Temperature-tuned optical parametric generation in MgO doped and undoped congruent $LiNbO_3$

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1. Abstract

We measured the experimental data for the temperature-tuned wavelengths for QPM/OPO between 30 and 190℃ in the undoped PPLN and MgO:PPLN sample used in our previous experiments [1, 2]. These results indicate that our thermo-optic dispersion formula of MgO:PPLN [1] can be useful for predicting the temperature-dependent QPM properties of undoped PPLN combined with the accurate Sellmeier equations for undoped $LiNbO_3$.

2. Introduction

Periodically poled 5mol.% MgO doped $LiNbO_3$ (MgO:PPLN) has been widely used for frequency conversion based on 1-μm-laser. In 2014, Umemura *et al.* reported the accurate Sellmeier and thermo-optic dispersion formulas for the extraordinary ray of MgO: $LiNbO_3$ [1], which can reproduce well the quasi phase-matching conditions of MgO:PPLN in the 0.39-4.95 μm spectral range. In addition, Umemura and Matsuda presented the Sellmeier and thermo-optic dispersion formulas for the ordinary ray and found that temperature insensitive second-harmonic generation (SHG) wavelength exists around (λ_1 = 0.915 μm) in the quasi-phase-matching (QPM) process with the oe-o interaction [2].

In order to clarify the temperature-dependent QPM properties at a crystal temperature higher than 120℃, we attempted to measure the temperature-tuned wavelengths by using the MgO:PPLN sample (Λ = 29.0 μm) used in our previous experiments [1, 2] and undoped PPLN (Λ = 30.0 μm) between 30 and 190℃.

3. Experiments and Discussions

3. 1 MgO:PPLN

We measured the temperature-tuned signal and idler wavelengths for QPM optical parametric oscillation (OPO) (ee-e, m = 1) pumped by a Nd:YAG laser at 1.0642 μm. The pump source was EO Q-swithed Nd:YAG laser operating at 10 Hz. Fig. 1 shows our experimental points together with the theoretical curves calculated with the following Sellmeier and thermo-optic dispersion formulas for MgO:$LiNbO_3$.

$$\begin{cases} n_e^2(5\%) = 4.54514 + \dfrac{0.096471}{\lambda^2 - 0.043763} - 0.021502\lambda^2 \\ (0.39\mu m \le \lambda \le 2.7\mu m) \\ n_e^2(5\%) = 24.6746 + \dfrac{0.0456}{\lambda^2 - 2.280} + \dfrac{19166.65}{\lambda^2 - 953.52} + \dfrac{1.0103}{\lambda^2 - 45.86} \\ (2.7\mu m \le \lambda \le 4.95\mu m) \end{cases} \tag{1}$$

$$\begin{cases} \dfrac{\partial n_e}{\partial T} = \left(\dfrac{0.4175}{\lambda^3} - \dfrac{0.6643}{\lambda^2} + \dfrac{0.9036}{\lambda} + 3.5332 - 0.0744\lambda\right) \times 10^{-5} \times (1 + 0.00276T) \\ \qquad (0.40\mu m \le \lambda \le 4.0\mu m) \end{cases} \tag{2}$$

where λ is in micrometers. The thermal expansion along x-axis given by Y. S. Kim and R. T. Smith was employed for calculating a grating period at each temperature in this paper.

The theoretical curves calculated with the temperature-dependent Sellmeier equations of Paul *et al*. [3] and Gayer *et al*. [4] are also inserted into Fig. 1 for comparison. As can be seen from these figures, our theoretical values for the temperature-tuned QPM/OPO wavelengths agree with our experimental points between 30 and 190℃.

