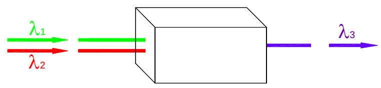
The nonlinear optical (NLO) crystals are used in frequency conversion for lasers. The basic NLO crystals include the LBO, BBO, KTP, KD*P, $KNbO_3$, $LiNbO_3$, MgO:$LiNbO_3$, $AgGaS_2$, $AgGaS_2$ etc. The BIBO (BiB_3O_6) is a new good NLO crystal for the UV and visible range wavelength. The right NLO crystals should be chosen taking into consideration the criteria transmission, efficiency of the nonlinear effect, phase matching range, damage threshold and laser beam quality.

Frequency Conversion

The frequency conversion processes include frequency doubling (which is a special case of sum frequency generation), sum frequency generation (SFG), differential-frequency generation (DFG) and optical parametric generation (OPG) which are demonstrated in the following equations:

Sum Frequency Generation (SFG)

$\omega_1 + \omega_2 = \omega_3$ (or $1/\lambda_1 + 1/\lambda_2 = 1/\lambda_3$ in wavelength)



NLO Crystal

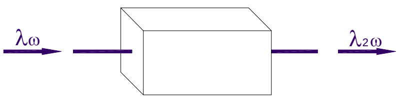
Sum Frequency Generation

It combines two low energy (or low frequency) photons into a high energy photon.
For example:

1064nm + 532nm $\rightarrow$ 355nm

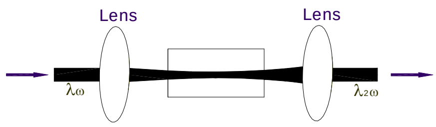
Frequency Doubling

Frequency Doubling or Second Harmonic Generation (SHG) is a special case of sum frequency generation if the two input wavelengths are the same: same: $2\omega_1 = \omega_2$ (or $\lambda_1 = 2\lambda_2$ in wavelength). The simplest scheme for frequency doubling is extra cavity doubling. The laser passes through the nonlinear crystal only once as shown. However, if the power density of laser is low, focused beam, intracavity doubling and external resonant cavity are normally used to increase the power density on the crystals, for example, for doubling of cw Nd:YAG laser and Argon Ion lasers.



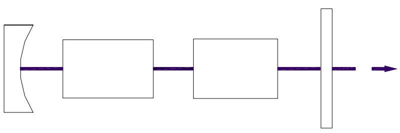
NLO Crystal

Extracavity SHG



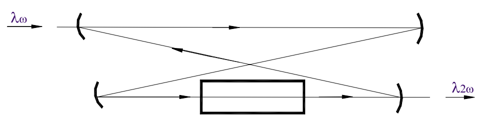
NLO Crystal

SHG with Focused Beam



Laser Crystal NLO Crystal

Intracavity SHG



NLO Crystal

External Resonant Cavity SHG

Frequency Tripling

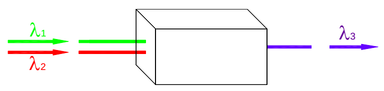
Frequency Tripling or Third Harmonic Generation (THG) is another example of Sum Frequency Generation, where THG of Nd:YAG laser, λ_1 = 1064 nm, λ_2 = 532 nm and generated wavelength λ_1 = 355 nm. By sum frequency of fundamental wavelength and THG of a Ti:Sapphire laser in BBO crystal, it can generate wavelengths as short as 193 nm.

Differential Frequency Generation (DFG)

$\omega_1 - \omega_2 = \omega_3$ (or $1/\lambda_1 - 1/\lambda_2 = 1/\lambda_3$ in wavelength)

It combines two high energy photons into a low energy photon.

532nm - 810nm → 1550nm



NLO Crystal

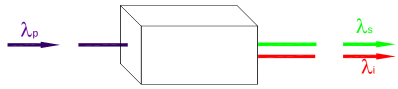
Differential Frequency Generation

Optical Parametric Generation (OPG)

$\omega_p - \omega_s = \omega_i$ (or $1/\lambda_p - 1/\lambda_s = 1/\lambda_i$ in wavelength)

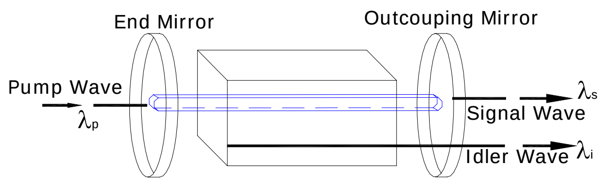
It splits one high energy photon into two low energy photons.

Optical Parametric Generation (OPG) is an inverse process of sum Frequency Generation. It splits one high-frequency photon (pumping wavelength, λ_p) into two low-frequency photons (signal, λ_s, and idler wavelength, λ_i). If two mirrors are added to from a cavity, an Optical Parametric Oscillator (OPO) is established. For a fixed pump wavelength, an infinite number of signal and idler wavelengths can be generated by tilting a crystal. Therefore, OPO is an excellent source for generating wide tunable range coherent radiation. BBO, KTP, LBO and $LINbO_3$ are good crystal for OPO and Optical Parametric Amplifier (OPA) applications.



NLO Crystal

Optical Parametric Generation



NLO Crystal

Optical Parametric Oscillator

Phase-matching

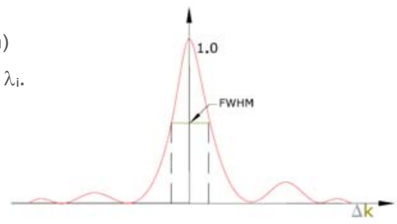
In order to obtain high conversion efficiency, the phase vectors of input beams and generated beams have to be matched:

$$\Delta K = k_3 - k_2 - k_1 = 2\pi n_3/\lambda_3 - 2\pi_2/\lambda_2 - 2\pi n_1/\lambda_1) = 0 \quad \text{(For sum frequency generation)}$$

Where: ΔK is phase mismatching, k_i is phase vector at λ_i and n_i is refractive index at λ_i.

In low power case, the relationship between conversion efficiency and phase mismatching is:

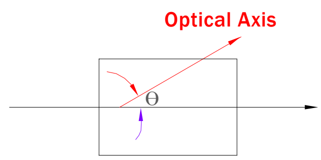
$$\eta \propto (\sin(\Delta KL)/\Delta KL)^2$$



Conversion Efficiency Vs ΔK

It is clear that the conversion efficiency will drop dramatically if ΔK increases.

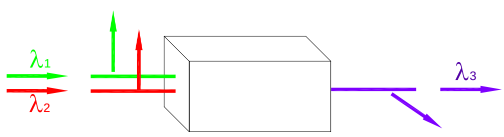
The phase-matching can be obtained by angle tilting, temperature tuning or other methods. The angle tilting is mostly used to obtain phase-matching as shown. If the angle between optical axis and beam propagation (θ) is not equal to 90° or 0°, we call it **Critical phase-matching (CPM). Otherwise, 90° non-critical phase-matching (NCPM)** is for θ = 90° and 0° **NCPM** is for θ = 0°.



NLO Crystal

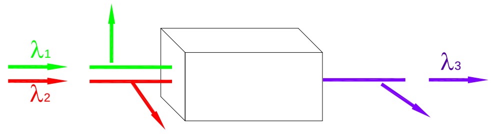
Critical Phase matching

Two types of phase-matching are classified in consideration of polarization of lasers. If the polarizations of two input beams (for sum frequency) are parallel to each other, it is called **type I phase-matching**. If the polarizations are perpendicular to each other, it is called **type II phase-matching**.



NLO Crystal

Type I Phase Matching



NLO Crystal

Type II Phase Matching

Conversion Efficiency

How to select a NLO crystal for a frequency conversion process with a certain laser? The most important thing is to obtain high conversion efficiency. The conversion efficiency has the following relationship with effective nonlinear coefficient (d_{eff}), crystal length (L), input power density (P) and phase mismatching (ΔK):

$$\eta \propto PL^2 (d_{eff} \sin(\Delta KL)/\Delta KL)^2$$

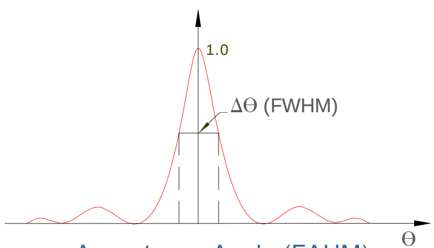
In general, higher power density, longer crystal length, larger nonlinear coefficients and smaller phase mismatching will result higher conversion efficiency. However, there is always some limitation coming from nonlinear crystals and lasers. For example, the d_{eff} is determined by the nonlinear crystal itself and the input power density has to be lower than the damage threshold of crystal. Therefore, it is important to select a right crystal for your applications. In the following Table we list the laser and crystal parameters for selecting right crystals.

Parameters for NLO Crystal selection

Laser Parameters	Crystal Parameters
NLO Process	Phase-Matching Type and Angle, d_{eff}
Power or Energy, Repetition Rate	Damage Threshold
Divergence	Acceptance Angle
Bandwidth	Spectral Acceptance
Beam size	Crystal Size, Walk-Off Angle
Pulse Width	Group velocity Mismatching
Environment	Moisture, Temperature Acceptance

Crystal Acceptance

If a laser light propagates in the direction with angle $\Delta\theta$ to phase matching direction, the conversion efficiency will reduce dramatically. We define the **acceptance angle** ($\Delta\theta$) as full angle at half maximum (FAHM), where $\theta = 0°$. is phase-matching direction. For example, the acceptance angle of BBO for type I frequency doubling of Nd:YAG at 1064nm is about 1 mrad-cm. Therefore, if a Nd:YAG laser has beam divergence of 3mrad for frequency-doubling, over half of the input power is useless. In this case, LBO may be better because of its larger acceptance angle, about 8 mrad-cm. For NCMP, the acceptance angle is normally much bigger than that for CPM, for example, 52 mrad-cm($^{1/2}$) for type I NCPM LBO.

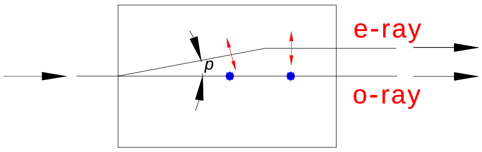


Acceptance Angle (FAHM)

In addition, you have to consider the Spectral acceptance ($\Delta\lambda$) of crystal and the spectral bandwidth of your laser, crystal **temperature acceptance** (ΔT) and the temperature change of environment.

