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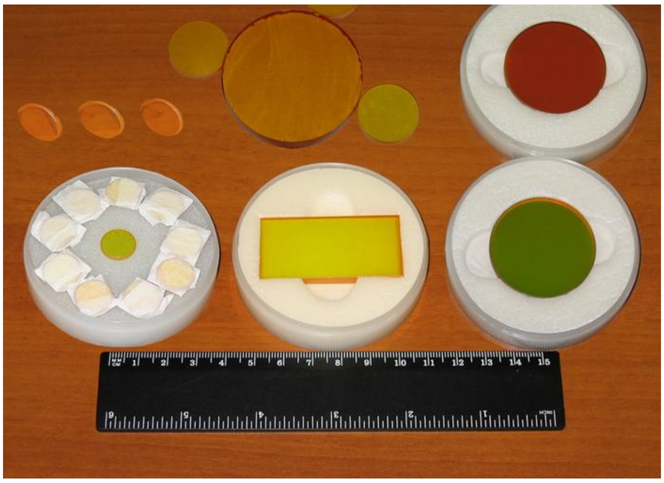
CVD ZnSe (CVD Zinc Selenide) - Main Properties

Zinc selenide is a clear yellow polycrystalline material with a grain size of approximately 70µm, transmitting in the range 0.5-15µm. It is essentially free of extrinsic impurity absorptions, providing extremely low bulk losses from scatter. Zinc Selenide, produced by the method of chemical vapour deposition, is the preferred material for optics used in high power CO_2 laser systems due to its low absorption at 10.6µm. However it is also a popular choice in systems operating at various bands within its wide transmission range. ZnSe has a high resistance to thermal shock making it the best material for high power CO_2 laser systems. ZnSe however is only 2/3 the hardness of ZnS multi-specral grade but the harder anti-reflectance coatings do serve to protect ZnSe. Zinc Selenide is a relatively soft material and scratches rather easily. It requires an anti-reflection coating due to its high refractive index if high transmission is required. ZnSe has a rather low dispersion across its useful transmission range. For high power applications, it is critical that the material bulk absorption and internal defect structure be carefully controlled, that minimum-damage polishing technology be employed, and the highest quality optical thin film coatings are used.



Optical Properties

Bulk Absorption Coefficient @ 10.6µm	0.0005/cm
Temp. Change of Refractive Index @ 10.6µm	61×10^{-6}/°C
Refractive Index Non-homogeneity @ 632.8nm	$<6 \times 10^{-6}$

Thermal Properties

Thermal Conductivity	0.18W/cm/°C
Specific Heat	0.356J/g/°C
Linear Expansion Coefficient @ 20°C	7.57×10^{-6}/°C

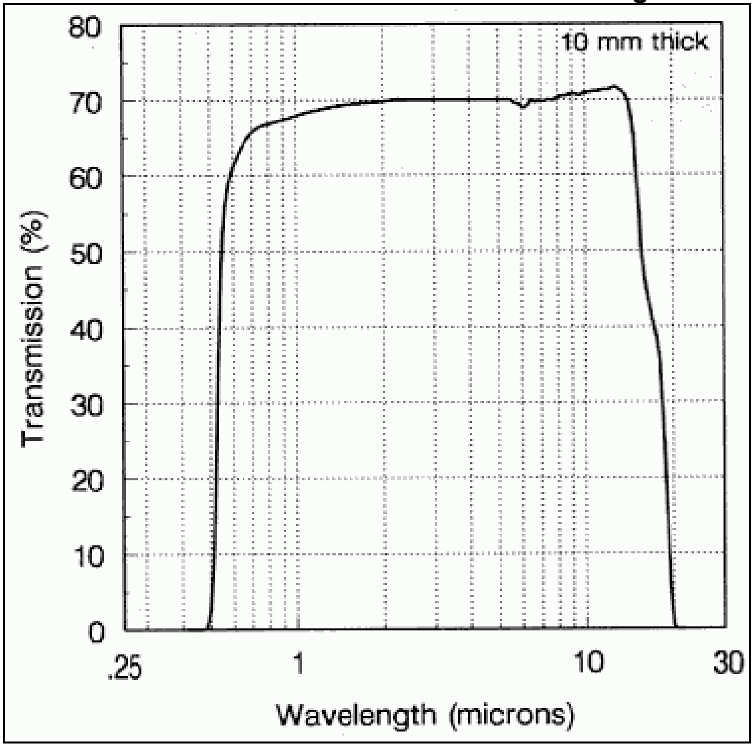
Mechanical Properties

Young's Modulus	6.85×10^{11} dyne/cm2
Rupture Modulus	5.7×10^{8} dyne/cm2
Knoop Hardness	110-130Kg/mm^2
Density	5.27g/cm^3
Poisson's Ratio	0.28

