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Sellmeier and thermo-optic dispersion formulas for β-BaB_2O_4 (revisited)

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ABSTRACT

This paper reports the high-accuracy Sellmeier and thermo-optic dispersion formulas for β-BaB_2O_4 (β-BBO) that provide the excellent reproduction of our data for second-harmonic generation (SHG) and sum-frequency generation (SFG) down to 0.2048 and 0.1925μm as well as the optical parametric oscillator (OPO) tuning points up to 3.2μm, and the temperature-dependent phase-matching angles for SHG and SFG that we have measured in the 0.193-0.6420μm range as well as the recent data for SFG at 0.1934μm.

Keywords: Nonlinear optical material, Frequency conversion, Second-harmonic generation, Sum-frequency generation, Optical parametric oscillator, Sellmeier equations, Thermo-optic dispersion formula, β-BaB_2O_4

1. INTRODUCTION

Although there are many publication on the subject of harmonic generation and parametric oscillation in β-BBO, as far as we know only one paper has been published on the thermo-optic constants for this material [1]. To present correctly the temperature dependent phase-matching conditions, we decided to investigate this important parameter for the nonlinear optics. In this paper, we report on the high-accuracy thermo-optic dispersion formula together with the improved Sellmeier equations in the IR absorption edge that provide reproduction of the nonlinear experiments thus far reported in the literature as well as our new experimental results.

2. SELLMEIER EQUATIONS

Prior to phase-matching experiments, we have recorded the IR transmission curves of β-BaB_2O_4 sample cut at θ=90° and ϕ=0°, where θ and ϕ are polar coordinates referring to z and x, respectively. As shown in Fig.1, the transmission near the absorption cutoff wavelength exhibits the polarization dependence.

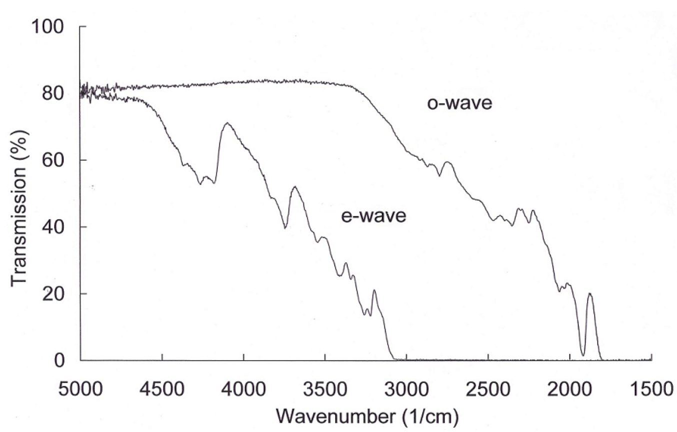

Fig.1 IR transmission curves of β-BaB_2O_4.

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Since our Sellmeier equations reported in the Ref.2 do not fit the OPO tuning points given by Zhang et al.[3] at wavelengths longer than 2.9μm. We have adjusted the Sellmeier constants from the phase-matching angles for type-1 and type-2 SFG between the outputs of BiB_3O_6 (BiBO) OPO and its pump source at 1.0642μm.

The resulting Sellmeier equations are expressed as

$$n_o^2 = 3.63357 + \frac{0.01878}{\lambda^2 - 0.01822} + \frac{60.9129}{\lambda^2 - 67.8505}$$

$$n_e^2 = 3.33469 + \frac{0.01237}{\lambda^2 - 0.01647} + \frac{79.0672}{\lambda^2 - 82.2919} \qquad (1)$$

$(0.2048\mu m \leqq \lambda \leqq 3.22\mu m)$

where λ is in μm.

As shown in Fig.2, this index formula reproduces well the OPO tuning points given by Zhang et al.[3] except near the retracing point at θ=20.90° which is only ~0.2° smaller than our calculated value of 21.07°.