Walk-Off

Due to the birefringence of NLO crystals, the extraordinary wave (n_e) will experience Poynting vector walk-off as shown. If the beam size of input beam will be separated at walk-off angle (ρ) in the crystal and it will cause low conversion efficiency. Therefore, for focused beam or intracavity doubling, the walk-off is a main limitation to high conversion efficiency.



Walk-Off Angle (ρ)

Group Velocity Mismatching

For NLO processes of ultrafast lasers such as Ti:Sapphire and Dye lasers with femtosecond (fs) pulse width, the main limitation to conversion efficiency is group velocity mismatching (GVM). The GVM is caused by group velocity dispersion of NLO crystal. For frequency doubling a Ti:sapphire laser at 800nm, for example, the inverse group velocities ($1/V_G$)of BBO are respectively $1/V_G$ = 56.09 ps/cm at 800nm and $1/V_G$=58.01 ps/cm at 400nm and GVM = 1.92 ps/cm. That means a 1mm long BBO crystal will make 192 fs separation between the pulses at two wavelengths. Therefore, for an 100 fs Ti:sapphire laser, we normally recommend a 0.5mm long BBO crystal (with 96 fs separation) in order to obtain high efficiency without dramatic pulse broadening.

Damage Threshold

The damage threshold is a function of the wavelength of fundamental and harmonic radiation, pulse duration, beam profile and other parameters.

The reference parameter of damage threshold

λ	LBO	BBO	KTP	KD*P
266nm	200 MW/cm² 10ns, 10Hz	120MW/cm² 8ns 10Hz	—	—
355nm	500MW/cm² 10ns, 10Hz	400W/cm² 10ns 10Hz	—	10GW/cm² 0.03ns 10Hz
532nm	1GW/cm² 10ns, 50Hz	700W/cm² 10ns 10Hz	500MW/cm², 8ns, 2Hz	8GW/cm² 0.03ns 10Hz
532nm	400KW/cm² cw	40KW/cm² cw	10GW/cm² 0.03ns, 10HZ	—
1064nm	19GW/cm² 1.3ns, 10Hz	10GW/cm² 1.3ns, 10Hz	2.4GW/cm², 11ns, 2Hz	6GW/cm² 1ns 10Hz
1064nm	1MW/cm² cw	80KW/cm² cw	300MW/cm² 30ns, 10Hz	25MW/cm² 140ns, 10Hz

How to Handle A NLO Crystal

Keep crystal clean

When you receive the NLO crystals from AOTK, please make sure that only qualified personnel are able to open the inner plastic boxes at clean environment. When the plastic box of a NLO crystal is opened, please prevent finger print, oil and other substances from adhering to the polished or coated surfaces.

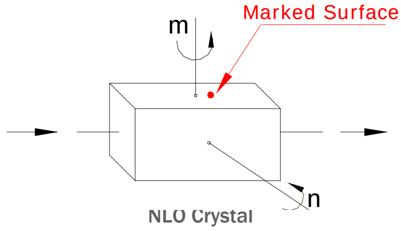
If the surfaces are contaminated, please blow the surface with air ball. If there is still pollution on the crystal surfaces, please clean the surfaces with cleaning liquid and soft silk. For BBO crystal, the mixing liquid of 50% high purity alcohol and 50% high purity ether is recommended as cleaning liquid. Please notify that the contaminated surfaces are very easy to be damaged.

Some NLO crystals have a low susceptibility to moisture, you are advised to provide dry atmosphere conditions for both use and preservation of them. When polished surfaces are fogged or damaged, pleasure ask AOTK for repolishing and coating service.

How to Order A Right crystal

Angle Tilting

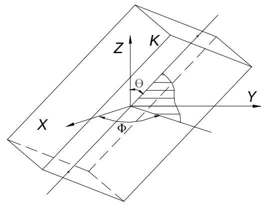
In order to obtain maximum conversion efficiency, angle tilting is normally used to reach phase-matching direction. There are two axes for tilting crystal angles as shown. Because the NLO crystals are normally cut in principal crystal plane, conversion efficiency is not sensitive to the angle tilting around b-axis. Customers have to pay attention when rotating the crystal around a-axis. A crystal mount with angle accuracy of about 5 arc second is recommended.



Crystal Angle Tilting

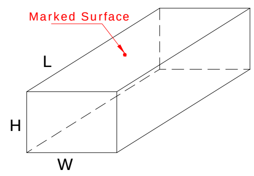
Optimum Crystal Size and Cut

When ordering a nonlinear optical crystal, crystal **orientation** (or crystal cut) and size have to be known. The orientation is solely determined by the nonlinear optical process. For example, for type I frequency-doubling of 1064nm, BBO is cut at θ= 22.8°. and Φ = 0°. Where: θ is the polar angle between the optical axis and the propagation direction, Φ is the azimuthal angle between the projection of propagation direction onto the XY plane and the X axis. If you aren't sure about the crystal orientation and merely provide the nonlinear optical process of your application, AOTK 's salesmen and engineers will help you.



Polar Coordinate System Crystal
(K is the light propagation direction)

The crystal **size** is divided into three dimensions, Width (W), High (H) and Length (L), which is common written as W x H x L mm³ . The careful design of crystal size is important because the price of crystal varies from crystal sizes. More important, the conversion efficiency has direct relation to crystal length.



Dimension of Crystal

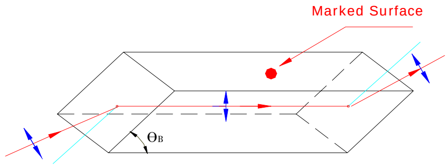
To select the optimum crystal **height** (H), the laser beam diameter upon the crystal should be taken into account. The optimum crystal height should be slightly (for instance, 1 mm to 2mm) larger than the laser beam diameter upon the crystal.

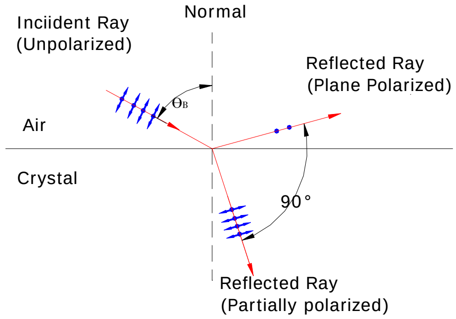
Both of laser beam diameter upon NLO crystal and tunable wavelength range have to be considered when designing the optimum crystal **width** (W). If it is a single NLO process, for example, frequency doubling 532 nm, we select W = H. If it is wide wavelength tuning NLO process, for example, frequency doubling a Dye laser from 440 nm to 660 nm by using BBO crystal, the crystal should be tuned from θ= 36° to θ= 66.6°. The width (W) is set to H + 2xtan((66.6°- 36°)/2)xL. Because if the crystal height (H) is 4 mm and length (L) is 7 mm, the W should be approximately 8 mm long.

Every NLO crystal has a standard **length** (L) for frequency doubling lasers with pulse width longer than nanosecond (ns). For example, the standard crystal lengths for BBO and KTP are 7 mm and 5 mm, respectively. However, OPO and OPA need longer length, for example, > 12 mm for BBO, and the SHG and THG of ultrashort pulse lasers use thin crystals with length of less than 1 mm. AOTK's salesmen and engineers collected a series of standard crystal lengths for various applications. This information is provided free.

Brewster's angle NLO crystals

For laser beam propagates from Air to NLO crystal (with refractive indices n). Brewster's angle is defined as θ_B = arctan(n). At Brewster's angle, the surface reflectance is zero for the light with polarization inside the plane defined by the direction of light propagation and the normal to the surface.





In order to have a low surface reflection, Brewster's angle cut (B-cut) NLO crystals are used. Without special notices, AOTK will fabricate the standard B-cut crystals according to the enclosed drawing. If customers design different sketch from our standard one, please notify AOTK by providing us a drawing

Order Information

Crystal Name	Application Type I or Type II θ = ?, ϕ = ?	Dimension WxHxL	Polished	Coated

For Example:

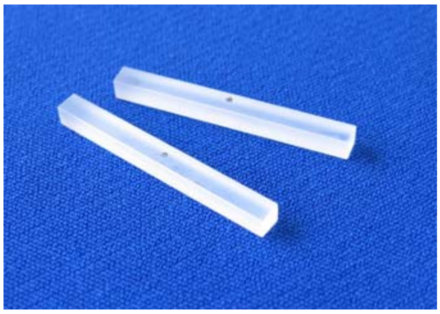
LBO Crystal	Type I SHG 1064nm θ = 90°, ϕ = 11.36°	3x3x10 mm	Polished	AR/AR @ 1064&532 nm

- Free services for calculating the parameters of custom NLO processes is provided by AOTK.

AOTK
AOTK, Inc. 1502, No. 694 Xianyue Rd. Xiamen 361009, P.R. China
Phone: +86-592-550 2081 Fax: +86-592-550 2082 E-mail: sales@aotk.com www.AOTK.com

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/cm^2, 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/cm^3
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

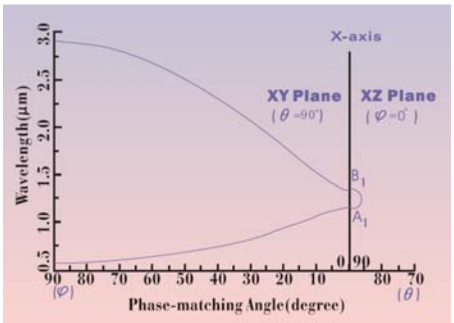
2. Optical and Nonlinear Optical Properties

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

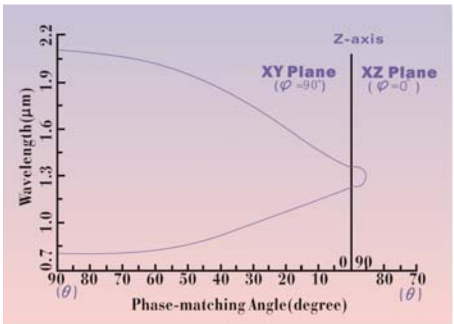
Harmonic Generation

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

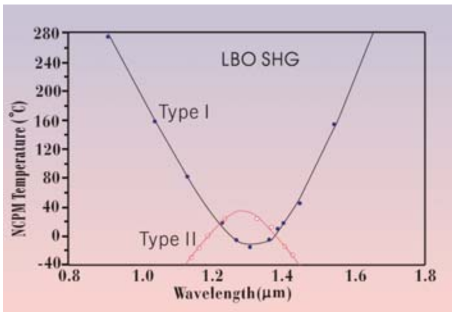
Applications

- 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

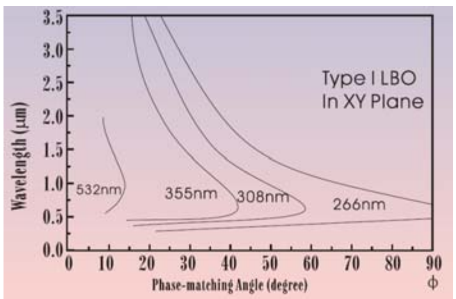
NCPM Temperature	148°C
Acceptance Angle	52 mrad-cm$^{1/2}$
Walk-off Angle	0
Temperature Bandwidth	4°C -cm
Effective SHG Coefficient	2.69 d_{36}(KDP)

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.