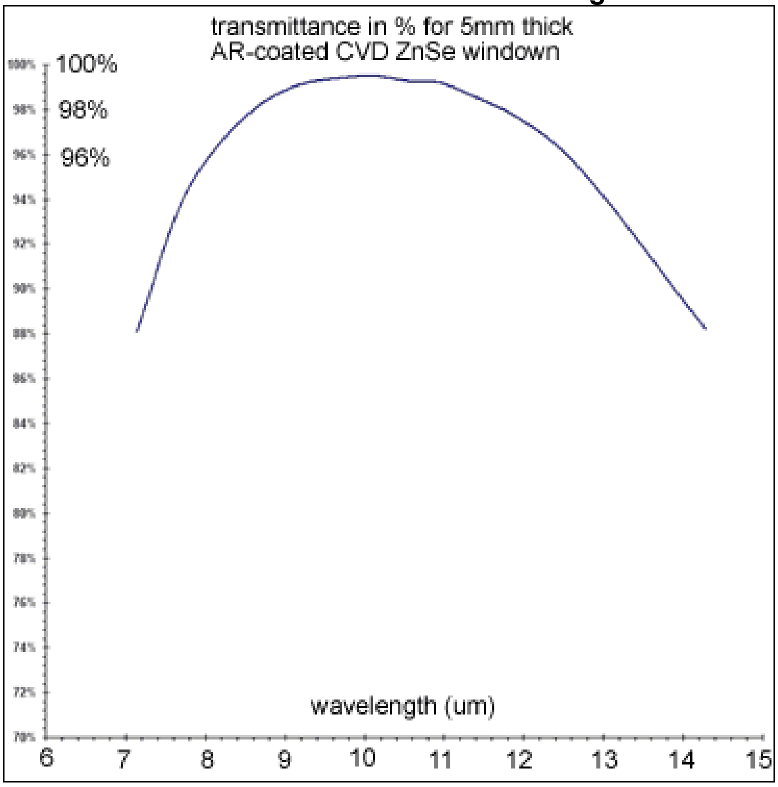
Refractive Index of CVD ZnSe:

Wavelength (µm)	Index	Wavelength (µm)	Index	Wavelength (µm)	Index	Wavelength (µm)	Index
0,54	2,68	1,8	2,45	7,4	2,42	13.0	2,39
0,58	2,63	2,2	2,44	7,8	2,42	13,4	2,38
0,62	2,60	2,6	2,44	8,2	2,42	13,8	2,38
0,66	2,58	3.0	2,44	8,6	2,41	14,2	2,37
0,70	2,56	3,4	2,44	9.0	2,41	14,6	2,37
0,74	2,54	3,8	2,43	9,40	2,41	15.0	2,37
0,78	2,53	4,2	2,43	9,80	2,41	15,4	2,36
0,82	2,52	4,6	2,43	10,2	2,41	15,8	2,36
0,86	2,51	5.0	2,43	10,6	2,40	16,2	2,35
0,90	2,50	5,4	2,43	11.0	2,40	16,6	2,35
0,94	2,50	5,8	2,43	11,4	2,40	17.0	2,34
0,98	2,49	6,2	2,43	11,8	2,39	17,4	2,34
1.0	2,49	6,6	2,42	12,2	2,39	17,8	2,33
1,4	2,46	7.0	2,42	12,6	2,39	18,2	2,33

Zinc Serenade Transmission without AR-caoting



Zinc Serenade Transmission with AR-coating at 10.6um



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Nd:YAG Rods

Capabilities:

- Rod size: 2 - 12mm in diameter and 1 - 180mm in length;
- Nd dopant concentration : 0.6% - 1.3%;
- Polishing;
- AR-coating or/and dichroic coating;

