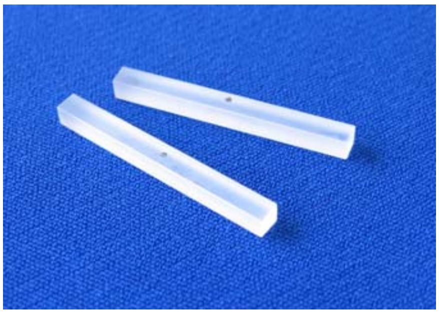
LBO

Lithium triborate (LiB_3O_5 or **LBO**) is an excellent nonlinear optical crystal for many applications. It is grown by an improved flux method.



AOTK's LBO is Featured by

- High damage threshold (18.9 GW/cm², 1.3ns pulse-width at 1053nm)
- Very small walk-off angle
- Wide acceptance angle
- Broad transparency range from 160nm to 2600nm (SHG range from 550nm to 2600nm)
- High optical homogeneity ($\Delta n \approx 10^{-6}$/cm) and free of inclusion
- Relatively large effective SHG coefficient (over 3 times than that of KDP)
- Both type I and type II non-critical phase-matching (NCPM) in a wide wavelength range

LBO Main Applications

- SHG of high power Nd:YAG and Nd:YLF lasers for R&D and military
- SHG of diode laser pumped Nd:YVO_4, Nd:$GdVO_4$, Nd:YAG and Nd:YLF lasers
- SHG of Ti:Sapphire, Alexandrite and Cr:LiSAF lasers
- SHG of medical and industrial Nd:YAG lasers
- Frequency-tripling (THG) of Nd:YAG and Nd:YLF lasers
- Frequency-doubling (SHG) and -tripling (THG) of high power Nd:YAP laser at 1340 nm
- Optical parametric amplifiers (OPA) and optical parametric oscillators (OPO) by harmonics of Nd:YAG lasers and Excimer lasers

Basic Properties

1. Structural and Physical Properties

Crystal Structure	Orthorhombic, Space group $Pna2_1$, Point group mm2
Lattice Parameter	a = 8.4473Å, b = 7.3788Å, c = 5.1395Å, Z = 2
Melting Point	About 834°C
Mohs Hardness	6
Density	2.47 g/cm³
Thermal Conductivity	3.5W/m/K
Thermal Expansion Coefficient	$a_x = 10.8\times10^{-5}$/K, $a_y = -8.8\times10^{-5}$/K, $a_z = 3.4\times10^{-5}$/K

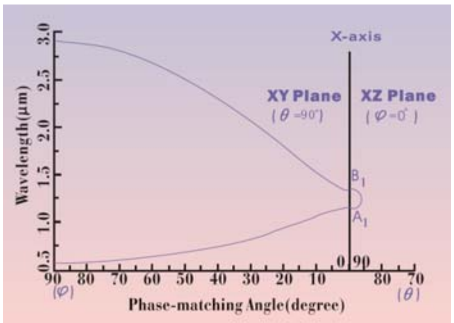
2. Optical and Nonlinear Optical Properties

Transparency Range	160-2600nm
SHG Phase Matchable Range	551 ~ 2600nm (Type I); 790-2150nm (Type II)
Therm-optic Coefficient (λ in µm)	$dn_x/dT = -9.3\times10^{-6}/°C$ $dn_y/dT = -13.6\times10^{-6}/°C$ $dn_z/dT = (-6.3-2.1\lambda)\times10^{-6}/°C$
Absorption Coefficient	<0.1%/cm at 1064nm; <0.3%/cm at 532nm
Angle Acceptance	6.54mrad-cm (φ, Type I, 1064nm SHG) 15.27mrad-cm (θ, Type II, 1064nm SHG)
Temperature Acceptance	4.7°C/cm (Type I, 1064nm SHG) 7.5°C/cm (Type II,1064nm SHG) 3.8°C/cm (Type I, 1064nm THG)
Spectral Acceptance	1.0nm-cm (Type I, 1064 SHG) 1.3nm-cm (Type II,1064 SHG)
Walk-off Angle	0.60° (Type I 1064nm SHG) 0.12° (Type II 1064nm SHG)
NLO Coefficient	$d_{eff}(I) = d_{32}\cos\varphi$ Type I, in XY plane $d_{eff}(I) = d_{31}\cos^2\theta + d_{32}\sin^2\theta$ Type I, in XZ plane $d_{eff}(II) = d_{31}\cos\theta$ Type II, in YZ plane $d_{eff}(II) = d_{31}\cos^2\theta + d_{32}\sin^2\theta$ Type II, in XZ plane