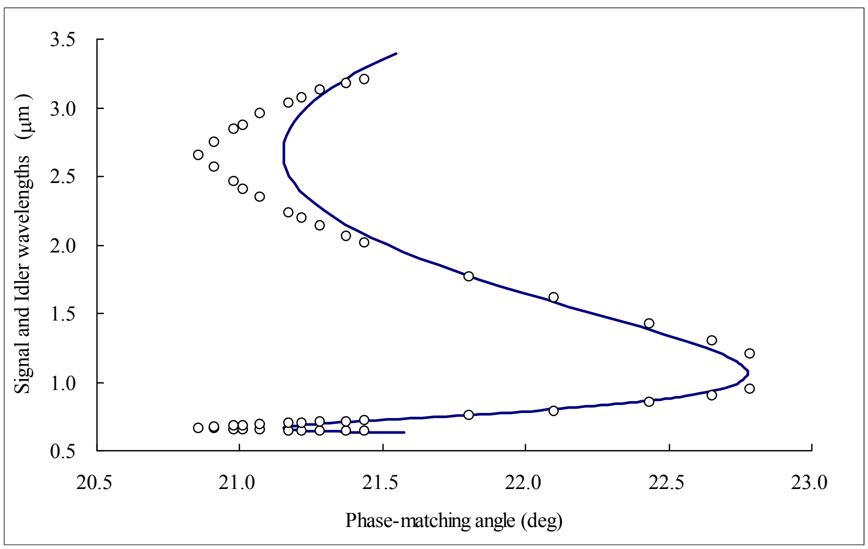

Fig.2 Phase-matching curve for type-1 OPO pumped at 0.5321μm. The circles are the experimental points reported by Ref.3.

While this index formula is not accurate below 0.2048μm, we next have modified the Sellmeier constants for the extraordinary ray below 0.2048μm to give the best fit to the phase-matching conditions for type-1 SFG between the fourth-harmonic of a Nd:YAG laser and the BiBO OPO pumped by the SHG of the same pump source that shown in Fig.3.

$$n_e^2 = 3.38630 + \frac{0.00921}{\lambda^2 - 0.02073} + \frac{79.0672}{\lambda^2 - 82.2919} \qquad (2)$$

$(0.1916\mu m \leqq \lambda \leqq 0.2048\mu m)$

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where λ is in μm.

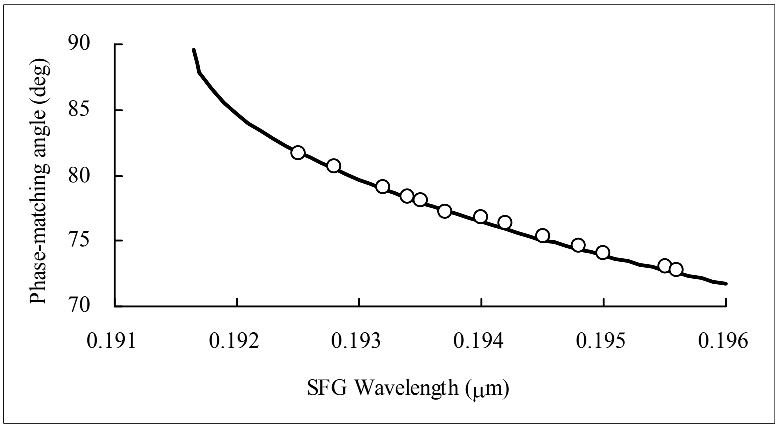

Fig.3 Phase-matching curve for type-1 SFG between the fourth harmonic of a Nd:YAG laser at 1.0642μm and the output of the BiBO OPO pumped at 0.5321μm. The circles are our experimental points.

In order to verify the validity of our index formula for SFG below 0.2μm, we calculated the phase-matching angles for the type-1 third-harmonic generation ($\omega+2\omega \Rightarrow 3\omega$) of a dye laser. Fig.4 shows the phase-matching curve calculated with Eqs.1-2 and the experimental points given by Glab and Hessler [4] and Heitmann et al.[5].