Nd:YAG Crystal

During the last decade, Nd:YVO4 has been developed as a promising substitutes for Nd:YAG in diode-pumped lasers due to its high absorption and emission cross-sections. However, the applications of Nd:YVO4 are limited due to its poor physical-mechanical properties and growth difficulty etc. Now, we have developed the high-doped Nd:YAG (SUPER-Nd:YAG) recently. It shows high absorption cross-section and have many advantages over Nd:YVO4:

- Due to the cubic symmetry and high quality, Nd:YAG is easy to operate with TEM_{00} mode
- Nd:YAG can be Q-switched with Cr4+:YAG directly
- Nd:YAG can produce blue laser with the frequency-doubling of 946nm
- Nd:YAG can be operated in a very high power laser up to kW level

The high neodymium-ion doped YAG has been grown by the novel technique-Temperature Gradient Technique(TGT). The Nd concentration can be doped up to 3%. As large as ϕ100x80mm bulk crystals with excellent optical homogeneity, less scattering particles, low dislocation density have been obtained.

Basic Properties:

Chemical Formula:	$Y_3Al_5O_{12}$
Crystal structure:	Cubic
Lattice constant:	12.01Angstrom
Melting point:	1970° C
Density:	4.5g/cm^3
Reflective Index:	1.82
Thermal Expansion Coefficient:	7.8x10^{-6} /K <111>
Thermal Conductivity (W/m/K):	14W/m/K, 20° C 10.5W/m/K, 100° C
Mohs hardness:	8.5
Stimulated Emission Cross Section:	2.8x10^{-19} cm^{-2}
Relaxation Time of Terminal Lasing Level:	30 ns
Radiative Lifetime:	550 μs
Spontaneous Fluorescence:	230 μs
Linewidth:	0.6 nm
Loss Coefficient:	0.003 cm^{-1} @ 1064nm

Laser Properties:

- SUPER-Nd:YAG shows high absorption coefficients at pumping wavelengths. Therefore, a crystal short-in length (e.g.1mm) is preferred and compact microchip lasers can be constructed by using SUPER-Nd:YAG.
- Due to the broader and smoothly-varied bandwidth of absorption, it allows of less stringent requirements of temperature control.
- Almost same output have been achieved both in a (111)-cut 1mm long Nd:YAG and an a-cut 1mm long YVO4 microchip lasers with a very short (9mm) laser cavity.

Spectra properties with concentration:

Nd:Dopant	2.5%	2%	1.5%	1.3%	1.1%	1%

Fluorescence lifetime	160µs	180µs	200µs	210µs	220µs	240µs
Absorption coefficient	7.55cm^{-1}	6.57 cm^{-1}	5.36 cm^{-1}	4.66 cm^{-1}	3.88 cm^{-1}	3.55 cm^{-1}

Optical Quality/Grades/Nd Level									
Rod Size		Standard Grade		Premium Grade		Standard [Nd]: 1.1 Atom%		Low [Nd]: 0.8 Atom%	
L	D	Extinct. Ratio	Wave Error	Extinct. Ratio	Wave Error	Tolerance of [Nd] Over Rod Length		Tolerance of [Nd] Over Rod Length	
mm	mm	(dB)	(waves)	(dB)	(waves)	Average [Nd]	delta [Nd]	Average [Nd]	delta [Nd]
50	3	>25	<0.19	>30	<0.13	±.08	0.06	±.07	0.05
50	4		<0.21		<0.15				
50	5		<0.24		<0.16				
100	4	>22	<0.28	>27	<0.18	±.08	0.13	±.06	0.09
100	5		<0.32		<0.21				
100	6		<0.36		<0.23				
100	6.35		<0.37		<0.24				
150	6.35	>20	<0.48	>25	<0.30	±.05	0.18	±.04	0.13
150	8		<0.58		<0.35				
150	9.52		<0.67		<0.40				
200	8	>19	<0.71	>24	<0.42	±.02	0.23	±.02	0.17
200	9.53		<0.82		<0.49				
200	10		<0.86		<0.51				

Coatings			
Type	Reflectivity (%R per Surface)	Damage Threshold (<20nS Pulse, GW/cm^2)	Damage Threshold (CW, kW/cm^2)
AR @1064nm	<0.15	>1.4	>25
HR @1064nm	>99.9	>1.0	>25

