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Widely tunable high power OPO based on a periodically poled MgO doped lithium niobate crystal

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Abstract

An optical parametric oscillator (OPO) based on a highly MgO doped periodically poled lithium niobate (PPMgLN) crystal was experimentally demonstrated and the result is presented in this report. The PPMgLN wafer was fabricated from a MgO doped (with 6 mol% doping concentration) lithium niobate crystal by means of high voltage pulse trigged domain reversal technique and has 20 domain reversal periods from 27.8 to 31.6 μm with a step of 0.2 μm between the neighbor periods. An acousto-optic (AO) Q-switched $Nd^{3+}:YVO_4$ laser was used as the pumping laser. A maximum laser output power of 4.8 W has been achieved for the OPO when the pumping power is 10.8 W and it corresponds to an optic-optic conversion efficiency of 44%. By shifting the PPMgLN wafer, the periods of the domain structure on the PPMgLN wafer can be changed, thus enabling a wide spectral tuning range of the laser output from 1.42 to 1.73 μm (for the signal light) and from 2.76 to 4.27 μm (for the idler light).

Keywords: Optical parametric oscillator; PPMgLN; Highly MgO doped $LiNbO_3$

1. Introduction

Optical parametric oscillator (OPO) is one kind of attractive mid-IR sources that are used in the applications where the wavelength of laser sources using normal amplifying media cannot reach or where the wide tunability is needed. After the method of domain reversal by external electric field was devised [1], the technology of quasi-phase matching (QPM) has been widely used in second-harmonic generation (SHG) and OPO systems. The periodically poled lithium niobate (PPLN) was one of the representative devices for the QPM based SHG [2], and OPO [3–6] application.

However, the undoped $LiNbO_3$ bears the problems of high coercive force (about 24 kV/mm at room temperature) [1], which limits the thickness of PPLN, and the low resistance to photorefraction effect, which limits the processable laser power density. Both of these problems greatly affect its suitability in high power laser frequency conversion systems. To overcome these disadvantages, periodically poled MgO doped $LiNbO_3$ (PPMgLN) has been presented for high power laser frequency conversion application [7–9]. It has been reported that the resistance of 5 mol% MgO doped $LiNbO_3$ to photorefraction is enhanced up to 100 times higher than that of pure $LiNbO_3$ [9,10]. In the meantime, the much lower coercive force of MgO-doped $LiNbO_3$ (about one fourth of pure $LiNbO_3$ [9,11] enables the fabrication of much thicker PPMgLN. Owing to these characteristics of MgO-doped $LiNbO_3$, PPMgLN is becoming more and more important in SHG [12–14] and OPO systems.

There have been a lot of reports about the OPO based on the PPLN (fabricated from undoped $LiNbO_3$) and PPMgLN (from 5 mol% MgO doped $LiNbO_3$) in recent years. PPMgLN (5 mol% doped) with 3 and 5 mm thickness have been fabricated in the year of 2004 and 2005 [15,16], and some of the OPO based on PPMgLN (5 mol% doped) could reach 70% conversion efficiency [17,18]. However, seldom reports about that from the

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6 mol% MgO doped $LiNbO_3$ have been published. In this report, a wide tunable, low threshold and high power OPO using the PPMgLN fabricated from the 6 mol% MgO doped $LiNbO_3$ is presented. The work on the fabrication of PPMgLN with a thickness of 1 mm is reported together with the Sellmeier equation concerned with the 6 mol% MgO doped $LiNbO_3$ crystal.

2. Fabrication of PPMgLN

For PPMgLN fabrication, the 6 mol% MgO doped congruent grown lithium niobate with a thickness of 1 mm and a diameter of 76.2 mm was used (purchased from HuaYing Corp., Zhejiang, China). Aluminum electrodes were patterned on the +Z face of the wafer with its grating directions parallel to X-direction of the crystal. The grating periods of twenty patterned channels range from 27.8 to 31.6 μm by a step of 0.2 μm.

The poling process of PPMgLN was carried out in a similar way to that of 5 mol% MgO doped lithium niobate as reported [9,11]. During the poling process, the voltage applied to the wafer was less than 1.4 kV/mm at 170 °C, which was seventeenth of the voltage required for the poling of the undoped $LiNbO_3$ at room temperature. The lasting time of the pulse voltage was controlled up to 0.8 s.

After poling, the MgO doped $LiNbO_3$ wafer was placed in a 40% concentration hydrofluoric acid at room temperature for about 1 h. The etched surface was checked by using an optical microscopy and the amplified image of the domain inverted structures on the +Z-face is shown in Fig. 1. This image reflects a homogeneously poling structure with a duty cycle close to 1:1, which is considered to be the optimal duty cycle for high efficiency laser frequency conversion [19]. The smooth edge of the inverted domain is also believed to contribute much for high conversion efficiency.

