# BBO Crystals - Beta Barium Borate and Lithium Borate

## (BBO and LBO)

(Table of Material Properties appears below)

Beta Barium Borate (BBO) and Lithium Triborate (LBO) single crystals combine unusually wide transparency, moderate to moderately large nonlinear coupling, high damage threshold and good mechanical/chemical properties.

BBO has band edges at 0.19 and 3.3um. Its useful transmission range ( <5%/cm) is 0.21 to 2.1um and it has been demonstrated to be efficient for the generation of second harmonic radiation down to about 0.21um [3,14,15]. It is also useful for broadly tunable optical parametric oscillators (OPOs) and amplifiers (OPAs). Autocorrelation applications may be performed down to 0.19um. Its exceptional IR transmission and wide thermal acceptance bandwidth allow high average power OPO/OPA operation, with minimal heating from long wavelength idler radiation.

BBO's relatively narrow angular acceptance bandwidth (especially in the UV) may limit its usefulness in certain applications involving lasers with less than diffraction limited beam quality. Its mild hygroscopicity should not limit its usefulness in most circumstances. Hermetically sealed housing are available.

BBO's broad phase-matchability makes it an excellent candidate for general use with Nd:YAG and other Q-switched/mode-locked solid-state lasers. Using a tunable Ti:sapphire, Alexandrite, or dye laser, BBO can be used to generate tunable radiation from the near IR to the UV. Such high power, widely tunable radiation would be useful for many applications, including spectroscopy, medicine, materials processing, nonlinear optics, LIDAR, remote sensing, and photochemistry. In the commercial market, solid state nonlinear systems based on BBO could compete with dye lasers, and have the advantage of lower operating cost and more convenient tuning over large frequency ranges.

LBO has band edges at 0.16[6] and 3.3um. Its useful transmission range ( <5%/cm)is 0.21 to 2.3um. However, if higher absorption is acceptable, LBO compliments BBO by allowing deeper UV mixing. It also allows temperature-controllable non-critical phase matching (NCPM) for nominal 1.0-1.3um, Type I SHG[16]. LBO also provides room temperature, quasi-NCPM (angle tune while maintaining =90°) for Type II SHG(0.8-1.1um) and THG(0.95-1.2um), a unique capability attributable , in part, to its biaxiality. LBO's lower birefringence limits its UV phase matching to certain combinations of longer wavelength radiation, but it possesses significantly larger angular acceptance bandwidths, reducing the beam quality requirements for source lasers.

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# Properties of BBO and LBO [a]

| | Beta-$BaB_2O_4$ (BBO) | $LiB_3O_5$ (LBO) |
|---|---|---|
| **Crystal Data** | | |
| **Crystal Symmetry and Class** | Rhombohedral, 3m[1] | Orthorhombic, mm2[6] |
| **Space Group** | R3c[1] | $Pbn2_1$[6,j] |
| **Lattice Constants (angstroms)** | a=12.726 +/-0.001[b]<br>c=12.726 +/-0.001 | a=7.3788 +/-0.0005[6,j])<br>b=8.4473 +/-0.0007[6,j]<br>c=5.1395 +/-0.0005[6,j] |
| **Density, g/cc** | 3.849 | 2.474 |
| **Cleavage** | (001) poor | none observed |
| **Optical Properties** | | |
| **Optical Transmission (um)**<br>**50% transmission, t=3mm** | 0.196 to 2.2[c,2,3] | 0.16 to 2.3[c,6] |
| **Indices of refraction at (um)** | $n_o$[3], $n_e$[3] | $n_{b=x}$[18,h], $n_{c=y}$[18,h], $n_{a=z}$[18,h] |
| 0.2537 | ---,--- | 1.6326,1.6577,1.6844 |
| 0.2660 | 1.7571,1.6146 | 1.6256,1.6597,1.6761 |
| 0.4358 | 1.6868,155638 | 1.5857,1.6147,1.6299 |
| 0.5461 | 1.6738,1.5547 | 1.5777,1.6056,1.6207 |
| 0.6328 | 1.6673,1.5500 | 1.5740,1.6014,1.6164 |
| 1.0642 | 1.6551,1.5425 | 1.5648,1.5904,1.6053 |
| **Thermooptic coefficient, dn/dT** | See (g) | See (g) |
| **Fresnel Refection Loss per surface** | | |
| 0.266um | 7.5%,5.5% | 5.7%,6.2%,.4% |
| 1.06um | 6.1%,4.1% | 4.8%,5.2%,5.4% |
| **Absorption Coeff. ($cm^{-1}$)** | | |
| 0.266um | 0.04 to 0.15[1] | --- |
| 1.0um | 0.001 to 0.002 | --- |
| 2.09um | e-ray: 0.0085<br>o-ray: 0.07 | --- |
| **Laser Damage Threshold ($GW/cm^2$)[f]** | | |
| 1.064um, 10ns pulse | 4.6[10] | --- |