Non-vanished NLO susceptibilities	d_{31} = 1.05 ± 0.09 pm/V d_{32} = -0.98 ± 0.09 pm/V d_{33} = 0.05 ± 0.006 pm/V
Sellmeier Equations (λ in μm)	$n_x^2=2.454140+0.011249/(\lambda^2-0.011350)-0.014591\lambda^2-6.60\times10^{-5}\lambda^4$ $n_y^2=2.539070+0.012711/(\lambda^2-0.012523)-0.018540\lambda^2+2.00\times10^{-4}\lambda^4$ $n_z^2=2.586179+0.013099/(\lambda^2-0.011893)-0.017968\lambda^2-2.26\times10^{-4}\lambda^4$
Refractive Indexes	n_x n_y n_z Wavelength 1.5656 1.5905 1.6055 1064 nm 1.5785 1.6065 1.6212 532 nm 1.5973 1.6286 1.6444 355 nm
Damage Threshold	>10GW/cm² (10 ns, 10 Hz) @1064 nm >18.9GW/cm² (1.3 ns, 4.1 Hz) @1053 nm

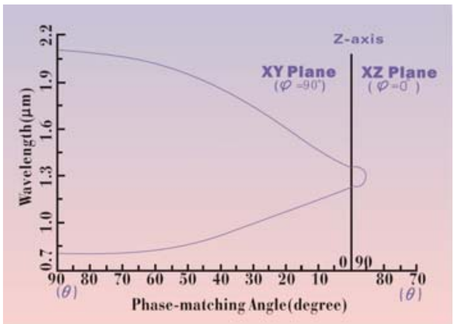
Harmonic Generation

LBO is phase-matchable for SHG and THG of Nd:YAG and Nd:YLF lasers by using either Type I or Type II interaction. For SHG at room temperature, Type I phase-matching can be reached and has maximum effective SHG coefficient in the principal XY and XZ planes in a wide wavelength range from 551 nm to about 3 μm. The optimum Type II phase-matching falls in the principal YZ and XZ planes.



Type I SHG Tuning Curve of LBO

SHG conversion efficiencies of more than 70% for pulse and 30% for cw Nd:YAG lasers, and THG conversion efficiency of over 60% for pulse Nd:YAG laser have been observed respectively. The SHG conversion efficiency of LBO in an unstable resonator Nd:YAG laser vs the average power density in comparison with that of KTP is shown in right figure.



Type II SHG Tuning Curve of LBO

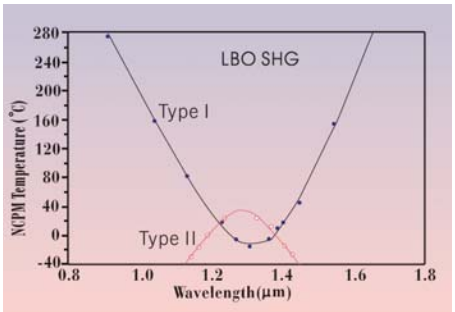
Applications

- More than 480 mW output at 395 nm is generated by frequency-doubling a 2W mode-locked Ti:Sapphire laser (<2ps, 82MHz). The wavelength range of 700 - 900 nm is covered by a 5x3x8 mm³ LBO crystal.
- Over 60 W green output is obtained by SHG of a Q-switched Nd:YAG laser in a Type II, 18 mm long LBO crystal.
- The frequency-doubling of a diode pumped Nd:YLF laser (> 500 mJ @ 1047 nm, < 7 ns, 0-10 KHz) reaches over 40% conversion efficiency in a 9 mm LBO.
- The VUV output at 187.7 nm is obtained by sum-frequency generation.
- 2 mJ/pulse diffraction-limited beam at 355 nm is obtained by intracavity tripling a Q-switched Nd:YAG laser.
- LBO is very promising for the generation of 266 nm from Nd:YAG, Nd:YVO_4 laser because of its low absorption at 266 nm.
- Due to its high damage threshold and small group velocity dispersion, LBO is an excellent crystal for SHG, THG and autocorrelators of ultrashort pulsed lasers including Ti:Sapphire, Cr:LiSrAlF and Cr:LiCaAlF lasers.