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Nd:YVO4 Crystal

Nd:YVO4 is the most efficient laser crystal for diode-pumped solid-state lasers. Its good physical, optical and mechanical properties make Nd:YVO4 an excellent crystal for high power, stable and cost-effective diode-pumped solid-state lasers. Compared with Nd:YAG for diode laser pumping, Nd:YVO4 lasers possess:

- Lower lasing threshold and higher slope efficiency
- Large stimulated emission cross-section at lasing wavelength
- High absorption over a wide pumping wavelength bandwidth
- Low dependency on pumping wavelength and tend to single mode output
- Optically uniaxial and large birefringence emit strongly-polarized laser

We provide high quality and large size Nd:YVO4 and pure YVO4 crystal as large as ϕ35x50mm^3 bulk crystal and ϕ20x20mm^3 finished crystal at a very competitive price.

Basic Properties:

Atomic Density:	1.26x10^{20} atoms/cm^3 (Nd 1.0%)
Crystal Structure:	Zircon Tetragonal, space group D_{4h}-I4/amd a=b=7.1193 Angstrom, c=6.2892 Angstrom
Density:	4.22g/cm^3
Mohs Hardness:	4-5 (Glass-like)
Thermal Expansion Coefficient (300K):	a_a=4.43x10^{-6}/K; a_c=11.37x10^{-6}/K
Thermal Conductivity Coefficient (300K):	//C: 0.0523W/cm/K; $\perp$ C: 0.0510W/cm/K

Optical Properties:

Lasing wavelength:	1064nm, 1342nm
Thermal optical coefficient (300K):	dn_o/dT=8.5x10^{-6}/K, dn_e/dT=2.9x10^{-6}/K
Stimulated emission cross-section:	25x10^{-19}cm^2 @1064nm
Fluorescent lifetime:	90μs
Absorption coefficient:	31.4cm^{-1} @810nm
Intrinsic loss:	0.02cm^{-1} @1064nm
Gain bandwidth:	0.96nm @1064nm
Polarized laser emission:	π polarization; parallel to optic axis(c-axis)
Diode pumped optical to optical efficiency:	>60%

Laser Properties:

The Nd:YVO4 crystal has large stimulated emission cross-sections at both 1064nm and 1342nm. The stimulated emission cross-section of an a-axis cut Nd:YVO4 crystal at 1064nm is about 4 times higher than that of the Nd:YAG crystal. Although the lifetime of Nd:YVO4 is about 2.7 times shorter than that of Nd:YAG. Because of its high pump quantum efficiency, the slope efficiency of Nd:YVO4 can be very high if the laser cavity is properly designed.

Nd:YVO4 Specifications:

Transmitting wavefront distortion	less than λ/4 @ 633 nm
Dimension tolerance	(W ± 0.1 mm) x (H ± 0.1 mm) x (L + 0.2 mm/-0.1)
Clear aperture	>90% central area
Flatness	λ/8@633nm, & λ/4@633nm for thickness less than 2mm
Scratch/Dig code	10/5 to MIL-O-13830A
Parallelism	better than 20 arc seconds
Perpendicularity	5 arc minutes
Angle tolerance	< ± 0.5°
AR coating	R<0.2% at 1064nm, HR coating R>99.8% at 1064nm, T>95% at 808nm
Quality warranty period	one year under proper use.

Er:YAG

Erbium doped Yttrium Aluminum Garnet ($Er:Y_3Al_5O_{12}$ or Er:YAG) combine various output wavelength with the superior thermal and optical properties of YAG. It is an excellent laser crystal which lasers at 2.94μm. This wavelength is the most readily absorbed into water and hydroxylapatite of all existing wavelengths and is considered a highly surface cutting laser. It is a well known material for medical applications.

