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計畫名稱: 非可見光元件與技術之研究及其在植物生長之應用(3/3)

※ 子計畫四: 壓電效應自我補償之高效率紫外發光與檢光器之研究※

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Efficient Green Laser Generation by Periodically Poled Quasi-Phase-Matched ZnO-Doped $LiNbO_3$

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Abstract — A 0.5-mm-thick periodically ZnO-doped (6 mol%) $LiNbO_3$ (PPZnLN) crystal with domain inverted periods of 6.7 μm and an interaction length of 6 mm has been successfully fabricated by an electric field poling process. Experiments on quasi-phase-matched (QPM) second harmonic generation (SHG) green laser using a PPZnLN crystal were performed and optical damage resistance was enormously arisen.

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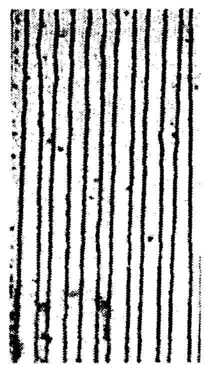
1.INTRODUCTION

Lithium niobate ($LiNbO_3$) single crystal is an excellent material for various optical applications such as frequency conversion, optical switches, optical modulators and so on. Commercially available $LiNbO_3$ crystals are grown from a melt of congruent composition by the conventional Czochralski (CZ) method, and generally have good optical quality and uniformity. A **serious** disadvantage of the congruent grown $LiNbO_3$ (CLN) crystals is the so called "optical damage",[1] i.e., the photorefractive effects, when they are irradiated with high-power laser beam at visible lengths.[2] This effect **limits** the usability of CLN crystals in nonlinear optical applications. For an example, in the SHG experiments, the PPLN crystal must be heated to ~180 °C to prevent photorefractive damage,[2] but such high temperature would not be **suitable** for system operation. On the other hand, due to the domain merge by the high coercive field (E_c~21kV) of CLN, the fabrication of short period (<10μm) PPLN becomes a difficult task. Doping **with impurities** such as MgO, ZnO etc in pure $LiNbO_3$ can arise the optical damage resistance and reduce the coercive field.[3] Using an electric field poling process with appropriate conditions, the PPZnLN crystals with domain inverted periods of 6.7 and 6.8 μm and thickness 0.5 mm were been successfully fabricated. Using a CW Nd:YAG laser pump the PPZnLN crystals, the green laser with wavelength 532 nm were been generated. In experiment with **undoped** PPLN crystals, due to photorefractive effects, the SHG power decayed with time until a stable value **was reached**. This phenomenon can be ascribed to the **improved optical damage resistance by** using the PPZnLN crystals.

2. EXPERIMENT

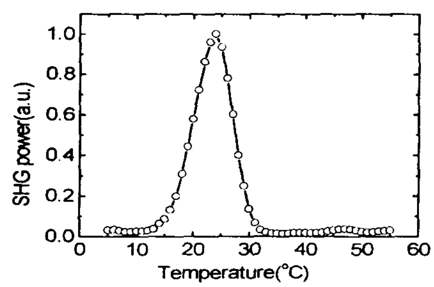
The 6 mol.% ZnO doped congruent grown $LiNbO_3$ crystals used in this study were 0.5 mm thick, z-cut, double-side polished, purchased from Casix Inc., China. The area of liquid electrodes consisted of saturated NaCl solution defined by a pair of O-rings of 6mm in diameter. We used a high voltage amplifier (Trek 20/20A) for generating the electrical poling pulses. The poling circuit included a large resistor to regulate the switching current, a small resistor to monitor the switching current, and a diode[4] to prevent the back-switching phenomenon.[5] To suppress the fringe field effect, we used a sandwich layer structure **composed of** a metal electrode, a photoresistance layer and a silicon glue layer. With appropriate conditions, the 0.5-mm-thick PPZnLN with domain inverted periods of 6.7 and 6.8 μm and the interaction length of 6 mm has been successfully fabricated. Fig.1 is the picture of the +z and –z faces of the PPZnLN etched by hydrofluoric acid.



(a)

Fig. 1 pictures of the PPZnLN structure with domain inverted period of 6.8 μm. (a)+z face (b)-z face

After the high electric field poling process, the PPZnLN crystals **were** annealed at 300°C for 3 hours. After the **annealing** process, the SHG power apparently increases. This effect is believed to **result from the recovery of nonlinear coefficient which is known degraded** during the high electric field poling process. In



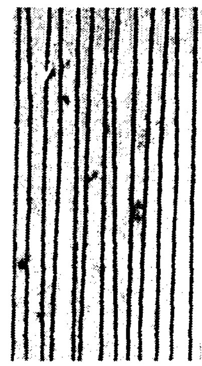
the SHG experiment, we used a CW Nd:YAG laser as the pumping source, two objective lens to focus the fundamental and second harmonic beams, a pair of hot mirror and cold mirror and a band pass filter to filter the fundamental power. The relation between SHG power and temperature is shown as Fig. 2.

