material for nonlinear optical applications because it has a higher resistance to photorefractive damage than that of $LiNbO_3$ (LN) [3], and it has a large nonlinear optical coefficient, d_{33} comparable to that of LN [4,5]. However, the demonstration of QPM-OPO using periodically poled MgO-doped $LiNbO_3$ (PPMgLN) has not been reported. The QPM-OPO device using PPMgLN has an advantage in that it can be miniaturized further than the device using PPLN because in the former case, a heating apparatus is not necessary to prevent the photorefractive damage.

2. Fabrication of PPMgLN

Z-cut, 0.5-mm-thick LN crystals doped with 5 mol% MgO were used. The fabrication process for PPMgLN is summarized here. By means of the electric field poling process and the liquid electrode technique, 0.5-mm-thick PPMgLN crystals with domain-inverted periods of ~30 μm and an interaction length of 30 mm were fabricated. Periodic electrodes with the grating direction parallel to the crystal *X*-axis were patterned on the +*Z* (+*c*) surface of the MgO: LN substrates by a photolithographic process. In PPMgLN fabrication, the inversion voltage applied was less than one-fourth of that applied in the case of PPLN.

To investigate the domain-inverted structures in the fabricated PPMgLN, the cross section of the domain-inverted structures was observed by cutting PPMgLN along the *Y*-face and etching it in a mixture of hydrofluoric acid and nitric acid (HF: HNO_3=1:2) at 60 °C for 5-10 minutes. Figure 1 shows the optical microscopic image of the domain-inverted structures in the cross section (*Y* face) of PPMgLN with the domain-inverted period of 30.0 μm. Figure 1 indicates that the domains are uniformly inverted from the +*Z* surface to the −*Z* surface, so that the bulk periodically domain-inverted structure can be obtained.

The quality of a periodically domain-inverted structure is mainly determined by two factors, namely (1) periodicity and (2) duty cycle. The periodicity of the domain-inverted structures strongly affects the phase-matching wavelength of a QPM device, while the duty cycle of the domain-inverted structure affects conversion efficiency. A maximum conversion efficiency can be achieved for a perfectly uniform duty cycle of 50 %. To estimate the uniformity of duty cycles, domain-inverted widths were measured in PPMgLN

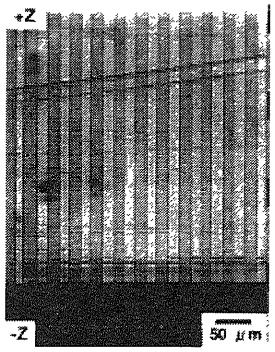

Fig. 1. Optical microscopic image of the domain-inverted structures in the cross section (*Y* face) of PPMgLN with the domain-inverted period of 30.0 μm.

with the domain-inverted period of 30.0 μm and the interaction length of 30 mm. Numerical analysis confirmed that the average duty cycle was 50.69 % and the standard deviation was 4.13 %. This indicates that the duty cycle of PPMgLN is close to the optimum value of 50 % within the interaction length of 30 mm.

3. PPMgLN QPM-OPO Experimental

After polishing of its *Y-Z* plane PPMgLN had the interaction length of 30.0 mm and was uncoated. The OPO was pumped by a *Q*-switched Nd:YLF laser (wavelength, 1047 nm ; pulse duration, 70 ns; pulse repetition rate, 2 kHz). The OPO linear cavity was a singly resonant oscillator (SRO) at the signal wave and consisted of two spherical mirrors with a radius of curvature r=11.2 mm with reflectivity of 99 % at the signal wave. The pump transmittance was 80 % and the idler transmittance was limited to 45 %. The cavity length was 35 mm and the beam spot diameter of a signal wave was ~100 μm at the center of the PPMgLN crystal. The optical output power was measured using a optical energy meter. The power spectra were measured using a spectroscope.

To investigate the photorefractive damage in QPM-OPO using PPMgLN, the average idler output power was measured by changing the PPMgLN crystal temperature from room temperature to 100 °C. Figure 2 shows the temperature dependence of the average idler output power at the average pump input power of 260 mW (3.3 kW_{av}/cm^2, 23.6 MW_{peak}/cm^2) for PPMgLN with the domain-inverted period of 30.2 μm. Figure 2 shows the significant difference between the characteristics of PPMgLN and PPLN. The idler output power of PPLN rapidly decreases with decreasing temperature below 60 °C. In contrast, the idler output power of PPMgLN

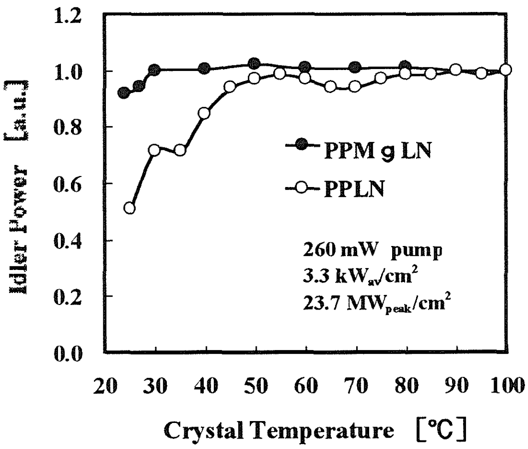

Fig. 2. Temperature dependence of the average idler output power at the average pump input power of 260 mW (3.3 kW_{av}/cm^2, 23.6 MW_{peak}/cm^2).

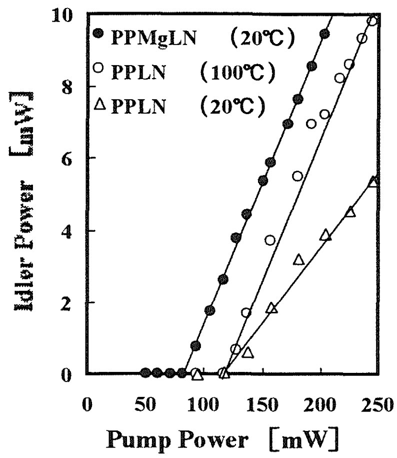

Fig. 3. Idler output power as a function of pump input power.

is almost temperature independent, causing no photorefractive damage. However, the idler output power of PPMgLN below 30 °C exhibits a small decay. Therefore, to investigate the photorefractive damage of PPMgLN below 30 °C in detail, the characteristics of idler output power vs pump input power were measured with the domain-inverted period of 30.2 μm at 20 °C. Figure 3 shows the idler output power as a function of pump input power. For PPMgLN at 20 °C, an average output power of 10 mW at 3.5 μm with an average pump power of 200 mW, an oscillation threshold of 80 mW, a slope efficiency of 10 % and typical pump depletion of 46 % were obtained. These properties of PPMgLN at 20 °C were comparable to those of PPLN heated to 100 °C for the elimination of photorefractive damage. These results indicate that the QPM-OPO device using PPMgLN experience no photorefractive damage at room temperature, and can thus be operated in the steady state at room temperature. The PPMgLN QPM-OPO device is expected to be widely used as a compact mid-IR source in laser applications.

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