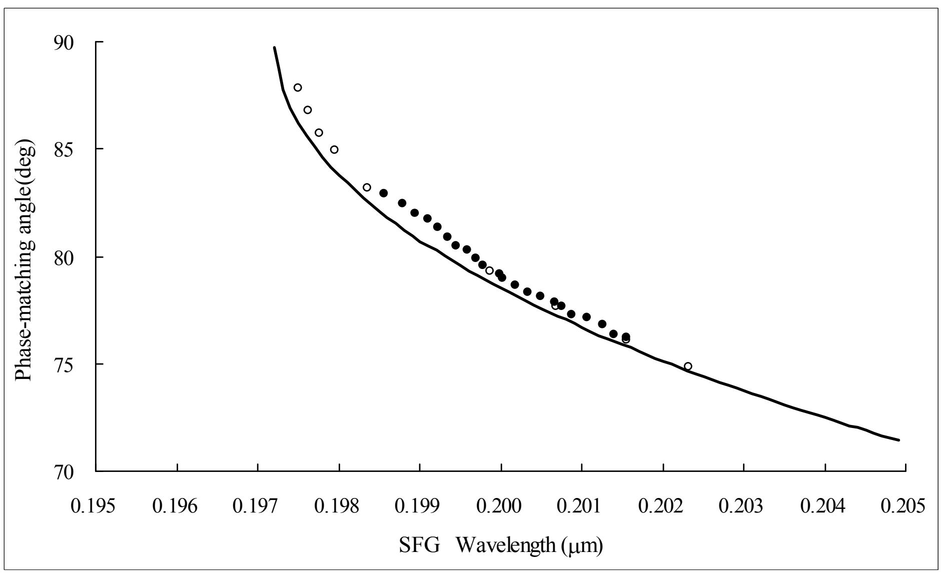

Fig.4 Phase-matching curve for type-1 THG of a dye laser. The open and closed circles are given by Ref.4 and Ref.5, respectively.

3. THERMO-OPTIC DISPERSION FORMULA

We next have constructed the thermo-optic dispersion formula of this material by using the raw data given by Eimerl et al.[1] at 1.014, 0.5790, and 0.4047μm and adjusted them to give the best fit to the temperature phase-matching

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bandwidths (FWHM) tabulated in Table 1, in which we have also inserted the experimental values presented by Eimerl et al.[1] for comparison.

These procedures gave

$$\frac{dn_o}{dT} = \left(-\frac{0.0137}{\lambda^3} + \frac{0.0607}{\lambda^2} - \frac{0.1334}{\lambda} - 1.5287 \right) \times 10^{-5} (^\circ C^{-1})$$

$$\frac{dn_e}{dT} = \left(\frac{0.0413}{\lambda^3} - \frac{0.2119}{\lambda^2} + \frac{0.4408}{\lambda} - 1.2749 \right) \times 10^{-5} (^\circ C^{-1}) \tag{3}$$

$$(0.195\mu m \leqq \lambda \leqq 1.618\mu m)$$

where λ is in μm.

Besides the experimental data listed in Table.1, Merriam et al.'s data of $\Delta T \cdot \ell = 0.66°C \cdot cm$ [6] for generating the 0.1934μm radiation at T_{pm}=225K agrees well with our measured and calculated values of $\Delta T \cdot \ell = 0.62°C \cdot cm$ at 20-120°C, despite the fact that the value for $\Delta\theta_{ext} \cdot \ell$=0. 62±0.07mrad·cm that is 1.4 times larger than our calculated value of $\Delta\theta_{ext} \cdot \ell$=0. 43mrad·cm.

In addition, we note that the earlier data of Lokai et al.[7] for the 90° phase-matched SFG at 0.1953μm achieved at T_{pm}=-178±10°C agrees fairly well with our calculated value of T_{pm}=-200°C (ΔT=-180°C). However, large discrepancies between the theory and experimental points were encountered for the SFG reported by Kouta and Kuwano [8] below 0.197μm. As shown in Fig.5, their data points are 1.5~2.4° smaller than our calculated and measured values in the 0.193~0.197μm range. The reason for this discrepancy is probably due to the crystal to crystal variation of the refractive indices near the absorption edge, although we cannot rule out the possible misorientation of their crystal.