| | | |
|---|---|---|
| 1.064um, 0.1ns pulse, 2.3J | 15[6,i] | 25[6,i] |
| **NLO Susceptibility, pm/V<br>SHG at 1.06um[e]<br>[$d_{31}=d_{15}$ & $d_{32}=d_{24}$], Kleinman symmetry** | | |
| $d_{22}$ | 2.3[11,21] | --- |
| $d_{15}$ | <=0.1[3,21] | 0.85[21,j] |
| $d_{24}$ | $=d_{15}$ by symmetry | -0.67[21,j] |
| $d_{33}$ | unknown,irrelevant | 0.04[21,j] |
| **Phasematching Range ( ,um)** | | |
| Type I SHG | 0.4096 to 3+[3] | 0.55 to 3.0 |
| Type II SHG | 0.53 to 3+[3] | 0.79 to 2.2 |
| **Phasematching Angle [j]<br>at max $d_{eff}$ and 25°C** | , | , |
| 0.532um, Type I SHG | 47.6°[4,g], 90° | --- |
| 0.532um, Type II SHG | 81.0°[4,g], 0° | --- |
| 1.064um, Type I SHG | 22.8°[4,g], 90° | 11.4°[18,g], 0° |
| 1.064um, Type II SHG | 32.8°[4,g], 0° | 90°, 69.1°[18,g] |
| **Pockels Coeffs.(pm/V)[8](0.5145um)<br>(Linear Electro-Optic)** | | |
| $r_{22}$ | 2.7 +/-0.4 | --- |
| $r_{31}$ | ~0 | --- |
| $r_6$ | 0.055 | --- |
| **Half Wave Voltage** | 87kV[3] | --- |
| Mechanical Properties | | |
| **Hardness, Mohs** | 4.5 | 6 |
| **Elastic Compliances, ($TPa^{-1}$)[3,f]** | | |
| $s_{11}$ | 25.63 | --- |
| $s_{12}$ | -14.85 | --- |
| $s_{13}$ | -9.97 | --- |
| $s_{14}$ | -63.97 | --- |
| $s_{33}$ | 37.21 | --- |
| $s_{44}$ | 331.3 | --- |
| $s_{66}$ | 81 | --- |
| **Young's Modulus, $1/s_{11}^E$(GPa)** | 39 | --- |

| | | |
|---|---|---|
| **Poisson's Ratio, $-s_{12}/s_{11}$** | 0.58 | --- |
| **Elastic Stiffnesses, (GPa)[3,f]** | | |
| $c_{11}$ | 123.8 | --- |
| $c_{12}$ | 60.3 | --- |
| $c_{13}$ | 49.4 | --- |
| $c_{14}$ | 12.3 | --- |
| $c_{33}$ | 53.3 | --- |
| $c_{44}$ | 7.8 | --- |
| $c_{66}$ | 31.8 | --- |
| Thermal Properties | | |
| **Melting point (°C)** | 1095( phase)[9] | 834(peritectic)[19] |
| **Thermal Expansion Coeff.($10^{-6}$/°C)[3]** | | |
| a | 4[3] | 33.6[17,j] |
| b | -- | 108.2[17,j] |
| c | 36[3] | -88[17,j] |
| **Phase transitions, °C** | 925 +/-5[9] | none observed |
| **Specific Heat (J/g/°C)** | 0.49 +/-0.02 | 1.06 +/-0.05 |
| **Thermal Conductivity (W/m/°C)** | | |
| perpendicular to c | 1.2 | 2.7 \|\| to x<br>3.1 \|\| to z |
| parallel to c | 1.6 | 4.5 \|\| to y(=c) |
| Electrical Properties | | |
| **Resistivity (ohm-cm)** | $>10^{11}$ | $>10^{11}$ |
| **Relative dielectric constant** | | |
| $_{11}{}^{S}/_{o}$ | 6.7[3] | --- |
| $_{33}{}^{S}/_{o}$ | 8.1[3] | --- |