AOTK can provide LBO crystal as thin as 0.02 mm for 10 fs lasers. To select the best LBO crystal design for your ultrashort pulsed lasers, please consult AOTK.

Non-Critical Phase-Matching

Non-Critical Phase-Matching (NCPM) of LBO is featured by no walk-off, very wide acceptance angle and maximum effective coefficient. It promotes LBO to work in its optimal condition. The SHG conversion efficiencies of more than 70% for pulse and 30% for cw Nd:YAG lasers have been obtained with good output stability and beam quality.



NCPM Temperature Tuning Curve of LBO

Type I and type II NCPM can be reached along x-axis (θ = 90°, φ = 0°) and z-axis (θ = 0°, φ = 0°), respectively. As shown in the figure, **NCPM** SHG over a broad wavelength range from 900 nm to about 1700 nm was measured. The properties of **NCPM** SHG of Nd:YAG laser at 1064nm are listed in table.

AOTK develops an assembly of stabilized oven and temperature controller for NCPM SHG of Nd:YAG, Nd:YLF and Nd:Glass lasers as well as NCPM OPO and OPA systems. The assembly can keep LBO crystal within ±0.1°C from room temperature to 200°C. Please refer to oven and temperature controller for more information.

Properties of Type I NCPM SHG at 1064 nm

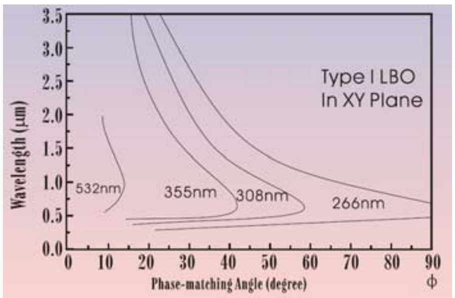
NCPM Temperature	148°C
Acceptance Angle	52 mrad-cm$^{1/2}$
Walk-off Angle	0
Temperature Bandwidth	4°C -cm
Effective SHG Coefficient	2.69 d_{36}(KDP)

Application

- More than 480 mW output at 395 nm is generated by frequency-doubling a 2W mode-locked Ti:Sapphire laser (<2ps, 82MHz). The wavelength range of 700 - 900 nm is covered by a 5x3x8 mm^3 LBO crystal.
- Over 10 W and highly stable green output @ 532 nm was obtained with NCPM LBO for frequency doubling of diode pumped Nd:YVO_4 lasers. All solid state SLM, Q-switched green and UV lasers are available.
- Over 100 W green output was achieved with Type II LBO for frequency doubling of Q-switched Nd:YAG laser.
- LBO can reach both temperature NCPM and spectral NCPM (very wide spectral bandwidth) at 1300 mm.
- More than 11 W @ 532 nm was obtained by extracavity SHG of a 25 W mode-locked Nd:YAG laser. Following drawing shows the SHG output vs input power of Nd:YLF laser (76MHz, 45ps).

OPO and OPA

LBO is an excellent NLO crystal for the widely tunable wavelength range and high power OPO and OPA. The Type I and Type II OPO and OPA pumped by SHG and THG of Nd:YAG laser and XeCl excimer laser at 308 nm have been reported. The figure shows the calculated OPO tuning curves of a Type I LBO pumped by SHG, THG and 4HG of Nd:YAG laser in XY plane at room temperature, and also shows the calculated OPO tuning curves of a Type II LBO pumped by SHG and THG of Nd:YAG laser in YZ and XZ planes.