Table 1 Temperature phase-matching bandwidths (FWHM) for SHG and SFG in β-BaB_2O_4

	Wavelength (μm)[a]			Phase-matching	$\Delta T \cdot \ell$ (°C·cm)		
	λ_1	λ_2	λ_3	angle (deg)	measured	calculated	Refs.
SHG	1.0642	1.0642	0.5321	θ_{ooe}= 22.8	58.4	58.4	
					51.8		1
	1.0642	1.0642	0.5321	θ_{eoe}= 32.7	45.2	45.5	
					38.3		1
	0.5321	0.5321	0.2660	θ_{ooe}= 47.6	3.8	3.6	
					3.8		1
SFG	1.6180	1.0642	0.6420	θ_{ooe}= 20.5	106.5	102.0	
	1.6180	1.0642	0.6420	θ_{eoe}= 26.5	73.5	73.6	
	1.5380	1.0642	0.6290	θ_{ooe}= 20.6	96.5	97.5	
	1.5380	1.0642	0.6290	θ_{eoe}= 27.2	73.7	71.6	
	1.0642	0.5321	0.3547	θ_{ooe}= 31.3	15.0	15.1	
					15.1		1
	1.0642	0.5321	0.3547	θ_{eoe}= 38.5	13.1	12.9	
					13.3		1
	1.0642	0.5321	0.3547	θ_{oee}= 59.7	11.2	11.9	
					9.9		1
	1.0642	0.3547	0.2660	θ_{ooe}= 40.3	4.9	4.8	
	1.0642	0.3547	0.2660	θ_{eoe}= 46.6	4.0	4.0	
	1.0642	0.2660	0.2128	θ_{ooe}= 51.1	1.5	1.4	

a) $1/\lambda_1 + 1/\lambda_2 = 1/\lambda_3$.

b) The superscripts of the wavelengths represent the polarization directions.

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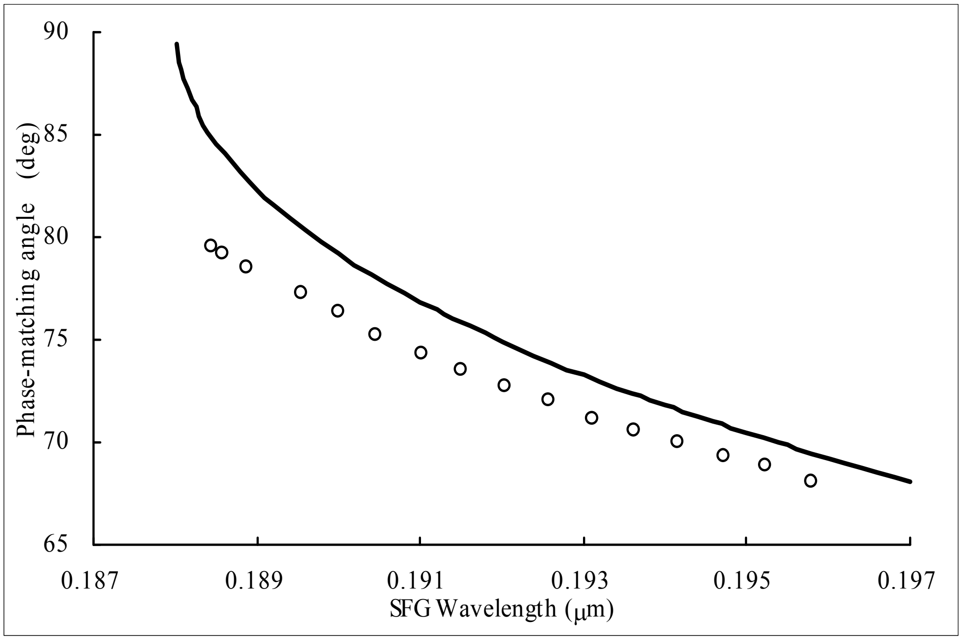

Fig.5 Phase-matching curve for type-1 fourth-harmonic generation (ω+3ω => 4ω) of a Ti:Sapphire laser. The open circles are given by Ref.8.

4. CONCLUSIONS

In summary, we have reported the improved Sellmeier equations and thermo-optic dispersion formulas for β-BaB_2O_4 that reproduce the temperature dependent phase-matching conditions in the 0.195-1.618μm range. We believe that these two formulas are useful for designing a stable temperature, high average power frequency conversion system based on β-BaB_2O_4.

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