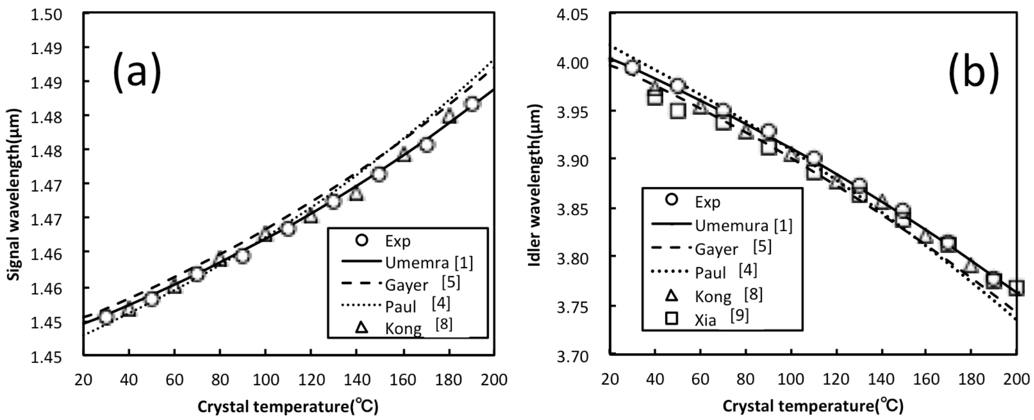

Fig 1. Temperature-tuned signal (a) and idler (b) wavelengths for QPM/OPO (ee-e, m = 1) pumped by a Nd:YAG at 1.0642 μm in MgO:PPLN with a grating period of 29.0 μm.

We measured the temperature-dependent QPM / SHG wavelengths by using the idler output of BiB_3O_6 / OPO pumped at 0.5321μm in MgO:PPLN (Λ = 30.8 μm). The experimental points are shown in Fig 2 together with theoretical curves calculated with our Sellmeier and thermo-optic dispersion formula [1] (solid lines), and the temperature-dependent Sellmeier equations given by Paul *et al*. [3] (dotted lines) and Gayer *et al*. [4] (dashed lines) respectively. As can be seen from these figures, our theoretical values for the temperature-tuned QPM/SHG wavelengths agree with our experimental points between 30 and 190℃.

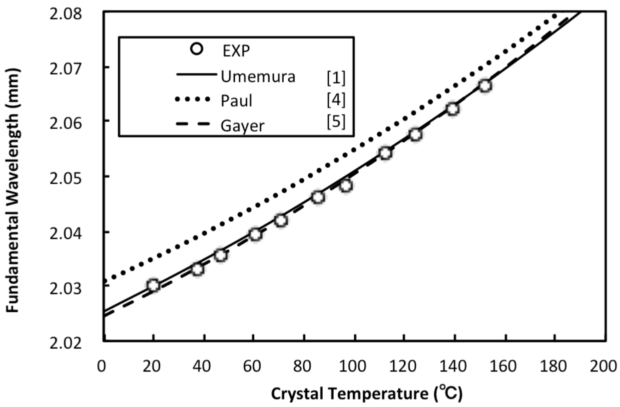

Fig 2. Temperature-dependent wavelengths for QPM / SHG in MgO:PPLN (Λ = 30.8 μm).

3. 2 Undoped PPLN

In order to verify the validity of our thermo-optic dispersion formula Eq. (2) for undoped congruent $LiNbO_3$, we measured the temperature-tuned signal and idler wavelengths of QPM/OPO by pumping with a Nd:YAG laser between 30 and 190℃. The undoped PPLN sample (Λ = 30.0μm) used in this experiment was supplied from Gooch & Housego Inc. The experimental results ~~are~~ is shown in Fig. 3 together with the theoretical curves (solid lines) calculated with the following Sellmeier equation and Eq. (2) in this text.

$$n_e^2 = 25.8762 + \frac{0.09986}{\lambda^2 - 0.04303} + \frac{22274.87}{\lambda^2 - 1049.83} + \frac{4.914}{\lambda^2 - 62.03} \qquad (3)$$
$$(0.4615\mu m \le \lambda \le 5.0\mu m)$$

where λ is in micrometers. This index formula Eq. (3) was obtained by adjusting the temperature-dependent Sellmeier equation given by Jundt [7] to give the best fit to our experimental values for QPM/SHG wavelengths in the visible. As can be seen from these figures, our theoretical values for the temperature-tuned QPM/OPO wavelengths agree with our experimental points between 30 and 190℃. Deng *et al*. [6] also reported the temperature-dependent Sellmeier equation of undoped $LiNbO_3$ from Jundt's index formula [7], as we did. The resulting tuning curves (dotted lines) given by Deng *et al.* are also inserted into Fig. 3 and are different from our data points at crystal temperature higher than 100℃.

