Beta-Barium Borate (β-BaB2O4 or BBO)

Introductions

◇ Broad phase-matchable range from 409.6 nm to 3500 nm;

◇ Wide transmission region from 190 nm to 3500 nm;

◇ Large effective second-harmonic-generation (SHG) coefficient about 6 times greater than that of KDP crystal;

◇ High damage threshold;

◇ High optical homogeneity with $\delta n \approx 10^{-6}$/cm;

◇ Wide temperature-bandwidth of about 55°C.

Basic Properties

Items	Specifications
Crystal Structure	Trigonal, Space group R3c
Lattice Parameter	a=b=12.532Å, c=12.717⊕, Z=6
Melting Point	About 1095°C
Mohs Hardness	4
Density	3.85 g/cm3
Thermal Conductivity	1.2W/m/K(⊥c); 1.6W/m/K(//c)
Thermal Expansion Coefficient	α,4x10-6/K; c,36x10-6/K
Transparency Range	190-3500nm
SHG Phase Matchable Range	409.6 ~ 3500nm (Type I) 525-3500nm (Type II)
Therm-optic Coefficient (° C, λ in μ m)	dno/dT=-9.3X10-6 dne/dT=-16.6X10-6
Absorption Coefficient	<0.1%/cm at 1064nm <1%/cm at 532nm
Angle Acceptance	0.8mrad-cm (θ, Type I,1064 SHG) 1.27mrad-cm (θ, Type II,1064 SHG)
Temperature Acceptance	55°C-cm
Spectral Acceptance	1.1nm-cm
Walk-off Angle	2.7° (Type I 1064 SHG) 3.2° (Type II 1064 SHG)
NLO Coefficien	deff(I)=d31sinθ+(d11cos3ϕ- d22 sin3ϕ) cosθ deff (II)= (d11 sin3ϕ + d22 cos3ϕ) cos2θ
Non-vanished NLO susceptibilities	d11 = 5.8 x d36(KDP) d31 = 0.05 x d11 d22 < 0.05 x d11

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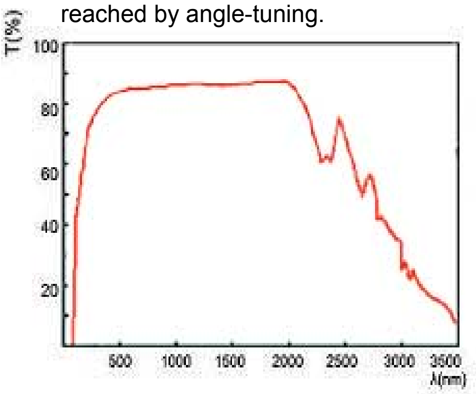
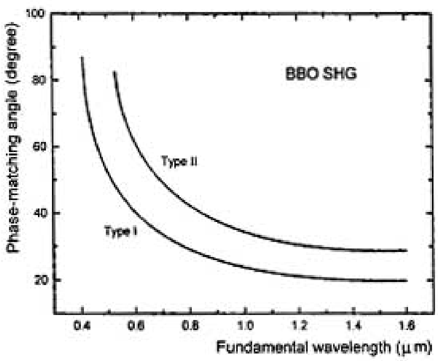
Sellmeier Equations (λ in μm)	no2=2.7359+0.01878/(λ2-0.01822)-0.01354λ2 ne2=2.3753+0.01224/(λ2-0.01667)-0.01516λ2
Electro-optic coefficients	γ11 = 2.7 pm/V, γ22, γ31 < 0.1γ11
Half-wave voltage	7 KV (at 1064 nm,3*3*20mm^3)
Resistivity	>1011 ohm-cm
Relative Dielectric Constant	εs11 / εo : 6.7 εs33 / εo : 8.1 Tanδ<0.001

BBO is a negative uniaxial crystal, with ordinary refractive-index (no) larger than extraordinary refractive-index (ne). Both type I and type II phase-matching can be reached by angle-tuning.



Transparency curve of BBO



SHG tuning curves of BBO

Application in Nd:YAG 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 at 213nm. Conversion efficiencies of more than 70% for SHG, 60% for THG and 50% for 4HG, and 200 mW output at 213 nm (5HG) have been obtained, respectively.

BBO is also an efficient crystal for the intracavity SHG of high power Nd:YAG lasers. For the intracavity SHG of an acousto-optic Q-switched Nd:YAG laser, more than 15 W average power at 532 nm was generated in a AR-coated BBO crystal. When it is pumped by the 600 mW SHG output of a mode-locked Nd:YLF laser, 66 mW output at 263 nm was produced from a Brewster-angle-cut BBO in an external enhanced resonant cavity.

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.

Laser Crystals
NLO Crystals
Birefringent Crystals
AO and EO Crystals

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Applications in Tunable Lasers

1. Dye lasers

Efficient UV output (205nm - 310 nm) with a SHG efficiency of over 10% at wavelength of ≥206 nm was obtained in type I BBO, and 36% conversion efficiency was achieved for a XeCl-laser pumped Dye laser with power 150KW which is about 4 - 6 times higher than that in ADP. The shortest SHG wavelength of 204.97 nm with efficiency of about 1% has been generated.

Our BBO is widely used in the Dye lasers. With type I sum-frequency of 780 - 950 nm and 248.5 nm (SHG output of 495 nm dye laser) in BBO, the shortest UV outputs ranging from 188.9nm to 197 nm and the pulse energy of 95 mJ at 193 nm and 8 mJ at 189 nm have been obtained, respectively.