Material Properties of Er:YAG crystal

Chemical formula	$Er^{3+}:Y_3Al_5O_{12}$
Crystal structure	cubic
Melting point:	1970 °C
Density, g/cm^3	5,35
Mohs hardness	8.5
Thermal expansion coefficient	9,5 x 10-6 K-1 (a axis) 4,3 x 10-6 K-1 (b axis) 10,8 x 10-6 K-1 (c axis)
Thermal conductivity at 25°C	0.12 W x cm^{-1} x $°K^{-1}$
Loss coefficient at 1064 nm	0.003 cm^{-1}

Laser Properties

Laser Transition	$^4I_{11/2}$ to $^4I_{13/2}$
Laser Wavelength	2940nm
Fluorescence Lifetime	90 m s
Photon Energy	6.75×10^{-20}J(@2940nm)
Emission Cross Section	$3\times10^{-20}cm^2$
Index of Refraction	1.79 @2940nm
Pump Bands	600~800 nm

Standard specifications

Dopant concentration, at.%	Up to 50
Orientation:	<111>within 5°
Flatness	< λ/10 measured at 633 nm
Parallelism	≤ 30"
Perpendicularity	≤ 5 ′
Surface Quality	10-5 per scratch-dig MIL-O-13830A
Optical Quality:	Interference fringes ≤ 0.125 λ /inch(@1064nm)
Extinction ration	≥ 25dB
Size:	Rods:Φ (3-10)mm ×(30-180)mm
Slabs:	(3-12)mm ×(6-24)mm ×(60-180)mm
Dimensional tolerances	Diameter:+0.000"/-0.05", Length: ± 0.05" Chamfer: 0.07+0.005/-0.00" at 45°
AR Coating Reflectivity	≤ 0.2% (@2940nm)

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(Nd, Ce):YAG

Nd:Ce:YAG is an excellent laser material used for no-water cooling and miniature laser systems. the (Nd,Ce): YAG laser rod we produce has the characteristics of high efficiency(laser efficiency than Nd: YAG high about 30-50%), low threshold, anti-violet radiation and high repetition frequency for lasers operation. It has achieved the international advanced level .it is the most ideal laser material for the high repetition air cooling lasers. It suitable for different modes of operation (cw, pulsed , Q-switched, mode locked, doubling of frequency) and high-average power lasers

Physical and Chemical Properties

Chemical formula	$Nd^{3+}:Ce^{3+}:Y_3Al_5O_{12}$
Crystal Structure	Cubic
Lattice Parameters	12.01A
Melting Point	1970 ℃
Moh Hardness	8.5
Density	4.56±0.04g/cm^3
Specific Heat (0-20)	0.59J/g.cm^3
Modulus of Elasticity	310GPa
Young's Modulus	3.17×104Kg/mm^2
Poisson Ratio	0.3(est.)
Tensile Strength	0.13~0.26GPa
Thermal Expansion Coefficient	[100]:8.2 × 10^{-6}/ ℃ [110]:7.7 × 10^{-6}/ ℃ [111]:7.8 × 10^{-6}/ ℃
Thermal Conductivity	14W/m/K(@25 ℃)
Thermal Optical Coefficient (dn/dT)	7.3×10^{-6}/ ℃
Thermal Shock Resistance	790W/m

Laser Properties

Laser Transition	$^4F_{3/2} \to {}^4I_{11/2}$
Laser Wavelength	1.064µm
Photon Energy	1.86×10^{-19}J@1.064µm
Emission Linewidth	4.5A @1.064µm
Emission Cross Section	2.7~8.8×10^{-19}cm^{-2}
Fluorescence Lifetime	230µs
Index of Refraction	1.8197@1064nm

Standard Specifications

Dopant concentration, at.%	0.1-2.5%
orientation:	<111>within 5°
Flatness	< λ/10
Parallelism	≤ 10"
Perpendicularity	≤ 5 ′
Surface quality	10-5 per scratch-dig MIL-O-13830A
Optical Quality:	Interference fringes ≤ 0. 25λ /inch Extinction ration ≥ 30dB
Size:	Diameter:3～8mm; Length:40～80mm(Upon request of customer)
Dimensional tolerances	Diameter+0.000"/-0.05"; Length ±0.5"; Chamfer: 0.07+0.005/-0.00" at 45°
AR Coating Reflectivity	≤ 0.2% (@1064nm)

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Yb:YAG - Ytterbium Doped Yttrium Aluminum Garnets

Ytterbium doped Yttrium Aluminum Garnet (Yb:$Y_3Al_5O_{12}$ or Yb:YAG) is one of the most promising laser-active materials and more suitable for diode-pumping than the traditional Nd-doped crystals. It can be pumped at 0.94 µm and generates 1.03 µm laser output. Compared with the commonly used Nd:YAG crystal, Yb:YAG crystal has a larger absorption bandwidth in order to reduce thermal management requirements for diode lasers, a longer upper-state lifetime, three to four times lower thermal loading per unit pump power. Yb:YAG crystal is expected to replace Nd:YAG crystal for high power diode-pumped lasers and other potential applications, such as, its doubling wavelength is 515 nm very close to that of Ar-ion laser (514 nm), which makes it possible to replace large volume Ar-ion laser.