In addition, the experimental points given by Gross et al. [10] are also plotted in Fig. 3 (b) and their data points are located between the theoretical curve calculated with Deng *et al*.'s index formula [6] and ours.

The 2-μm of OPM/SHG is one of the data which is important to unravel the QPM properties. Finally, we measured the temperature-tuned fundamental wavelengths for QPM/SHG of the idler output of BiB_3O_6 OPO pumped at 0.5321 μm in undoped PPLN (Λ=30.0μm). The experimental points are shown in Fig 4 together with the theoretical

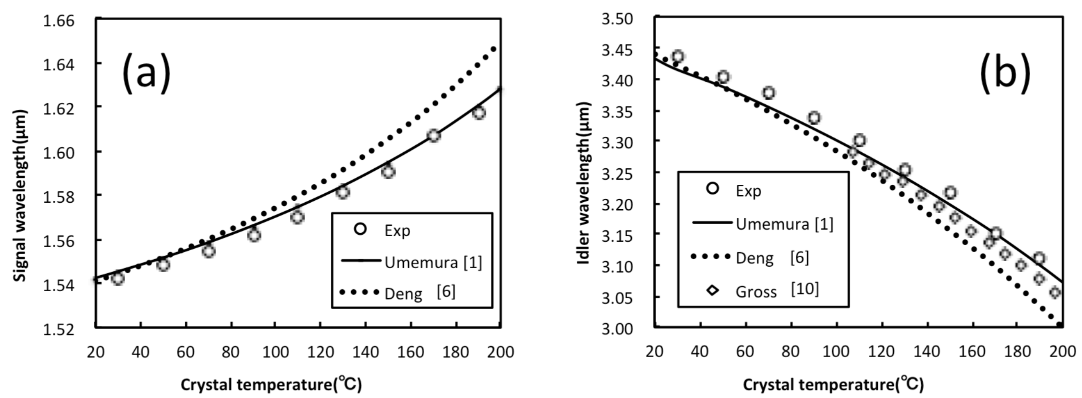

Fig 3. Temperature-tuned signal (a) and idler (b) wavelengths for QPM/OPO (ee-e, m=1) pumped by a Nd:YAG at 1.0642 μm in undoped PPLN with a grating period of 30.0 μm.

curves (solid lines) calculated with our Sellmeier and thermo-optic dispersion formula (Eqs.(2) and (3)), and the temperature-dependent Sellmeier equation given by Jundt [7] (dashed lines) and Deng *et al.* [6] (dotted lines) respectively. As can be seen from these figures, our theoretical values for the temperature-tuned QPM/SHG wavelengths fairly agree with our experimental points between 30 and 190℃.

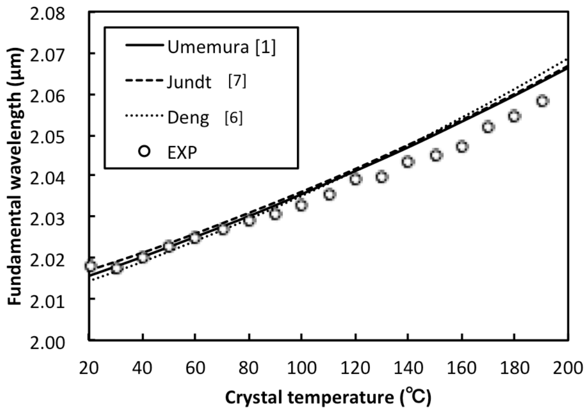

Fig 4. Temperature-tuned fundamental wavelength for QPM/SHG(ee-e, m= 1) pumped by a Nd:YAG at 1.0642 μm in undoped PPLN with a grating period of 30.0 μm.

4. Conclusions

We found that our thermo-optic dispersion formula of MgO:PPLN [1] can be useful for predicting the temperature-dependent QPM properties of undoped PPLN combined with the accurate Sellmeier equations for undoped $LiNbO_3$.

5. References

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