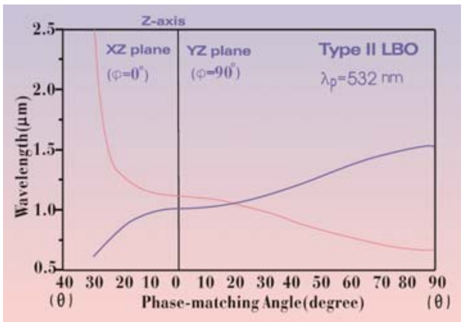


Type I OPO Tuning Curve of LBO

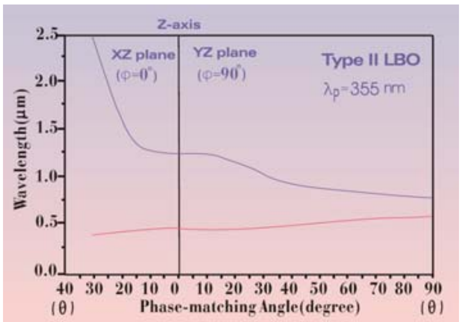
Applications

- 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

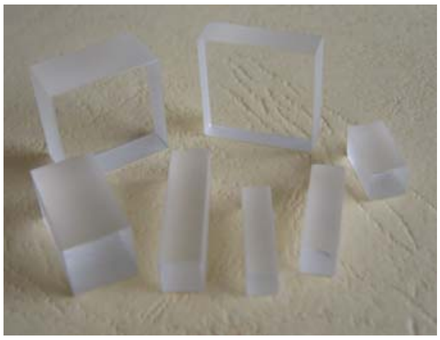
   SHG @ 1053 nm, NCPM temperature at 163°C

   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).

AOTK, Inc. 1502, No. 694 Xianyue Rd. Xiamen 361009, P.R. China
Phone: +86-592-550 2081 Fax: +86-592-550 2082 E-mail: sales@aotk.com www.AOTK.com

BBO



Beta-Barium Borate (β-BaB_2O_4 or **BBO**) is one of the most excellent NLO crystals. Using a newly improved flux method, AOTK now produces high-quality BBO crystal with high optical homogeneity, no inclusion and lower defects, lower absorption, high damage threshold and better laser performance. AOTK supplies the crystal length from 0.005mm to 20mm with various aperture and coating.

AOTK's BBO advanced properties

- Broad phase-matchable range from 409.6 nm to 3500 nm
- Wide transmission region from 190 nm to 3500 nm
- High damage threshold of 10 GW/cm^2 for 100 ps pulse-width at 1064 nm
- Large effective second-harmonic-generation (SHG) coefficient
- Wide temperature-bandwidth of about 55°C
- High optical homogeneity with $\Delta n > 10^{-6}$/cm
- Good mechanical and physical properties

Typical applications of BBO

- SHG, THG, 4HG and 5HG harmonic generations of Nd: lasers
- SHG, THG, and 4HG harmonic generations of Ti:Sapphire and Alexandrite lasers
- Frequency-doubling, -tripling and -mixing of Dye lasers
- Frequency-doubling and -tripling of ultrashort pulse Ti:Sapphire and Dye lasers
- Frequency-doubling of Argon ion, Cu-vapor and Ruby lasers
- Optical parametric amplifiers (OPA) and optical parametric oscillators (OPO)

Basic Properties

1. Structural and Physical Properties

Crystal Structure	Trigonal Point group 3m, Space group R_{3c}
Lattice Parameters	a=b=12.532Å, c=12.717Å, z=6
Density	3.84 g/cm^3
Mohs Hardness	4.0
Melting Point	1095 ± 5°C
Transition Temperature	925 ± 5°C
Resistivity	>10^{11} ohm-cm
Absorption Coefficient	α<0.1%/cm @1064 nm; α<1%/cm @532 nm
Optical Homogeneity	$\Delta n \approx 10^{-6}$/cm
Hygroscopic Susceptibility	low
Thermal Conductivity Coefficient	⊥c, 1.2W/m/K; //C, 1.6W/m/K
Thermal Expansion Coefficient	$\alpha_1=\alpha_2=4\times10^{-6}$/°C, $\alpha_3=36\times10^{-6}$/°C
Relative Dielectric Constant	$\varepsilon^T_{11}/\varepsilon_0=6.7$, $\varepsilon^T_{33}/\varepsilon_0=8.1$; Tan δ<0.001

2. Linear Optical Properties

Transparency Region	189 - 3500 nm
Refractive Indexes at 1064 nm at 532 nm at 355 nm at 266 nm at 213 nm	 n_o = 1.6551 n_e = 1.5425 n_o = 1.6750 n_e = 1.5555 n_o = 1.7055 n_e = 1.5775 n_o = 1.7571 n_e = 1.6146 n_o = 1.8465 n_e = 1.6742
Therm-Optic Coefficients	$dn_o/dT = -9.3 \times 10^{-6}$/°C $dn_e/dT = -16.6 \times 10^{-6}$/°C
Sellmeier Equations (λ in μm, T=20 °C)	$n_o^2=2.7359+0.01878(\lambda^2-0.01822)-0.01354\lambda^2$ $n_e^2=2.3753+0.01224(\lambda^2-0.01667)-0.01516\lambda^2$

3. NonLinear Optical Properties

Phase Matching Output Wavelength	189 - 1750 nm
Nonlinear Coefficients	d_{11} = 5.8 x d_{36}(KDP) d_{31} = 0.05 x d_{11} d_{22} < 0.05 x d_{11}
Effective SHG Coefficients	Type I: $d_{eff} = d_{31}\sin\theta+(d_{11}\cos3\phi-d_{22}\sin3\phi)\cos\theta$ Type II: $d_{eff} = (d_{11}\sin3\phi+d_{22}\cos3\phi)\cos2\theta$ (where θ & ϕ are polar angles referring to Z & X axis respectively)
Electro-Optic Coefficients	γ_{11} = 2.7 pm/V, γ_{22}, γ_{31} < 0.1 γ_{11}
Half-Wave Voltage	48 KV (at 1064 nm)
Damage Threshold at 1064 nm at 532 nm at 266 nm	 5GW/cm² (10 ns), 10GW/ cm² (1.3 ns) 1GW/cm² (10 ns), 7GW/ cm² (250 ps) 120MW/cm² (8 ns)

Main Applications

I. Applications in Nd:YAG Lasers

Base on its superior optical and NLO properties, BBO is the most efficient NLO crystal used for SHG, THG, 4HG of Nd:YAG lasers. Moreover, BBO is the ONLY NLO crystal which can produce 5HG at 213 nm. More than 70% for SHG, 60% for THG and 50% for 4HG conversion efficiencies have been obtained respectively, and output 200 mW at 213 nm. Basic NLO properties from SHG to 5HG of Type I BBO crystal are shown in Table 1, and Table 2 shown the harmonic generation results of BBO and KD*P crystals.

Table 1. Relevant NLO Properties of Type I BBO crystal

Fundamental Wavelength: 1064 nm	SHG	THG	4HG	5HG
Effective NLO Coefficient (d_{36}(KDP))	5.3	4.9	3.8	3.4
Angular Acceptance (mrad-cm)	1.0	0.5	0.3	0.2
Walk-off Angle (Degree)	3.2	4.1	4.9	5.5
Temperature Acceptance (°C)	51	16	4	/

Table 2. Harmonic Generations using BBO and KD*P crystal

Crystal	1ω (mJ)	SHG (mJ)	THG (mJ)	4HG (mJ)	5HG (mJ)
BBO	220	105	39	18.5	5
	600	350	40	70	20
KD*P	600	270	112.5	45	/

Both type I and type II phase-matching can be reached by angle-tuning. The phase matching angles of frequency doubling determined by input radiation wavelength is shown in Fig. 1.

BBO is a very efficient crystal for intracavity SHG of high power Nd:YAG lasers. For example, greater than 15 W average power at 532 nm was obtained in intracavity SHG of an acousto-optic Q-switched Nd:YAG laser with AR-coated BBO crystal.

66 mW output was obtained when pumped by 600 mW SHG output of a mode-locked Nd:YLF laser in an external resonant cavity with a Brewster-angle-cut BBO.

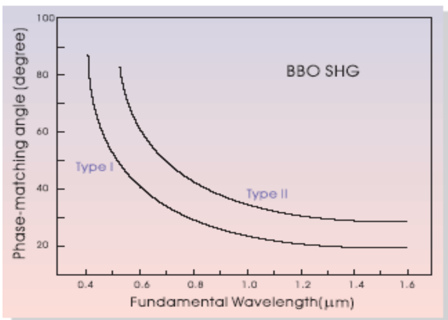


Fig. 1. SHG Turing curves of BBO

Good laser beam quality (such as: small divergence, good mode condition, etc.) is the key for BBO to obtain high conversion efficiency, due to BBO's small acceptance angle and large walk-off. Tight focus of laser beam is not recommended.

II. Applications in Tunable Lasers

♦Dye lasers

Efficient UV output (205 - 310 nm) with a SHG efficiency of over 10% at wavelength of more than 206 nm was obtained in type I BBO, and 36% conversion efficiency have been achieved for a XeCl-laser pumped Dye laser (for example, Lambda Physik's Model

LDP3000 and FL 3000) with power 150KW. The conversion efficiency is about 4 - 6 times higher than that of ADP. Furthermore, the shortest SHG wavelength 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.

With sum-frequency of 780 - 950 nm and 248.5 nm (SHG output of 495 nm dye laser) in Type I 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.