**Footnotes**

a) Unreferenced data were determined at Cleveland Crystals, Inc.

b) The rhombohedral lattice constatns are a=8.387 angstroms, = 96.68°[1]

c) Fine structure is observed between ~2.2 and 3.28um

d) Calculated fom Sellmeier euqations, refs 4 and 18

e) Converted using $d_{36}$(KDP)=0.39pm/V[20,21]. Original papers sometimes report values relative to a different absolute scale.

f) Gpa=$10^9$N/$m^2$. TPa=$10^{12}$N/$m^2$. GW=$10^9$J/s

g) Private communication from K. Kato

h) Measured at 20°C

i) Surface damage threshold[6]

j) Crystallographic axes abc and tensor reporting frame axes XYZ are designated here according to IEEE/ansi sTD 176-1987, which, for LBO, equates X=a=z, Y=b=x, Z=c=y, relative to principal optical axes xyz. Note that most literature designations [except in (21)] reverse a and b (also $d_{31}$ and $d_{32}$; also $d_{15}$ and $d_{24}$) from these conventions. For BBO and LBO, phase matching angle is measured from x and meausred from y towards z [see(21)].

k) UV absorption edge for LBO from ref 6, for BBO from ref 2.

l) Transmission is intensity dependent. (Unreferenced Cleveland Crystals data)

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**References**


1) J. Liebertz and S. Stahr, Z. Krist. 165, 91-3(1983)

2) L.K. Cheng, W. Bosenberg, and C.L. Tang, J. Cryst.Growth 89, 553-9(1988)

3) D. Eimerl, L. Davis, S. Velsko, E.K. Graham, and A.Zalkin, J. Appl. Phys. 62, 1968-83(1987)

4) K. Kato, IEEE J. Quantum Electron. 22, 1013-4(1986)

5) S.K. Kurtz, J. Jerphagnon, and M.M. Choy, Landolt-Bornstein, New Series Vol.11, 671-4(1979);
J. Jerphagnon, S.K. Kurtz and J.L. Oudar, ibid Vol18, 456-7(1984)

6) C. Chen, Y. Wu, A Jiang, B. Wu, G. You, R. Li, and S.Lin, J. Opt. Soc. Am. B6, 616-21(1989)

7) S.Zhao, C. Huang, and H. Zhang, J. Cryst. Growth 99,809-10(1990)

8) C.A Ebbers, Appl. Phys. Lett. 52, 1948-9(1988)

9) C. CHen, B.Wu, A.Jiang, and G. You, Scientia Sinica B28,235-43(1985)

10) B.S. Hudson, Spectroscopy 2(4), 33-5(1987)

11) R. Eckardt, H. Masuda, Y. Fan, and R. Beyer, IEEE J. Quantum Electron. 26, 922-33(1990)

12) R.L. Beyer, "Optical parametric oscillators", in Treatise in Quantum Electronics, H. Rabin,C.L. Tang, Editors, 587-702, Academic Press,New York(1973)

13) "IEEE Standard on Piezoelectricity", IEEE/ANSI Std. 176-1987,IEEE, Inc. 345 E. 47th St., NY,NY 10017

14) W.R. Bosenberg, W.S. Pelouch, and C.L. Tang, Appl. Phys.Lett. 55, 1952-4(1989)

15) C. Chen, B. Wu, G. You and Y. Huang, "High-efficiency and wide-band second-harmonic generation of new crystal,beta-$BaB_2O_4$" dig. Tech. Papers Xiii IQEC (1984), paper MCC5

16) T. Ukachi, R.J. Lane, W.R. Bosenberg, and C.L.Tang, Appl.Phys. Lett 57, 980-2(1990)

17) Fujian Institute, private communication

18) K. Kato, IEEE J. Quantum Electron. 26, 1173-5(1990)

19) B.S.R. Sastry and F.A. Hummel, J. Am. Ceram. Soc. 41,7-17(1958)

20) D. Eimerl, "Electro-optic, linear and nonlinear optical properties of KDP and its isomorphs" ,Ferroelectrics Vol.72, 95-139(1987)

21) D. A Roberts "Simplified Characterization of Uniaxial and Biaxial Nonliner Optical Crystals: A plea for Standardization of Nomenclature and Conventions", IEEE J. Quantum Electron, 28, 2057-74(1992). Reprints available from Cleveland Crystals.