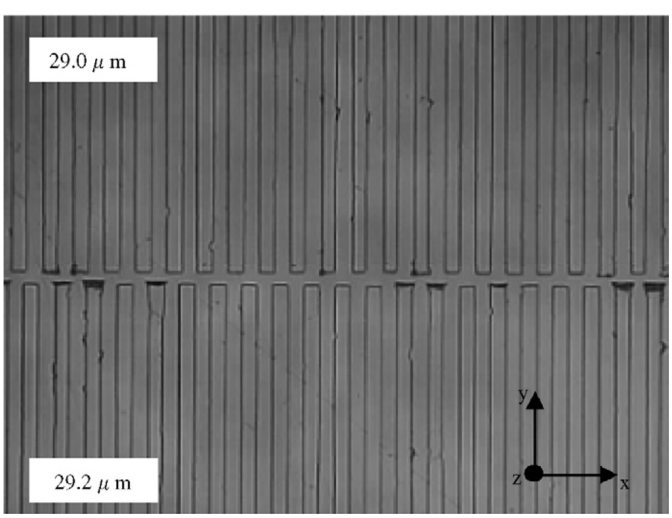

Fig. 1. The optical microscopic image of etched PPMgLN surface. It shows the $+Z$ surface of PPMgLN after it has been etched in a 40% hydrofluoric acid at room temperature for about 1 h.

3. OPO experiment

The fabricated PPMgLN wafer was cut into pieces with a size of 40 mm in length and 10 mm in width. After polishing, both end surfaces of the wafer were coated with anti-reflection film at bands of 1.064, 1.4–1.8 and 3.2–4.3 μm. For the OPO experiment, a commercial AO Q-switched Nd:YVO_4 laser was applied as the pump. Its output wavelength was 1.064 μm, pulse duration 30 ns at a repetition rate of 17 kHz. The cavity of the OPO was a double pass singly resonant oscillator (DSRO) configuration as shown in Fig. 2. A plane mirror was used as the input mirror of the cavity, which was designed to transmit high (above 90%) at 1.064 μm and to reflect high (above 98%) for both 1.4–1.7 μm (the signal) and 3.2–4.3 μm (the idler). A concave spherical mirror with a curvature radius of 200 mm was used as the output coupler, which was coated to be high reflective at 1.064 μm (about 98%), and with a reflectivity of about 70% for 1.4–1.7 μm band. The reflectivity of the output coupler for 3.2–4.3 μm was less than 10%. The substrate material used for both the input mirror and the output coupler was CaF_2 crystal. The cavity length of the OPO was about 80 mm. A spherical lens with a focal length of 500 mm was placed in front of the input mirror with a distance of 500 mm, and used for a loose pumping beam condensation. The radius of the focused beam waist was calculated to be 75 μm.

During the OPO experiment, the PPMgLN wafer was kept working at room temperature by putting it onto a heavy copper stage to keep temperature unchanged. No additional heating facility was used. The OPO began to oscillate at a low pumping power of less than 1 W and its output power increased with the pumping power. A maximum output power of 4.8 W (including the signal and the idler light, the wavelength of the signal was 1.602 μm at this point) was obtained at a pumping power of 10.8 W. By shifting the position of the PPMgLN wafer, the wavelength of the OPO output changed with the period of the inverted domain. The spectrum of the signal light as well as the cascaded conversion output of red, which is believed to be the sum of pump and signal, was recorded using an optical spectrum analyzer (OSA, Model AQ6317C from Ando, Japan).

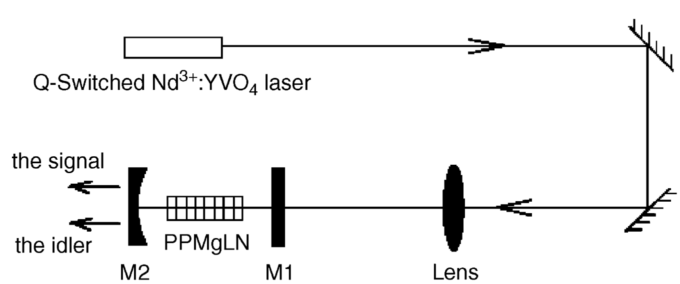

Fig. 2. The experimental setup of an OPO system. The pump laser was an AO Q-switched Nd:YVO_4 laser working at 1064 nm. M1 is the input mirror and M2 the output mirror. The substrate of both mirrors is CaF_2 crystal.