♦Ultrafast Pulse Laser

A laser pulse as short as 10 fs pulse can be efficiently frequency-doubled with very thin BBO wafer which shows its superior properties compared with KDP and ADP crystals, considering both phase-velocity and group-velocity matching. It has been reported that 10fs 438 nm ultrafast laser has been achieved by 0.01 mm doubling BBO crystal wafer. Now as thin as 0.01 mm thickness BBO wafers fabricated and supplied by AOTK are widely used in frequency-doubling, -tripling and autocorrelation measurient of ultrafast pulse lasers.

♦Alexandrite and Ti:Sapphire lasers

UV output in the region of 360 - 390 nm with pulse energy of 105mJ (31% SHG efficiency) at 378 nm, and output in the region 244 -259 nm with 7.5 mJ (24% mixing efficiency) have been obtained for type I BBO SHG and THG of an Alexandrite laser.

Greater than 50% of SHG conversion efficiency in a Ti:Sapphire laser has been obtained. High conversion efficiencies were also obtained for THG and 4HG of Ti:Sapphire lasers.

♦Argon Ion and Copper-Vapor lasers

By using 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 UV at 255.3 nm with maximum 8.9% conversion efficiency has been obtained for the SHG of Copper-Vapor laser at 510.6 nm.

III. Applications in OPO and OPA

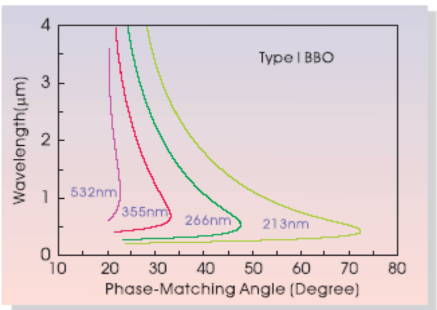


Fig. 2. Type I OPO Turing curves of BBO

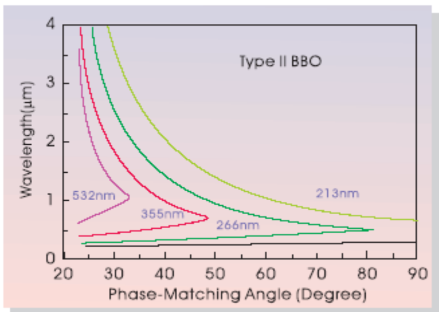


Fig. 3. Type II OPO Turing curves of BBO

BBO is one of the most suitable materials for optical parametric oscillators (OPO) and optical parametric amplifiers (OPA), to generate the widely tunable coherent radiation from UV to IR. Type I and Type II phase matching are applied in BBO's OPO and OPA shown in Fig. 2 and Fig. 3.

Generally long BBO (>15mm) shall be used to decrease the oscillation threshold when employing the type II phase-matching scheme. In order to obtain high efficient conversion, input laser radiation with good beam quality and low divergence is required because of small acceptance angle and large walk-off. Type I gives a larger tuning range and higher parametric amplification rate comparing to Type II, However, Type II interaction can produce narrower bandwidth (0.05 nm) output near degenerate points.

BBO OPO can generate more than 100mJ with wavelength tunable from 400nm to 2000nm by Nd:YAG laser. Meanwhile, BBO OPO system cover the tuning range from 400nm to 3100nm. A maximum of 30% conversion efficiency can be obtained from 400nm to 3100nm, and more than 18% conversion efficiency over the wavelength range from 430nm to 2000nm.

Pumped by picosecond Nd:YAG at 355 nm, narrow-band (< 0.3 nm), high energy (> 200mJ) and wide tunable (400nm ~ 2000nm) pulse have been produced by BBO's OPA. With > 50% conversion efficiency, BBO's OPA is superior to common Dye lasers in efficiency, tunable range and maintenance, and is easy to design and operate.

More than 30% energy conversion efficiency has been got by using 12 mm length BBO in OPO device synchronously pumped at 532 nm, which outputs at 406 nm ~ 3170 nm.

With a 1 mJ, 80 fs Dye laser at 615 nm pumping, OPA using two BBO crystals yields more than 50 μJ (maximum 130 mJ), < 200 fs ultrashort pulse over 800 nm ~2000 nm.

Parametric gain of BBO is over ten times higher than that of KDP at 355 nm pump for Type I interaction.

Tunable OPO with signal wavelengths between 422 nm and 477 nm has been generated by angle tuning a type I BBO crystal pumped with XeCl excimer laser at 308 nm.

BBO's OPO pumped by fourth harmonic of a Nd:YAG laser (at 266 nm) has been observed to cover the whole range of 330 - 1370 nm.

IV. BBO's E-O Applications

BBO can also be used for E-O applications. It has wide transmission range from UV to about 3500nm and it has much higher damage threshold than KD*P or $LiNbO_3$, More than 80W output power and 50KHz repetition rate have been reached by using AOTK's E-O BBO crystals and $Nd:YVO_4$ crystals as gain media. At 5KHz, its pulse has width as short as 6.4ns,and energy of 5.7mJ or peak power of 900 KW. It has advantages over the commercial A-O Q-switched one, including a very short pulse, high beam quality and size compact as well. Although it has a relative small electro-optic coefficient, the Half-wave voltage is very high (48KV at 1064nm), long and thin BBO can reduce the voltage requirements. AOTK now can supply 20mm long and 1mm thin high optical quality of BBO crystal with Z-cut, AR-coated and Gold/Chrome plated on the side faces.

Standard Size

The standard size crystals recommended by AOTK's engineers for various applications are listed as follows (assuming the laser beam diameter upon crystal is ϕ2mm to ϕ3mm):

1. Harmonic generations of Nd:YAG lasers

1064nm SHG –> 532nm	Type I, 4x4x7mm, θ = 22.8°, ϕ = 0°
1064nm THG –> 355nm	Type I, 4x4x7mm, θ = 31.3°, ϕ = 0° Type II, 4x4x7mm, θ = 38.6°, ϕ = 30°
1064nm 4HG –> 266nm	Type I, 4x4x7mm, θ = 47.6°, ϕ = 0°
1064nm 5HG –> 213nm	Type I, 4x4x7mm, θ = 51.1°, ϕ = 0°

2. OPO and OPA pumped by harmonics of Nd:YAG lasers

532nm Pump –> 680-2600nm	Type I, 6x4x12 -15mm, θ = 21°, ϕ = 0°
355nm Pump –> 410-2600nm	Type I, 6x4x12 - 15mm, θ = 30°, ϕ = 0° Type II, 7x4x15 - 20mm, θ = 37°, ϕ = 30°
266nm Pump –> 295-2600nm	Type I, 6x4x12 - 15mm, θ =39°, ϕ = 0°

3. Frequency doubling of Dye lasers

670-530nm SHG –> 335-260nm	Type I, 8x4x7mm, $\theta = 36.3°$, $\phi = 0°$
600-440nm SHG –> 300-220nm	Type I, 8x4x7mm, $\theta = 55.0°$, $\phi = 0°$
444-410nm SHG –> 222-205nm	Type I, 8x4x7mm, $\theta = 80.0°$, $\phi = 0°$

4. Harmonic generations of Ti:Sapphire lasers

700-1000nm SHG –> 350-500nm	Type I, 7x4x7mm, $\theta = 28°$, $\phi = 0°$
700-1000nm THG –> 240-330nm	Type I, 8x4x7mm, $\theta = 42°$, $\phi = 0°$
700-1000nm FHG –> 210-240nm	Type I, 8x4x7mm, $\theta = 66°$, $\phi = 0°$

5. Frequency doubling and tripling of Alexandrite lasers

720-775nm SHG –> 360-400nm	Type I, 6x4x7mm, $\theta = 31°$, $\phi = 0°$
720-775nm THG –> 240-265nm	Type I, 6x4x7mm, $\theta = 48°$, $\phi = 0°$

6. Intracavity SHG of Ar+ laser with Brewster-angle-cut BBO

514nm SHG –> 257nm	Type I, 4x4x7mm, $\theta = 51°$, $\phi = 0°$, B-cut
488nm SHG –> 244nm	Type I, 4x4x7mm, $\theta = 55°$, $\phi = 0°$, B-cut

Ultra-Thin BBO for Ultra-fast Laser Application

Frequency Conversion of Ultrafast Lasers

For frequency conversion of ultrafast lasers with femtosecond (fs) pulse width, the main concern is fs pulse broadening induced by group velocity mismatching (GVM) or group velocity dispersion of NLO crystal. In order to keep efficiency frequency conversion without significant pulse broadening, the suggested thickness (LGVM) of crystals is less than Pulse Width divides GVM.

Based on advanced crystal technology, AOTK is proud to provide as thin as 0.01 mm BBO crystals for frequency conversion of ultrafast lasers.

Application (Type I) BBO Crystals	SHG of 700 nm	SHG of 800 nm	SHG of 900 nm	THG of 700 nm	THG of 800 nm	THG of 900 nm
d_{eff} (pm/V)	1.296	1.365	1.408	0.893	1.101	1.221
GVM (ps/cm)	2.721	1.922	1.401	8.497	5.676	4.079
LGVM @ 10fs (micron)	40	50	70	10	20	30
Damage threshold @ 10fs (GW/cm^2)	20	25	30	10	15	20

Ultra - thin BBO Wafers

Frequency Doubling Crystal

Crystal	Clear Aperture	Thickness	Part No.
BBO	> ϕ3.5 (mm)	0.01 (mm)	BUT6211
BBO	> ϕ3.5 (mm)	0.02 (mm)	BUT6212
BBO	> ϕ3.5 (mm)	0.03 (mm)	BUT6213
BBO	> ϕ3.5 (mm)	0.05 (mm)	BUT6215
BBO	> ϕ3.5 (mm)	0.1 (mm)	BUT6210
BBO	> ϕ3.5 (mm)	0.2 (mm)	BUT6220
BBO	> ϕ3.5 (mm)	0.5 (mm)	BUT6250
BBO	> ϕ3.5 (mm)	1.0 (mm)	BUT6290

Frequency Tripling Crystal

Crystal	Clear Aperture	Thickness	Part No.
BBO	> ϕ3.5 (mm)	0.01 (mm)	BUT6311
BBO	> ϕ3.5 (mm)	0.02 (mm)	BUT6312
BBO	> ϕ3.5 (mm)	0.03 (mm)	BUT6313
BBO	> ϕ3.5 (mm)	0.05 (mm)	BUT6315

BBO	> ϕ3.5 (mm)	0.1 (mm)	BUT6310
BBO	> ϕ3.5 (mm)	0.2 (mm)	BUT6320
BBO	> ϕ3.5 (mm)	0.5 (mm)	BUT6350
BBO	> ϕ3.5 (mm)	1.0 (mm)	BUT6390

Frequency Quadrupling Crystal

Crystal	Clear Aperture	Thickness	Part No.
BBO	> ϕ3.5 (mm)	0.01 (mm)	BUT6411
BBO	> ϕ3.5 (mm)	0.02 (mm)	BUT6412
BBO	> ϕ3.5 (mm)	0.03 (mm)	BUT6413
BBO	> ϕ3.5 (mm)	0.05 (mm)	BUT6415
BBO	> ϕ3.5 (mm)	0.1 (mm)	BUT6410
BBO	> ϕ3.5 (mm)	0.2 (mm)	BUT6420
BBO	> ϕ3.5 (mm)	0.5 (mm)	BUT6450
BBO	> ϕ3.5 (mm)	1.0 (mm)	BUT6490

Mounting

Super polished or coated crystal surfaces are very easy to be damaged during transportation or handling when needed, especially for thin crystals. In order to prevent crystals from damaging or to be easily operated, AOTK provides three kinds of mount to install different dimension crystals. Custom made mounts or holders are also available. Please contact our sales for more information.