(a)

(b)

Fig. 2 The relation between SHG power and temperature of the PPZnLN with domain inverted period of (a) 6.8 μm (b) 6.7μm

In Fig. 2, the optimum temperature of the PPZnLN with 6.8 μm period is 24°C, but using the Sellmeier equation **reported** by R. Nevado et. al.,[6] would grant a period of 7 μm for the PPZnLN device used at room temperature. **The discrepancy may be due to the fact that** the ZnO doped lithium niobate crystals with different growing processes may have different refractive indexes.[6]



From the FWHM of Fig. 2, and using the following equations,

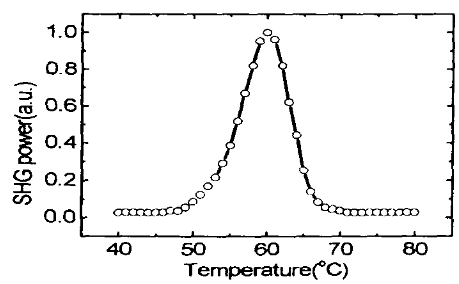
b

)

$$\delta T \cdot \frac{d(\Delta k_Q)}{dT} \cdot L = 2 \times 2 \times 1.2916 \qquad (1a)$$

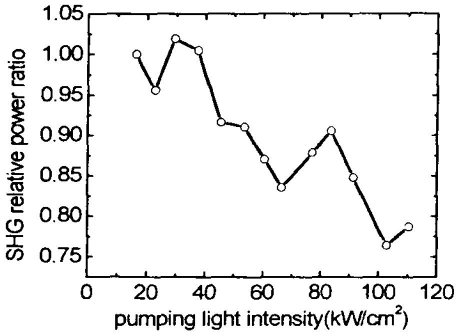
$$\frac{d(\Delta k_Q)}{dT} = \frac{4\pi}{\lambda}\frac{d}{dT}(n_{2\omega}(T) - n_{\omega}(T)) \qquad (1b)$$

we can calculate the effective interaction length of the PPZnLN is 4:nm. There is a quite difference between the O-ring size and effective interaction length that **can be**

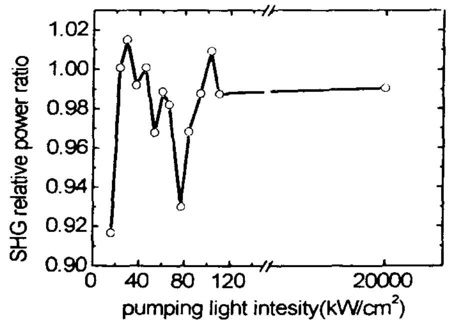


ascribed to the duty cycles of the PPZnLN crystals are not perfect 50 : 50 and are not very uniform.

To test the optical damage resistance of the ZnO doped $LiNbO_3$ crystals, we **continuously** pumped the PPZnLN crystals **with** domain inverted periods of 6.7, 6.8 μm, and at an optimum temperature of 56 and 24 °C, respectively. The SHG relative power ratio, i.e., the SHG stable power (after 10 mins) over SHG initial power, versus pumping intensity is showed in Fig. 3. At room temperature (24 °C), the photorefractive damage threshold intensity is about 40 kW/cm^2 for 6 mol% ZnO doped lithium niobate crystals. This value is two orders higher than CLN crystals.[7] Even with the pumping intensity **increased** up to 20 MW/cm^2, no photorefractive damage phenomenon can be observed at 56 °C. In the CLN case, however, the PPLN must be heated to ~180 °C to prevent the optical damage.



(a)



(b)

Fig. 3 SHG relative power ratio versus pumping light intensity (a) 6.8 μm period PPZnLN operated at 24 °C (b) 6.7 μm period PPZnLN operated at 56 °C.

3. SUMMARY

In summary, using a sandwich dielectric layers, PPZnLN with period of 6.7 μm suitable for 532 nm green laser output has been successfully demonstrated. And the optical damage resistance has been **drastically increased** by using the PPZnLN, even pumping intensity up to 20 MW/cm^2, no photorefractive damage phenomenon occurred at 56 °C (ZnO doping concentration is 6 mol%). This research is sponsored by the NSC Grant No. 90-2215-E-002-017.

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