SinoCeramics

Barium Borate (BBO)

Beta - Barium Borate (b-BaB_2O_4 or BBO) is an efficient NLO crystal for the second, third and fourth harmonic generation of Nd:YAG lasers, and the best NLO crystal for the fifth harmonic generation at 213nm. Conversion efficiencies of more than 70% for SHG, 60% for THG and 50% for 4HG have been obtained.

Basic Properties

Crystal Structure:	Trigonal, space group R_{3c}
Cell Parameters:	a = b = 12.532A , c = 12.717A , z = 6
Melting Point:	1095 ± 5°C
Transition Temperature:	925 ± 5°C
Optical Hardness:	Δn about 10^{-6}/cm
Mohs Hardness:	4
Density:	3.85g/cm^3
Absorption coefficient:	< 0.1% per cm @ 1064nm
Specific Heat:	1.91J/cm^3 K
Hyroscopic Susceptibility:	Low
Thermal Expansion Coefficients:	a, $4x10^{-6}$/K . c, $36x10^{-6}$/K
Thermal Conductivity:	c, 1.2W/m/K . ||c, 1.6W/m/K

Linear Optical Properties

Transparency Range:	189-3500nm		
Refractive Indicies:	@ 1064nm	n_e = 1.5425	n_o = 1.6551
	@ 532nm	n_e = 1.5555	n_o = 1.6479
	@ 266nm	n_e = 1.6146	n_o = 1.7571
Therm-Optic Coefficients:	$dn_e/dT = -16.6x10^{-6}$/C		$dn_o/dT = -9.3x10^{-6}$/C

Sellmeir Equations:

$n_o^2 = 2.7359 + 0.01878 / (\lambda^2 - 0.01822) - 0.01354\lambda^2$

$n_e^2 = 2.3753 + 0.01224 / (\lambda^2 - 0.01667) - 0.01516\lambda^2$

wavelength is in μm, T = 20°C

The Features for BBO:

- Broad phase-matchable range from 409.6-3500nm
- Wide transmission region from 190-3500nm
- Large effective coefficient for SHG is approx. 6 times greater than that of KDP crystal
- High damage threshold of 10 GW/cm^2 for 100ps pulse-width @ 1064nm
- High optical homogeneity with $\Delta n = 10^{-6}$/cm
- Wide temperature-bandwidth of approx. 55°C

Applications in Nd:YAG Laser:

- Second, third, fourth and fifth harmonic generation of Nd:YAG and Nd:YLF lasers
- Frequency-doubling, -tripling, and -mixing of Dye lasers
- Second, third, and fourth harmonic generation of Ti:Sapphire and Alexandrite lasers
- Optical parametric amplifier (OPA) and optical parametric oscillators (OPO)
- Frequency-doubling of Argon ion, Cu-vapor and Ruby lasers
- Research and development for advanced laser techniques, including all-solid state wide-tunable lasers, ultra fast pulse lasers, and DUV lasers.

BBO is an efficient NLO crystal for the second, third and fourth harmonic generation of Nd:YAG lasers, and the best NLO crystal for the fifth harmonic generation @ 213nm. Conversion efficiencies of more than 70% for SHG, 60% for THG and 50% for 4HG, and 200mW output @ 213nm (SHG) have been obtained.

BBO is also an efficient crystal for intra-cavity SHG of high power Nd:YAG lasers. For the intracavity SHG of an acoust-optic Q-switched Nd:YAG laser, more than 15W average power @ 532nm was generated in an AR-coated BBO crystal. When pumped by the 600 mW SHG output of a mode-locked Nd:YLF laser, 66mW output @ 266nm was produced from a Brewster-angle-cut BBO in an external enhanced resonant cavity.

Harmonic Generations Using BBO and KD*P

Crystal	1 (mJ)	SHG (mJ)	THG (mJ)	4HG (mJ)	5HG (mJ)
BBO	220	105	39	18.5	5
	600	350	140	70	20
KD*P	600	270	112.5	45	-

Relevant NLO Properties for Type I BBO Crystal

	SHG	THG	4HG	5HG
Effective NLO Coefficient [d_{36}(KDP)]	5.3	4.9	3.8	3.4
Acceptance Angle (mrad-cm)	1.0	0.5	0.3	0.2
Walk-off Angle (degree)	3.2	4.1	4.9	5.5

Because of a small acceptance angle and large walk-off, good laser beam quality (small divergence, good mode condition, etc.) is the key for BBO to obtain high conversion efficiency. Tight focus of laser beam is not recommended in BBO applications.