Part No.	Out Diameter (mm)	Thickness (mm)	Crystal Aperture (mm)	Crystal Length (mm)
BH101	25.4	5.0	4x4-10x10	0.1-2
BH102	25.4	9.5, 13.5	4x4-10x10	4-10
BH103	25.4	9.5	8x8-10x10	3-6

Standard Fabrication Specifications

Dimensional Tolerance	(W $\pm$ 0.1mm) x (H $\pm$ 0.1mm) x (L +0.2/-0.1 mm)
Wavefront Distortion	< λ/8 @633 nm
Angle Tolerance	$\Delta\theta < \pm 0.2°$, $\Delta\phi < \pm 0.2°$
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
Quality Warranty Period	one year under proper use

Coatings

1. Protective Coating (P-coating)

The polished surfaces of BBO are relatively easy to be fogged in humid air because of its low hygroscopic susceptibility. The protective coating (P-coating) was developed by AOTK to prevent BBO from exposure to moisture. The P-coated BBO with a mount is simpler and better than BBO with housing.

Significant advantages of P-coating show as following:

Better transmittance: Transmittance of P-coated BBO is better than that of uncoated BBO over a wide wavelength range from 200 nm-3500 nm.

High damage threshold: Over 7 GW/cm2 with laser pulse-width 30ps at 1064nm.

Long Lifetime: More than 6 months at 95% humidity and much longer at lower humidity.

2. Anti-Reflective Coatings (AR-coatings)

AOTK supplies single-band and dual-band AR-coatings for BBO at 1064 nm and 532 nm (at 800nm and 400 nm). The AR-coatings are characterized by low reflectance (less than 0.15% at 1064 nm and 0.4% at 532 nm), high damage threshold, anti-moisture and long durability. High damage threshold AR-coatings for 4HG of Nd:YAG or Nd:YLF laser are developed with R < 0.2% at 532 nm and R < 0.4% at 266 nm. AR-coatings at other wavelengths are also available upon request.

Note

- BBO has a low susceptibility to moisture. Users are advised to provide dry conditions for both use and preservation of BBO.
- BBO is soft and therefore the protection of its polished surfaces requires precautions.
- When angle adjusting is necessary, keep in mind that the acceptance angle of BBO is small.
- AOTK's engineers can select and design the best crystal for you if parameters of your laser are provided, for example, energy per pulse, pulse width and repetition rate for a pulsed laser, power for a CW laser, laser beam diameter, mode condition, divergence and wavelength tuning range, etc.
- Keep BBO crystals in a certain temperature, it will increase the damage threshold.

AOTK
AOTK, Inc. 1502, No. 694 Xianyue Rd. Xiamen 361009, P.R. China
Phone: +86-592-550 2081 Fax: +86-592-550 2082 E-mail: sales@aotk.com www.AOTK.com

KTP

Potassium Titanyl Phosphate (**$KTiOPO_4$, KTP**) is the most commonly used in both commercial and military lasers, including laboratory and medical systems, range-finders, lidars, industry systems, and optical communication.

KTP is a positive biaxial crystal, with the principal axes X, Y, and Z ($n_z>n_y>n_x$) parallel to the crystallographic axes a, b, and c, respectively.

To overcome the gray track or photorefractive breakdown problem for KTP commonly used in practices, AOTK has developed one improved technique to grow Super-KTP, which has up to 1.3-1.5 times higher gray track resistance comparing with common flux grown KTP, for high power density laser systems applications. For more information, please feel free to contact AOTK.

AOTK's KTP advanced properties

- Large nonlinear optical coefficients
- Broad temperature and spectral bandwidth
- Wide angular bandwidth and small walk-off angle
- High electro-optic coefficient and low dielectric constant
- Large figure of merit for an optical waveguide modulator
- Non-hygroscopic, chemically and mechanically stable

Typical applications of KTP

- Frequency doubling (SHG) of Nd-doped lasers for green/red output
- Frequency mixing (SFM) of Nd laser and diode laser for blue output
- Parametric sources (OPG, OPA and OPO) for 600 nm-4500 nm tunable output
- E-O modulators, optical switches, directional couplers
- Optical waveguides for integrated NLO and E-O devices

Basic Properties

1. Structural and Physical Properties

Crystal Structure	Orthorhombic, point group mm2
Lattice Parameters	a = 6.404Å, b = 10.616Å, c = 12.814Å, Z = 8
Density	3.01 g/cm^3
Mohs Hardness	≈ 5
Melting Point	~1172°C
Transition Temperature	936°C
Specific Heat	0.1643 cal/g°C
Thermal Conductivity	0.13 W/cm/°K
Electrical Conductivity	3.5×10^{-8}s/cm (c-axis, 22°C, 1KHz)
Hygroscopic Susceptibility	No
Dielectric Constant	$\varepsilon_{eff} = 13.0$, $\varepsilon_{11} = 11.6$, $\varepsilon_{22} = 11.0$, $\varepsilon_{33} = 15.4$
Color	Colorless

2. Linear Optical Properties

Transparency Region	350 - 4500 nm
Refractive Indexes at 1064 nm at 532 nm	 $n_x = 1.7377$, $n_y = 1.7453$, $n_z = 1.8297$ $n_x = 1.7780$, $n_y = 1.7886$, $n_z = 1.8887$

Sellmeier Equations (λ in μm)	$n_x^2 = 3.0065+0.03901/(\lambda^2-0.04251)-0.01327\lambda^2$ $n_y^2 = 3.0333+0.04154/(\lambda^2-0.04547)-0.01408\lambda^2$ $n_z^2 = 3.3134+0.05694/(\lambda^2-0.05658)-0.01682\lambda^2$
Therm-Optic Coefficients	$dn_x/dT = 1.1 \times 10^{-5}/°C$ $dn_y/dT = 1.3 \times 10^{-5}/°C$ $dn_z/dT = 1.6 \times 10^{-5}/°C$

3. NonLinear Optical Properties

Phase Matching SHG Wavelength	497 - 1800nm	
Nonlinear Coefficients	d_{31} = 6.5 pm/v d_{32} = 5.0 pm/v d_{33} = 13.7pm/v d_{24} = 7.6 pm/v d_{15} = 6.1 pm/v	
Effective Nonlinearity Expressions	$d_{eff}(II) \approx (d_{24} - d_{15})\sin2\phi\sin2\theta - (d_{15}\sin^2\phi + d_{24}\cos^2\phi)\sin\theta$	
For type II SHG of a Nd:YAG Laser at 1064nm	PM angle: $\theta = 90°$, $\phi = 23.5°$ Effective SHG coefficient: $d_{eff} \approx$ 8.3xd36(KDP) Angular acceptance: 20 mrad-cm Temperature acceptance: 25°C-cm Spectral acceptance: 5.6 Å -cm Walk-off angle: 4.5 mrad (0.26°)	
Electro-Optic Coefficients	Low frequency (pm/v)	High frequency (pm/v)
r_{13}	9.5	8.8
r_{23}	15.7	13.8
r_{33}	36.3	35.0
r_{51}	7.3	6.9
r_{42}	9.3	8.8
Optical Damage Threshold	> 450MW/cm², (@ 1064nm, 10ns, 10Hz)	

Main Applications

I. SHG and SFG of Nd:Lasers

KTP exhibits the superior nonlinear and electroptic properties. A combination of high nonlinear coefficient, wide transparency range, and broad angular as well as thermal acceptances makes KTP very attractive for intracavity and extracavity frequency doubler of Nd:YAG laser and other Nd-doped laser applications. The major NLO properties of KTP for frequency-doubling of Nd:YAG or Nd:YVO_4 lasers are listed as following table.

PM Angle	$\theta = 90°$, $\phi = 23.5°$; where q and f are polar angles referring to Z and X axis
Effective SHG Coefficient	$d_{eff} \approx$ 8.3xd36(KDP)
Angular Acceptance	20 mrad-cm
Temperature Acceptance	25°C-cm
Spectral Acceptance	5.6 Å -cm
Walk-off Angle	4.5 mrad (0.26°)

KTP is also being applied successfully for intracavity mixing of 808 nm diode and 1064 nm Nd:YAG laser to generate blue light and intracavity SHG of Nd:YAG or Nd:YAP lasers at 1300 nm to produce red light. With the development of diode-pumped Nd:lasers, KTP play more and more important role in the construction of the compact visible solid-state lasers. There are some typical results listed as follows:

- 20W green output was generated from CW Nd: YAG laser with intracavity KTP.
- More than 80% conversion efficiency and 700mJ green laser were obtained with a 900mJ injection-seeded Q-switch Nd:YAG laser with extracavity KTP SHG.
- 3W TEM_{00} mode-locked green laser was generated by intracavity SHG in a 5.3W mode-locked diode-pumped Nd:YAG laser.

- More than 600mW TEM_{00} green lasers are obtained from diode-pumped Nd:YAG and Nd:YVO4 lasers.
- 2.8mW green light was obtained from 50mW LD pumped intracavity Nd: YVO4 mini- lasers with a 8.5mm long cavity.
- KTP also exhibits its powerful applications for SHG and SFG laser with wavelength 1000-3400 nm.