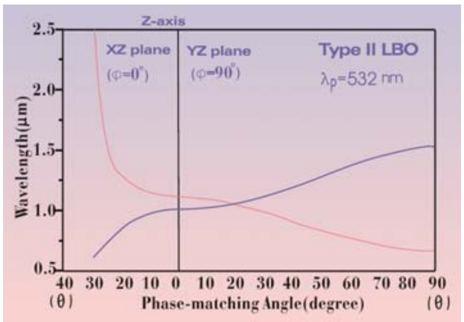


Type I OPO Tuning Curve of LBO

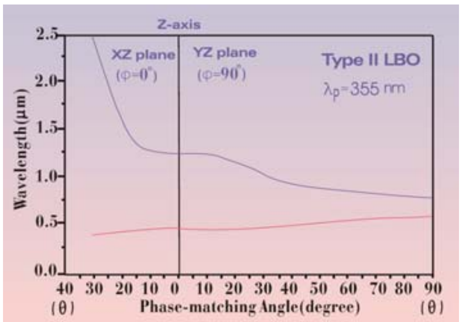
Applications

- By using 900 NCPM LBO, Spectra-Physics SPPO OPO synchronously pumped by femtosecond Ti:Sapphire laser generates < 130 fs pulse from 1.1 to 2.6 mm.
- Type I OPA pumped at 355 nm with pump-to-signal energy conversion efficiency of 30% has been reported.

- By using the NCPM technique, Type I OPA pumped by SHG of Nd:YAG laser at 532 nm was also observed to cover a widely tunable range from 0.75 mm to 1.8mm by temperature-tuning from 106.5°C to 148.5°C.
- By using Type II NCPM LBO as an optical parametric generator (OPG) and type I critical phase-matched BBO as an OPA, narrow linewidth (0.15 nm) and high pump-to-signal energy conversion efficiency (32.7%) were obtained when it is pumped by a 4.8 mJ, 30ps laser at 355nm. Wavelength tuning range from 482.6 to 415.9 nm is covered by increasing the temperature of LBO.



Type II OPO Tuning Curve of LBO
Pumped at 532 nm



Type II OPO Tuning Curve of LBO
Pumped at 355 nm

Standard Specifications

Dimensional Tolerance	(W ± 0.1mm) x (H ± 0.1mm) x (L +0.2/-0.1 mm)
Wavefront Distortion	< λ/8 @633 nm
Angle Tolerance	Δθ < ± 0.2°, Δϕ < ± 0.2°
Flatness	λ/10 @633 nm
Surface Quality	10/5 Scratch/Dig per MIL-O-13830A
Parallelism	< 10 arc seconds
Perpendicularity	< 5 arc minutes
Clear Aperture	> 90% central area
Damage Threshold	> 15 GW/cm² for a TEM_{00} mode, 1.3ns, 1Hz laser at 1064nm
Quality Warranty Period	one year under proper use

Anti-Reflective Coating (AR-coatings) Specifications

I. Dual Band AR-coating (DBAR) of LBO for SHG of Nd:YAG lasers

High Damage Threshold: >500MW/cm² at both wavelengths

Low Reflectance: R<0.2% at 1064nm and R<0.40% at 532nm

Long durability

II. Broad Band AR-coating (BBAR) of LBO for SHG of Ti:Sapphire lasers

III. Other coatings are available upon request

Note

- Users are advised to provide dry conditions for both use and preservation of LBO, due to a very low susceptibility to moisture.
- The polished surfaces of LBO requires precautions.
- Typical phase matching angles

1. Phase matching angles for angle tuning (at room temperature)

   Type I SHG @ 1064 nm: θ = 90°, ϕ = 11.36°

   Type II SHG @ 1064 nm: θ = 20.5°, ϕ = 90°

2. Phase matching angles for temperature tuning (NCPM)

   Type I: θ = 90°, ϕ = 0°

   SHG @ 1064 nm, NCPM temperature at 148°C

   SHG @ 1053 nm, NCPM temperature at 163°C

   SHG @ 1047 nm, NCPM temperature at 171°C

- AOTK engineers can design and select the best crystal for you if the 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, mode condition, divergence, laser beam diameter, wavelength tuning range, etc).

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