2. Ultrafast Pulse Laser

Frequency-doubling and -tripling of ultrashort-pulse lasers are the applications in which BBO shows superior properties to KDP and ADP crystals. Now, we can provide as thin as 0.02mm BBO for this purpose. A laser pulse as short as 10 fs can be efficiently frequency-doubled with a thin BBO, in terms of both phase-velocity and group-velocity matching.

3. Ti:Sapphire and Alexandrite lasers

UV output in the region 360nm - 390 nm with pulse energy of 105 mJ (31% SHG efficiency) at 378 nm, and output in the region 244nm - 259 nm with 7.5 mJ (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 been also obtained for the THG and FHG of Ti:Sapphire lasers.

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 33 mW at 250.4 nm and thirty-six lines of deep UV wavelengths ranging from 228.9 nm to 257.2 nm were generated in a Brewster-angle-cut BBO crystal.

Up to 230 mW average power in the UV at 255.3 nm with maximum 8.9% conversion efficiency was achieved for the SHG of a Copper-Vapor laser at 510.6 nm.

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 with the results shown in the following figures.

1. OPO pumped at 532 nm

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

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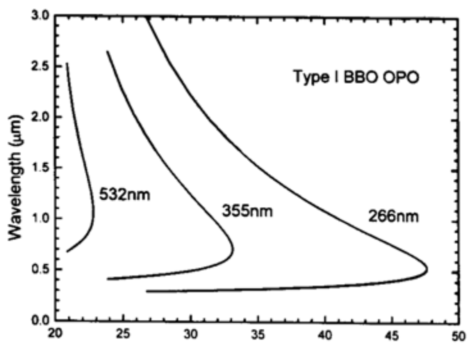
BBO's OPO and OPA

2. OPO and OPA pumped at 355 nm

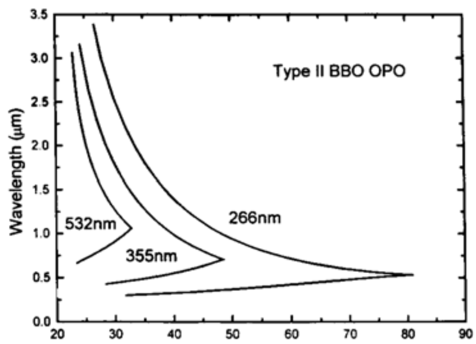
In the case of Nd:YAG pumping, BBO's OPOs can generate more than 100mJ, with wavelength tunable from 400nm to 2000nm. Using our BBO crystal, the OPO system covers a tuning range from 400nm to 3100nm which guarantees a maximum of 30% and more than 18% conversion efficiency, over the wavelength range from 430nm to 2000nm.

Type II BBO can be used to decrease linewidth near the degenerate points. A linewidth as narrow as 0.05 nm and usable conversion efficiency of 12% were obtained. However, a longer (> 15 mm) BBO should normally be used to decrease the oscillation threshold when employing the type II phase-matching scheme.

Pumping with a picosecond Nd:YAG at 355 nm, a narrow-band (< 0.3 nm), high energy (> 200μJ) and wide tunable (400 nm to 2000 nm) 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 nm to 3500 nm can be also generated by BBO's OPO or OPA plus a BBO for SHG.



Type I OPO tuning curves of BBO



Type II OPO tuning curves of BBO

3.Others

A tunable OPO with signal wavelength between 422nm and 477nm has been generated by angle tuning in a type Ⅰ BBO crystal pumped with a XeCl excimer laser at 308 nm. And a BBO's OPO pumped by the fourth harmonic of a Nd:YAG laser (at 266 nm) has been observed to cover the whole range of output wavelengths 330 nm - 1370 nm.

When pumped by a 1mJ, 80 fs Dye laser at 615 nm, the OPA with two BBO crystals yields more than 50 μJ (maximum 130 μJ), < 200 fs ultrashort pulse, over 800 nm - 2000 nm.

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AR-coating

◇Dual Band AR-coating (DBAR) of BBO for SHG of 1064nm.
◇Low reflectance (R<0.2% at 1064nm and R<0.5% at 532nm);
◇High damage threshold (>300MW/cm2 at both wavelengths);
◇Long durability.
◇Broad Band AR-coating (BBAR) of BBO for SHG of tunable lasers.
◇Broad Band P-coating of BBO for OPO applications.
◇Other coatings are available upon request.

Standard Specifications

Items	Specifications
Dimension Tolerance	(W±0.1mm)x(H±0.1mm)x(L+0.5/-0.1mm) (L≥2.5mm) (W±0.1mm)x(H±0.1mm)x(L+0.2/-0.1mm) (L<2.5mm)
Clear aperture	central 90% of the diameter
Flatness	≤ λ/8 @ 632.8nm
wavefront distortion	≤ λ/8 @ 632.8nm
Bevel	≤0.2mm@45°
Chip	≤0.1mm
Surface Quality	scratch and dig 10-5
Parallelism	≤ 20 arc seconds
Perpendicularity	≤ 5 arc minutes
Angle tolerance	≤0.1°
Damage threshold[GW/cm]:	>1 for 1064nm, TEM00, 10ns, 10HZ (polished only) >0.5 for 1064nm, TEM00, 10ns, 10HZ (AR-coated) >0.3 for 532nm, TEM00, 10ns, 10HZ (AR-coated)

Notes

◇ BBO has a low susceptibility to the moisture. The user is advised to provide dry conditions for both the use and 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.