Fig.1 shows Type II SHG phase-matching angle of KTP in X-Y plane. In X-Y plane the slope $\partial(\Delta k)/\partial\theta$ is small. It corresponds to quasi-angular noncritical phase matching, which ensures the double advantage of a small walk off and a large acceptance angle. Otherwise, in X-Z plane the slope $\partial(\Delta k)/\partial\lambda$ is almost zero for wavelengths in the range 1.5-2.5 μm and the corresponds to quasi-wavelength noncritical phase matching, which ensures a large spectral acceptance (see Fig 2). Wavelength noncritical phase matching is highly desirable for frequency conversion of short pulses. Fig.2 shows Type II SHG phase-matching angle of KTP in X-Z plane (1.1- 3.4 μm). KTP is seldom used to be phase-matched for SHG of 1.0- 3.45 μm in practices by cut in Y-Z plane, due to its very low non-linear coefficients.

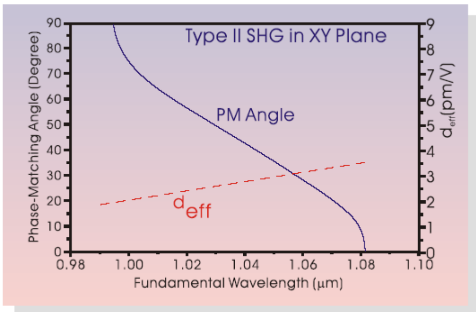


Fig. 1. Type II KTP SHG in X-Y Plane

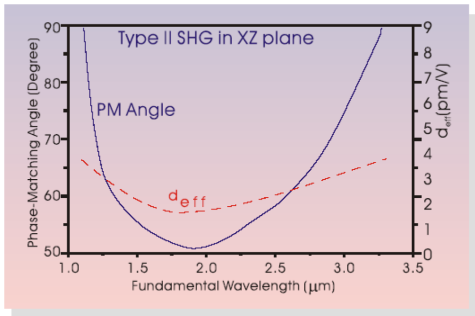


Fig. 2. Type II KTP SHG in X-Z Plane

II. OPG, OPA and OPO

As a lasing material for OPG, OPA or OPO , KTP can most usefully be pumped by the fundamental and second harmonics of a Nd:lasers, or any other source with intermediate wavelength, such as a Dye laser (near 600 nm) and Ti:Sapphire laser (near 700-1000 nm), in parametric sources for tunable output from visible (600 nm) to mid-IR (4500 nm). KTP's OPO results in stable, continuous outputs of fs pulse of 10^8 Hz repetition rate and miliwatt average power levels in both signal and idler output. KTP's OPO pumped by a 1064 nm Nd:laser has generated more than 66% conversion efficiency for degenerately converting range 1064-2120 nm. Fig.3 & Fig. 4 show KTP OPO pumped by 532 nm & 1064 nm tuning curve in XZ Plane respectively.

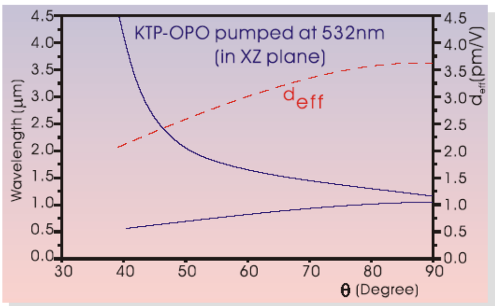


Fig.3 KTP OPO Pumped by 532 nm
Tuning Curves in X-Z Plane

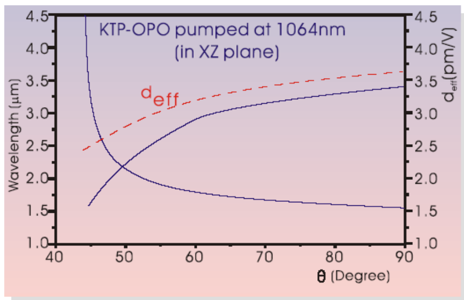


Fig.4 KTP OPO Pumped by 1064 nm
Tuning Curves in X-Z Plane

The new and effective application is the non-critical phase-matched (NCPM) KTP OPO/OPA pumped by the tunable lasers (as shown in Fig.5). The output can cover wavelength range from 1040 nm to 1450 mm (signal) and from 2150 nm to 3200 nm (idler), by fixed the NCPM KTP crystal fixed in X-axis, and tunes pumping wavelength (700 nm to 1000 nm). Due to the favorable NLO properties of NCPM KTP, as high as 45% conversion efficiency was obtained with narrow output bandwidth and good beam quality.

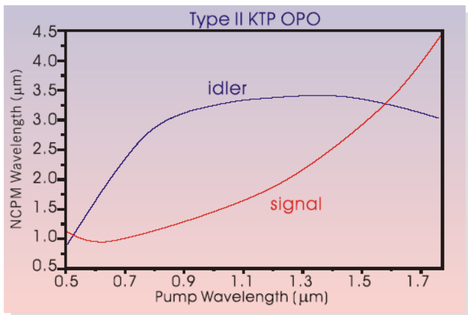


Fig.5 Type II KTP NCPM OPO

III. Quasi-Phase-Matched Waveguide

On low optical absorption and high damage threshold, the low optical loss waveguide fabricated by applying relatively simple ion-exchange process on KTP substrate, has created novel applications of integrated optics. Following table shows the comparison of KTP with other optical waveguide materials.

Recently, Type II SHG conversion efficiency of above 20%/W/cm² was obtained by balanced phase matching, in which the phase mismatch from one was balanced against a phase mismatch of opposite sign from a second section. Furthermore, segmented KTP waveguides have been applied to type I quasi-phase-matchable SHG of 760-960 nm for tunable Ti:Sapphire laser and directly doubled diode laser for 400-430 nm output. Conversion efficiency in excess of 100%/W/cm² have been obtained.
As large as 35x35x1 mm KTP with Z-cut or both surfaces polished for waveguide applications can be provided by AOTK. Other sizes of course available upon request.

Electro-Optic Waveguide Materials

Materials	$n^3\gamma/\varepsilon_{eff}$(pm/V)	g (pm/V)	ε_{eff} $(\varepsilon_{11}\varepsilon_{33})^{1/2}$	n
KTP	17.3	35	13	1.86
$KNbO_3$	9.2	25	30	2.17
$LiNbO_3$	8.3	29	37	2.20
$Ba_2NaNb_5O_{15}$	7.1	56	86	2.22
SBN(25-75)	5.1-0.14	56-1340	119-3400	2.22
GaAS	4.0	1.2	14	3.60
$BaTiO_3$	1.0	28	373	2.36

IV. E-O Devices

KTP's unique NLO features and E-O and dielectric properties make it extremely useful to various E-O devices. Table gives the comparison of KTP with those commonly used E-O modulator materials.

Electro-Optic Modulator Materials

			Phase			Amplitude		
Materials	ε	n	r pm/v	K 10^{-6}/°C	n^7r^2/ε (pm/v)²	r pm/v	K 10^{-6}/°C	n^7r^2/ε (pm/v)²
KTP	15.42	1.80	35.0	31	6130	27.0	11.7	3650
$LiNbO_3$	27.9	2.20	28.8	82	7410	20.1	42	3500
KD*P	48.0	1.47	24.0	9	178	24.0	8	178
$LiIO_3$	5.9	1.74	6.4	24	335	1.2	15	124

When these properties are combined with wide optical bandwidth (>15GHz), low loss, high damage threshold, thermal and mechanical stability, KTP can be expected to replace a considerable volume of $LiNbO_3$ crystals as E-O modulators, especially for mode-locking diode laser pumped Nd:YAG and Nd:YLF lasers as well as Ti:Sapphire and $Cr:LiSrAlF_6$ laser.

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	$\Delta\theta < \pm 0.2°$, $\Delta\phi < \pm 0.2°$
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
AR Coating	R < 0.1% @1064nm, R < 0.3% @532nm per surface
Quality Warranty Period	one year under proper use

Standard Products

Part No.	Dimension	Application	Coating	Type
KTPS203	2x2x3mm	SHG@1064nm	AR/HR coating	II
KTPS205	2x2x5mm	SHG@1064nm	DBAR coating	II
KTPS305	3x3x5mm	SHG@1064nm	DBAR-coating	II
KTPS310	3x3x10mm	SHG@1064nm	DBAR-coating	II
KTPS705	7x7x5mm	SHG@1064nm	DBAR-coating	II
KTPS805	8x8x5mm	SHG@1064nm	DBAR-coating	II
KTPS907	9x9x7mm	SHG@1064nm	DBAR-coating	II
KTPO720	7x7x20mm	OPO for 1064nm pumped, 1570nm output	AR coating	II

- DBAR Coating: AR@1064nm&532nm; HR Coating: HR@1064nm&HT@532nm; AR coatings:AR@1064nm&1570nm

AOTK, Inc. 1502, No. 694 Xianyue Rd. Xiamen 361009, P.R. China
Phone: +86-592-550 2081 Fax: +86-592-550 2082 E-mail: sales@aotk.com www.AOTK.com

$LiNbO_3$, $MgO:LiNbO_3$ and $Fe:LiNbO_3$

$LiNbO_3$ Crystal is widely used as frequency doublers for wavelength > 1μm and optical parametric oscillators (OPOs) pumped at 1064 nm as well as quasi-phase-matched (QPM) devices. Due to its large Electro-Optic (E-O) and Acousto-Optic (A-O) coefficients, $LiNbO_3$ crystal is the most commonly used material for Pockel Cells, Q-switches and phase modulators, waveguide substrate, and surface acoustic wave (SAW) wafers, etc.

I. Pure Lithium Niobate ($LiNbO_3$)

AOTK provides high quality and large size $LiNbO_3$ crystals for laser frequency doublers, OPOs and quasi-phase-matched doublers, as well as waveguide substrate and SAW wafers. High quality $LiNbO_3$ components with aperture of (2 - 15) x (2 - 15) mm^2 and length up to 50 mm for frequency doublers and optical parametric oscillators (OPOs), 50x50x1 mm^3 or Dia. 3" x 1 mm $LiNbO_3$ substrate for waveguide optics, and Dia. 3" & Dia. 4" SAW wafers are available with high volume and at low price.