Physical and Chemical Properties

Chemical formula	$Yb^{3+}:Y_3Al_5O_{12}$
Crystal structure	cubic
Lattice Parameters	12.01A
Melting Point	1970°C
Density, g/cm^3	4.56
Mohs hardness	8.5
Thermal expansion coefficient	7.8 x 10^{-6} x °K^{-1} , <111>, 0 - 250 °C 7.7×10^{-6}/°C, <110> (0~250°C) 8.2×10^{-6}/°C, <100> (0~250°C)
Thermal conductivity at 25°C	0.14 W x cm^{-1} x °K^{-1}
Loss coefficient at 1064 nm	0.003 cm^{-1}

Laser Properties

Laser Transition	$^2F_{5/2} \rightarrow {}^2F_{7/2}$
Laser Wavelength	1030nm
Photon Energy	1.93×10-19J(@1030nm)
Emission Linewidth	9nm
Emission Cross Section	2.0×10-20cm^2
Fluorescence Lifetime	1.2 ms

Spectral Properties

Diode Pump Band	940nm or 970nm
Thermal Optical Coefficient	7.3×10^{-6}/°C
Index of Refraction	1.82

Standard Specifications

Dopant concentration, at.%	0.5-30%
orientation:	<111>within 5°
Flatness	< λ/10
Parallelism	≤ 10"
Perpendicularity	≤ 5 ′
Surface Quality	10-5(MIL-O-13830A)
Optical Quality:	Interference fringes ≤ 0.125/inch, Extinction ration ≥ 30dB
Size:	Diameter:2~20mm,Length:5~150mm (Upon request of customer)
Dimensional tolerances	Diameter:+0.00"/-0.05"mm; Length: ± 0.02" ; Chamfer: 0.07+0.005/-0.00" at 45°
AR Coating Reflectivity	≤ 0.2% (@1030nm)

Nd:GGG

Nd:GGG is an optimal crystal for solid-state heat-capacity laser because of its high thermal diffusivity and large diameter resulting from its easiness of growth with flat interface between solid and melt. It is also a candidate for high average power laser with high pulse energy.

Advantages of Nd:GGG Crystals

- Suitable for high energy output at heat-capacity operation
- Large crystal diameter with good optical quality

Specifications

Dopant concentration	0.5~3at%
Orientation	[111] within± 5º
Wavefront distortion	≤ 0.5λ/inch@632.8nm(for the rod)
Extinction ratio	≥ 20dB @632.8nm(for the rod)
Sizes	Diameter 2~70mm, Length 3~100mm Upon request of customer
Dimensional tolerances	Diameter:+0.00"/-0.002", Length: ± 0.02"
Barrel finish	Ground Finish with 400# Grit or polished
Parallelism	≤ 10 arc seconds(for the rod)
Flatness	≤ λ/4@632.8nm(for the rod)
AR coating reflectivity	≤0.25% @1060nm

Optical and Spectral Properties of Nd:GGG Crystals

Laser transititon	$^4F_{3/2} \rightarrow {}^4I_{11/2}$
Laser wavelength	1060nm
Fluorescence lifetime	240µs
Index of refraction	1.94@1060nm
Diode pump band	808nm, 881nm

Physical and Chemical Properties

Crystal Structure	Cubic
Lattice Constant	12.383 Å
Moh Hardness	8
dn/dT	17 $\times 10^{-6}$/K
Poisson's Ratio	0.28
Melting Point	1725°C
Density	7.1 g/cm^3
Thermal Expansion	8 x 10^{-6}°C^{-1}

Cr^{4+}:YAG

$Cr^{4+}:Y_3Al_5O_{12}$ - Passive Q-switches or saturable absorbers provide high power laser pulses without electro-optic Q-switches, thereby reducing the package size and eliminating a high voltage power supply. Cr^{4+}:YAG is more robust than dyes or colour centres and is the material of choice for 1 um Nd lasers.