Applications in Tunable Lasers

1. **Dye Lasers**
   Efficient UV output (205-310nm) with a SHG efficiency of over 10% @ 206nm was obtained in type I BBO, and 36% conversion efficiency was achieved for a XeCI-laser pumped Dye laser with power 150KW which is about 4-6 times higher than that in ADP. The shortest SHG wavelength of 204.97nm with efficiency of about 1% has been generated. Also BBO is widely used in the Dye lasers. With type I sum-frequency of 780-950nm and 248.5nm (SHG output of 495nm dye laser) in BBO, the shortest UV outputs ranging from 188.9-197nm and the pulse energy of 95mJ @ 193nm and 8mJ @ 189nm have been obtained.
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2. **Ultra Fast Pulse Laser**
   Frequency-doubling and -tripling of ultra short-pulse lasers are the applications in which BBO shows superior properties to KDP and ADP crystals. Shenzhen Laser can provide as thin as 0.05mm BBO for this purpose. A laser pulse as short as 10fs can be efficiently frequency-doubled with a thin BBO, in terms of both phase-velocity and group-velocity matching.
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3. **Ti:Sapphire and Alexandrite Lasers**
   UV output in the region 360-390nm with pulse energy of 105mJ (31% SHG efficiency) @ 378nm, and output in the region 244-259nm with 7.5mJ (24% mixing efficiency) have been obtained for type I SHG and THG of an Alexandrite laser in BBO crystal. More than 50% of SHG conversion efficiency in a Ti:Sapphire laser has been obtained. High conversion efficiencies have also been obtained for the THG and FHG of Ti:Sapphire lasers.
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4. **Argon Ion and Copper-Vapor Lasers**
   By employing the intracavity frequency-doubling technique in an argon ion laser with all lines output power of 2W, maximum 33mW @ 250.4nm and thirty-six lines of deep UV wavelengths ranging from 228.9-257.2nm were generated in a Brewster-angle-cut BBO crystal. Up to 230mW average power in the UV at 255.3nm with maximum 8.9% conversion efficiency was achieved for the SHG of a Copper-Vapor laser at 510.6nm.

BBO's OPO and OPA

The OPO and OPA of BBO are powerful tools for generating a widely tunable coherent radiation from the UV to IR. The tuning angles of type I and type II BBO, OPO, and OPA have been calculated.

OPO pumped at 532nm

An OPO output ranging from 680-2400nm with the peak power of 1.6MW and up to 30% energy conversion efficiency was obtained in a 7.2mm long type I BBO. The input pump energy was 40mJ @ 532nm with a pulse-width of 75ps. With a longer crystal, higher conversion efficiency is expected.

OPO and OPA at 355nm

In the case of Nd:YAG pumping, BBO's OPOs can generate more than 100mJ, with a wavelength tunable from 400-2000nm. Using BBO crystal, the OPO system covers a tuning range from 400-3100nm which guarantees a maximum of 30% and more than 18% conversion efficiency

Type II BBO can be used to decrease line width near the degenerate points. A line width as narrow as 0.05nm with conversion efficiency of 12% was obtained. However, a longer (> 15mm) BBO should normally be used to decrease the oscillation threshold when employing the tepy II phase-matching scheme. Pumping with a picosecond Nd:YAG @ 355nm, a narrow-band (< 0.3nm), high energy (> 200mJ), and wide tunable (400-2000nm) pulse has been produced by BBO's OPAs. This OPA can reach as high as more than 50% conversion efficiency, and therefore is superior to common Dye lasers in many respects, including efficiency, tunable range, maintenance, and easiness in design and operation. Furthermore, coherent radiation from 205-3500nm can be also generated by BBO's OPO or OPA plus a BBO for SHG.

Others

A tunable OPO with signal wavelengths between 422-477nm has been generated by angle tuning in a type I BBO crystal pumped with a XeCl excimer laser @ 308nm. And a BBO's OPO pumped by the forth harmonic of a Nd:YAG laser (266nm) has been observed to cover the whole range of output wavelengths 330-1370nm. When pumped by a 1mJ, 80fs Dye laser at 615nm, the OPA with two BBO crystals yields more than 50mJ (maximum 130mJ), < 200fs ultra short pulse, over 800-2000nm.

Specifications

Dimension Tolerance: (W ± 0.1mm) x (H ± 0.1mm) x (L ± 0.2mm)
Wavefront Distortion: < 1/8 @ 633nm
Flatness: 1/8 @ 633nm
Surface Quality: 10/5 to MIL-O-13830A
Parallelism: < 20 arc seconds
Perpendicularity: 5 arc minutes
Angle Tolerance: $D_q < \pm 0.5°$, $D_f < \pm 0.5°$
Quality Warranty Period: one year under proper use
Coating: AR/AR on both sides for single wavelength or dual wavelength, R < 0.2%
Protective coating (p-coating) for high damage and wide wavelength range
Size: As large as 20x20mm and as thin as 0.02mm
Mounting: it will be mounted when thickness is less than 2mm (Free!)

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Note

- BBO has a low susceptibility to the moisture. The user is advised to provide dry conditions for both the use a preservation of BBO
- BBO is relatively soft and therefore requires precautions to protect its polished surfaces
- When angle adjusting is necessary, keep in mind that the acceptance angle of BBO is small
- Our engineers can select and design the best crystal, if the main parameters of your laser are provided, such as energy per pulse, pulse width and repetition rate for a pulsed laser, power for a CW laser, laser beam diameter, mode condition, divergence, wavelength tuning range, etc.