Basic Properties

1. Structural and Physical Properties

Crystal Structure	Trigonal, point group 3m
Lattice Parameters	a = 5.148Å, c = 13.863Å
Density	4.64 g/cm^3
Mohs Hardness	5
Melting Point	1250°C
Curie Point	1160°C
Thermal Expansion Coefficient	$\alpha_1=\alpha_2=2\times10^{-6}/°C$, $\alpha_3 = 2.2\times10^{-6}/°C$ at 25°C
Thermal Conductivity	38 W/m/K at 25°C
Elastic Stiffness Constant	$C^E_{11} = 2.04 \times 10^{11} N/m^2$, $C^E_{33} = 2.46 \times 10^{11} N/m^2$
Piezoelectric Strain Constant	$d_{22} = 2.04 \times 10^{-11}$ C/N, $d_{33} = 19.22 \times 10^{-11}$ C/N
Dielectric Constant	$\varepsilon_{11}/\varepsilon_0 = 85$, $\varepsilon_{33}/\varepsilon_0 = 29.5$
Absorption Coefficient	~ 0.1%/cm @1064 nm

2. Linear Optical Properties

Transparency Region	420-5200nm
Refractive Indexes at 1300 nm at 1064 nm at 632.8 nm	 $n_e = 2.146$, $n_o = 2.220$ $n_e = 2.156$, $n_o = 2.320$ $n_e = 2.203$, $n_o = 2.286$
Sellmeier Equations (λ in μm)	$n_o^2 = 4.9048+0.11768/(\lambda^2-0.0475)-0.027169\lambda^2$ $n_e^2 = 4.5820+0.099169/(\lambda^2-0.04443)-0.02195\lambda^2$
Optical Homogeneity	~ 5×10^{-5}/cm

3. NonLinear Optical Properties

NLO Coefficients	$d_{33} = 34.4$ pm/v $d_{31} = d_{15} = 5.95$ pm/v $d_{22} = 3.07$ pm/v

Effective NLO Coefficients	d_{eff} = 5.7 pm/V or ~14.6 x d_{36} (KDP) for frequency doubling 1300 nm d_{eff} = 5.3 pm/V or ~13.6 x d_{36} (KDP) for OPO pumped at 1064 nm d_{eff} = 17.6 pm/V or ~45.0 x d_{36} (KDP) for quasi-phase-matched structure
Electro-Optic Coefficients	γ^T_{33} = 32 pm/V, γ^S_{33} = 31 pm/V γ^T_{31} = 10 pm/V, γ^S_{31} = 8.6 pm/V γ^T_{22} = 6.8 pm/V, γ^S_{22} = 3.4 pm/V
Half-Wave Voltage, DC Electrical field || z, light ⊥ z: Electrical field || x or y, light || z:	 3.03 KV 4.02 KV
Optical Damage Threshold	> 200MW/cm² (@ 1064nm, 10ns, 10Hz)

Main Applications

I. Applications for Q-switch Elements

$LiNbO_3$ is extensively used as electro-optic modulator and Q-switch for Nd:YAG, Nd:YLF and Ti:Sapphire lasers as well as modulator for fiber optics, etc. The transverse modulation is mostly employed for $LiNbO_3$. If a $LiNbO_3$ crystal is used as Q-switch crystal, the light propagates in Z-axis and electric field applies to X-axis, the refractive retardation will be $\Gamma = \pi L n_o^3 \gamma_{22} V/\lambda d$. MgO:$LiNbO_3$ and ZnO: $LiNbO_3$ crystals have similar electro-optic properties to $LiNbO_3$ but with higher damage threshold. The specifications of $LiNbO_3$ Q-Switch Elements listed as the following table:

Standard Specifications

Standard Dimension	9x9x25 or 10x10x20mm³
Dimensional Tolerance	(W ± 0.1mm) x (H ± 0.1mm) x (L +0.2/-0.1 mm)
Wavefront Distortion	< λ/4 @633 nm
Angle Tolerance	Δθ < ± 0.2°, Δφ < ± 0.2°
Flatness	λ/8 @633 nm
Surface Quality	10/5 Scratch/Dig per MIL-O-13830A
Parallelism	< 20 arc seconds
Perpendicularity	< 5 arc minutes
Clear Aperture	> 90% central area
AR Coating	R < 0.2% @1064nm per surface
Electrodes	Au or Cr electrode on both X-surfaces
Quality Warranty Period	one year under proper use

II. Surface Acoustic Wave (SAW) Devices

$LiNbO_3$ crystal is widely applied as an excellent acousto-optic material for surface acoustic wave (SAW) devices (such as filters, oscillators and resonators) and ultrasonic transducer due to its high electro-mechanical coupling factor, low acoustic transmission loss, stable physical and chemical properties.

AOTK supplies large quantities of $LiNbO_3$ boules, as-cut or finished φ3" and φ4" wafers available up to 20,000 pieces per month with good quality and very low price.

Typical Applications of Piezoelectronic $LiNbO_3$

- Surface Acoustic Wave (SAW) Device
- Bulk Acoustic Wave (BAW) Device
- Leaky Surface Acoustic Wave (LBAW) Device
- Piezoelectric Transducer (PET)
- Piezoelectric Sensor (PES)

Typical Properties of Piezoelectric $LiNbO_3$

Orientation	127.86° Y-cut	Y-cut
SAW Velocity	3970 m/s	3485 m/s
Electromechanical Coupling Factor	K_s^2 = 5.5%	K_s^2 = 4.3%
Temperature Coefficients of Delay (TCD)	78 x 10^{-6}/°C	95 x 10^{-6}/°C
Temperature Coefficients of Velocity (TCV)	-60 x 10^{-6}/°C	-80 x 10^{-6}/°C

Specifications of $LiNbO_3$ SAW Wafer

Type Specifications	Boule		Wafer	
Diameter	Φ3"	Φ4"	Φ3"	Φ4"
Length or Thickness (mm)	⩽100	⩽50	0.35-1.0	
Orientation	127.86°Y, 64°Y, 135°Y, X, Y, Z, and other cut			
Ref. Flat Orientation	X, Y			
Ref. Flat Length	22±2mm	32±2mm	22±2mm	32±2mm
Front Side Polishing			Mirror polished 5-15 Å	
Back Side Lapping			0.3-1.0 μm	
Flatness (μm)			< 15	
Bow (μm)			< 25	

Note:

I. Other dimension is also available upon request.

II. Wafers are packaged in plastic containers (25 pieces wafers each).

III. Waveguide Substrates

$LiNbO_3$ crystal is the mostly used inorganic substrate for electro-optic waveguide applications.

Specifications of $LiNbO_3$ Waveguide Substrates

Standard Dimension	1) 50x50x1 mm^3 for X-cut, Y-cut, or Z-cut 2) ϕ3"x1 mm^3 for Y-cut or Z-cut 3) Other dimension is available upon request
Orientation Tolerance	< 10'
Surfaces Finish	One surface polished to better than λ/2 (with mount) and free from surface defects when observed by a 50X microscope, the other face fine ground

II. Magnesium Oxide Doped Lithium Niobate ($MgO:LiNbO_3$)

$MgO:LiNbO_3$ crystal is widely used for high power frequency doubling (SHG), mixing (SFG) and optical parameter oscillator(OPO). $MgO:LiNbO_3$ has similar effective nonlinear coefficients as pure $LiNbO_3$. But it has the advantages such as high damage threshold (over 300MW/cm^2 @ 1064 nm, 12ns), noncritical phase matching (NCPM) at room temperature, excellent E-O and NLO properties, good mechanical and chemical properties compared with pure $LiNbO_3$.

Its Sellmeier equations (7 mol% MgO doping) are:

$$n_o^2 = 4.8762+0.115540/(\lambda^2-0.04674)-0.033119\lambda^2 \ (\lambda \text{ in } \mu m)$$

$$n_e^2 = 4.5469+0.094779/(\lambda^2-0.04439)-0.026721\lambda^2$$

Over 45% and 60% of SHG efficient are obtained in pulsed and cw Nd:YAG lasers respectively, by angle tuned phase matchable SHG of Nd:YAG laser (1064 nm) and NCPM SHG of laser lasers (1053 nm) of $MgO:LiNbO_3$ at room temperature. $MgO:LiNbO_3$ is also a good crystal for high power quasi-phase-matched waveguide structure for doubler, optical parametric oscillator (OPO) and amplifier (OPA).

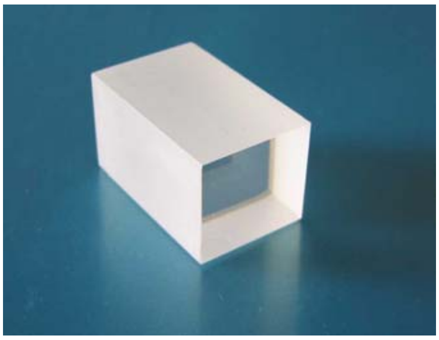
AOTK supplies the typical sizes of $MgO:LiNbO_3$ crystals - 5x5x(20-30) mm^3 for OPO and frequency doubler, (20-25)x(20-25)x1 mm^3 for waveguide substrates. Other sizes and AR or HR-coatings are available upon request.

III. Iron Doped Lithium Niobate ($Fe:LiNbO_3$)

$Fe:LiNbO_3$ is a excellent photorefractive crystal with high electro-optic coefficients, high photorefractive sensitivity and diffraction efficiency without applied electric field. Therefore, $Fe:LiNbO_3$ crystal will find the suitable applications in phase conjugation and holographic recording. High quality $Fe:LiNbO_3$ crystal, with size as large as ϕ3" and iron doped concentrations from 0.01 to 0.1 atm%, could be supplied by AOTK. Some special fabrications are also available to meet customers' requirements.

AOTK, Inc. 1502, No. 694 Xianyue Rd. Xiamen 361009, P.R. China
Phone: +86-592-550 2081 Fax: +86-592-550 2082 E-mail: sales@aotk.com www.AOTK.com

KDP & KD*P



Potassium Dihydrogen Phosphate (**KDP**) and Potassium Dideuterium Phosphate (**KD*P** or **DKDP**) Potassium Dihydrogen Phosphate (KDP) and Potassium Dideuterium Phosphate (KD*P) are among the most widely-used commercial NLO materials, characterized by good UV transmission, high damage threshold, and high birefringence, though their NLO coefficients are relatively low. They are usually used for doubling, tripling and quadrupling of a Nd:YAG laser at the room temperature. In addition, they are also excellent electro-optic crystals with high electro-optic coefficients, widely used as electro-optical modulators, such as Q-switches, Pockels Cells, etc.

AOTK supplies high quality KDP and KD*P crystals in large quantities for these applications. Because their polished surfaces are easier to be moistened, however, the user is advised to provide a dry condition (<50%) and the sealed housing for preservation. For this purpose, AOTK also provides polishing and sealed housing services for the KDP family crystals. Our engineers will serve you to select and design the best crystal, according to the laser parameters you provide.

Applications

- Second, third, and fourth harmonic generation of Nd:lasers
- Frequency doubling of dyer laser
- High power laser frequency conversion materials
- Shutter for high speed photography
- Electro-optical modulator and Q switches

Basic Properties

Structural and Physical Properties

	KDP	KD*P (DKDP)
Chemical Formula	KH_2PO_4	KD_2PO_4
Crystal Structure	Tetragonal	Tetragonal
Transmission Range	200-1500nm	200-1600nm
Nonlinear Coefficients	d_{36}=0.44pm/V	d_{36}=0.40pm/V
Refractive Indexes (at 1064nm)	n_o = 1.4938 n_e = 1.4599	n_o = 1.4948 n_e = 1.4554
Electro-Optical Coefficients	r_{41}=8.8pm/V r_{63}=10.3pm/V	r_{41}=8.8pm/V r_{63}=25pm/V
Longitudinal Half-Wave Voltage	V_p=7.65KV (λ=546nm)	V_p=2.98KV (λ=546nm)
Absorption	0.07/cm	0.006/cm
Temperature Synchronism Width	11.5 °C*cm	7.4 °C*cm
Spectral Synchronism Width	106 Å*cm	32 Å*cm
Angle Synchronism Width	0.84 mrad*cm	0.94 mrad*cm
Absorption Coefficient, cm^{-1}	0.07	0.006

Sellmeier Equations

KDP	$n_o^2 = 2.259276 + 0.01008956/(\lambda^2 - 0.012942625) + 13.005522\lambda^2/(\lambda^2 - 400)$ $n_e^2 = 2.132668 + 0.008637494/(\lambda^2 - 0.012281043) + 3.2279924\lambda^2/(\lambda^2 - 400)$
KD*P	$n_o^2 = 1.9575544 + 0.2901391/(\lambda^2 - 0.0281399) - 0.02824391\lambda^2 + 0.004977826\lambda^4$ $n_e^2 = 1.5005779 + 0.6276034/(\lambda^2 - 0.0131558) - 0.01054063\lambda^2 + 0.002243821\lambda^4$

Specifications

Dimensional Tolerance	(W ± 0.1mm) x (H ± 0.1mm) x (L +0.2/-0.1 mm)
Angle Tolerance	$\Delta\theta < \pm 0.2°$, $\Delta\phi < \pm 0.2°$
Flatness	$\lambda/8$ @633 nm
Surface Quality	10/5 Scratch/Dig per MIL-O-13830A
Parallelism	< 20 arc seconds
Perpendicularity	< 5 arc minutes
Clear Aperture	> 90% central area
Quality Warranty Period	one year under proper use
Dimensional Tolerance	(W ± 0.1mm) x (H ± 0.1mm) x (L +0.2/-0.1 mm)

Note

- KDP and KD*P is highly hygroscopic and the coating can Not be available.
  Please keep it in a dry environment, and sealed housing is recommended.

- The $LiIO_3$ crystals is available too.

AOTK

AOTK, Inc. 1502, No. 694 Xianyue Rd. Xiamen 361009, P.R. China
Phone: +86-592-550 2081 Fax: +86-592-550 2082 E-mail: sales@aotk.com www.AOTK.com

We provide specially design precision crystal oven and temperature controller to install, heat and stabilize crystal to a certain temperature. In response to the demand of precision crystal oven and temperature controller,and the trend of miniaturization of optical devices, AOTK now introduces our second generation of crystal oven and temperature controller.

Precision Crystal Oven Specifications

Size	ϕ50×55mm
Host Crystal Size	up to 5×5×35mm
Temperature Range	Room Temperature to 160°C
Accuracy	0.1°C
Weight	300g
Power Consumption	20W/110VAC
Connector	4-pin audio plug
Cable	4 lines cable about 1 meter

Temperature Controller Specifications

The temperature controller is microprocessor controlled, and has dual line 4 digits LED display (set point and real temperature). It is very easy to operate, and accepts both 110VAC power sources.

Physical Size	120(L)×48(W)×96(H)mm
Temperature Range	Room Temperature to 165°C
Warm-up Time	60 minutes
Resolution	0.1°C
Stability	better than ±0.1°C
Dissipation Power	< 25W
Power Consumption	< 5VA
Environment Temperature	-10°C to +55°C
Weight	400g
Set point range	Selectable

- **Slow heating rate is suggested for LBO crystal, in order to prevent coating crack due to its inhomogeneous expansion.**

Applications

- LBO NCPM SHG of Nd:YAG/YLF/YVO_4 Lasers
- LBO NCPM OPO Pumped by SHG of Nd:YAG/YLF/YVO_4 or Ti:Sapphire Lasers
- $KNbO_3$ NCPM SHG of 860-940nm (a-cut); SHG 990-1070nm (b-cut)
- $LiNbO_3$ NCPM SHG of YAG/YLF/YVO_4
- Increase damage threshold of KTP, $LiNbO_3$ and BBO crystals
- Stabilized high power SHG, THG, 4HG and 5HG of Nd:YVO_4

Application Notes

One of the major application of temperature controlling in nonlinear optical conversion is to use the Non-Critical Phase-Matching (NCPM) for some non-linear optical crystals, e.g. LBO and $KNbO_3$. NCPM is preferred because it could generate superior beam quality and efficiency. It has very large acceptance angle and zero walk-off which are very important for doubling tightly focused laser beam or laser beams with large divergence.

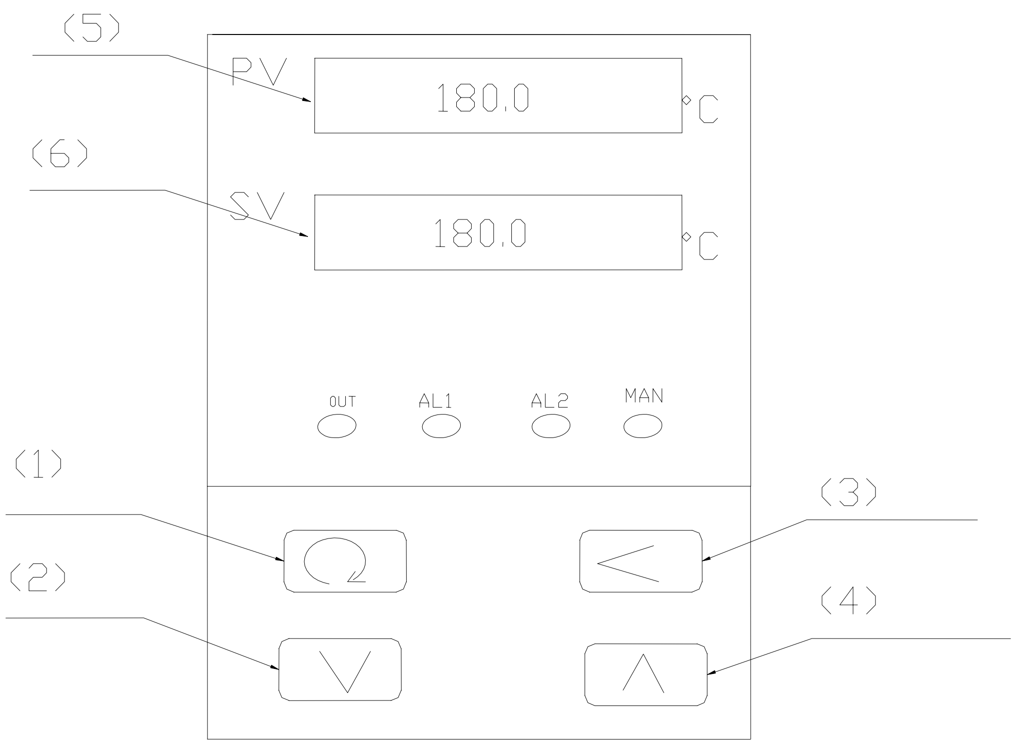
NCPM Applications

Crystal	NLO Applications	Temperature
LBO	SHG (I) 1064nm,1053nm,1047nm SHG (II) 1320nm	148°C - 170°C 40°C
$KNbO_3$ (a-cut)	SHG 860-940nm	20°C - 180°C
$LiNbO_3$	SHG 1064nm	120°C
KD*P	SHG 532nm	52.1°C
ADP	SHG 532nm	51.2°C

Installation of Crystals

1. Clean the end surfaces of crystal.
2. Make the oven in horizontal.
3. Put the crystal into the square hole of the core oven slowly.

Temperature Controller Manual



Function of buttons

(1) Display conversion (and the parameter set)
(2) Data reduces button
(3) Data moves button
(4) Data increases button
(5) Measured value LED dispay window
(6) Set value LED display window

Operation

1. Turn on power, the measured value shown on the upper LED display window (PV), the set value shown on the underside LED display window.
2. Set temperature, press down (1) button about 3 seconds, then press (3) button to make selection parameter, to change the value by press (2) or (4) button.

3. Set other parameters, press down (1) button about 3 press about 3 seconds, to set the related parameter.

(a). HIAL (The upper limit value to bell): The annunciator will bell when the measured value is higher in the HIAL. When the measured value is lower in the HIAL-DF, the annunciator will stop. Establishing the HIAL tacit approval is 165 degree.

(b). DF (Return to differ): Return bad used for avoiding trapping diagraph importation value to undulate but cause a type regulate a multifarious to break or annunciator. Suppose the initial value SV as 150 degree, the DF parameter establishes to 0.5 degree, then: When measure temperature value higher in or be equal to 150 degree, the OUT breaks after the electric appliances pass, stopping heating. While stopping heating, while measuring a temperature value less than 149.5 degree (SV-DF), just re- connecting to carry on heating then.

(c). LOC (parameter modification Class)

LOC=0, allow modification parameter and set a value.

LOC=1, allow show to look into parameter, disallow a modification, but allow set a value.

LOC=2, allow show to look into parameter, disallow a modification, also disallow set a value.

LOC=808, have a power out, again to turn on power, it can be recover the initializtion parameter set by the factory.

4. Generally, set the vale of HIAL and DF, then set the LOC to 1. While using the value which need to adjust SV value. Heating the process (30~160 degree) about 18 minutes, reducing the heat process about 14 minutes.

Ordering Information

- Crystal Oven (Specify the exact crystal size to be hosted, 110VAC)
- Temperature Controller (Auto detect 110VAC)