Physical and Chemical Properties

Formula	$Cr^{4+}:Y_3Al_5O_{12}$
Crystal structure	cubic
Mohs hardness	8.5
Melting point:	1970 °C
Density, g/cm^3	4.55
Thermal conductivity at 25°C	0.14 W x cm^{-1} x $°K^{-1}$
Thermal expansion coefficient	7.8 x 10^{-6}/°C <111> 8.2 x 10^{-6}/°C <100> 7.7×10^{-6}/°C <110>
Young's Modulus	3.17x10^4kg/mm^2
Thermal Shock Resistance	790 Wm^{-1}

Standard Specifications

Orientation:	<111>within 5° or <100>within 5°
Flatness	$< \lambda/10$
Parallelism	≤ 30"
Perpendicularity	≤ 5 ′
Surface quality	20-10(MIL-O-13830A))
Wavelength:	950 nm~ 1100nm
Initial transmittance:	5%~95%
Damage threshold	≥ 500MW/cm^2
AR coating reflectivity	≤ 0.2% (@1064nm)
Size	Diameter:3~ 20mm H × W:3 × 3~ 20 × 20mm
Dimensional tolerances	Diameter: ± 0.00/-0.05", Length: ± 0.05" Chamfer: 0.07+0.005/-0.00" at 45°

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KTP Crystal

Advantages:

- large nonlinear optical coefficient
- wide angular bandwidth and small walk-off angle
- broad temperature and spectral bandwidth
- high electro-optic coefficient and low dielectric constant
- large figure of merit
- nonhydroscopic, chemically and mechanically stable

Applications:

- 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 600nm-4500nm tunable output.
- E-O modulators, optical switches, directional couplers.
- Optical waveguides for integrated NLO and E-O devices.

Using advanced technique in crystal growth, $35x55x68mm^3$ transparent KTP boule with flux method has been grown. As large as $15x15x20mm^3$ KTP devices are fabricated.

We provide KTP with:

- strict quality control on optical homogeneity, transmission and scattering
- quick delivery
- unbeatable price and quantity discount
- technical support
- AR-coating, mounting and re-polishing service

Structural and Physical Properties:

Crystal structure	Orthorhombic, space group Pna21,point group mm2
Cell parameters	a=6.404 Angstrom, b=10.616 Angstrom, c=12.814 Angstrom, Z=8
Melting point	1172° C incongruent
Curie point	936° C
Mohs hardness	≈5
Density	$3.01 g/cm^3$
Color	colorless
Hygroscopic susceptibility	no
Specific heat	0.1643 cal/g°C
Thermal conductivity	0.13 W/cm/°K
Electrical conductivity	$3.5x10^{-8}$ s/cm (c-axis, 22° C, 1KHz)

Nonlinear Optical Properties:

Phase matchable SHG range:	497 - 1800nm
Nonlinear optical coefficients:	d_{31}=6.5pm/v, d_{32}=5pm/v, d_{33}=13.7pm/v, d_{24}=7.6pm/v, d_{15}=6.1pm/v $d_{eff}(II) \approx (d_{24} - d_{15})\sin2\phi \sin2\theta - (d_{15}\sin2\phi + d_{24}\cos2\phi)\sin\theta$
For type II SHG of a Nd:YAG laser at 1064nm:	PM angle: θ=90° , φ =23.3° Effective SHG coefficient: $d_{eff} \approx 8.3xd_{36}$(KDP) Angular acceptance: 20 mrad-cm Temperature acceptance: 25° C-cm Spectral acceptance: 5.6 Angstrom -cm Walk-off angle: 4.5 mrad (0.26°) Damage threshold: $>450MW/cm^2$ @1064nm, 10ns, 10Hz
Electro-optic coefficients: r_{13} r_{23}	Low frequency (pm/V) High frequency (pm/V) 9.5 8.8 15.7 13.8

r_{33} r_{51} r_{42}	36.3 35.0 7.3 6.9 9.3 8.8
Dielectric constant:	e_{eff}=13

Optical Properties:

Transmitting range:	350 nm - 4500 nm
Refractive indices: 1064nm 532nm	n_x n_y n_z 1.7377 1.7453 1.8297 1.7780 1.7886 1.8887
Therm-optic coefficients:	$dn_x/dT=1.1x10^{-5}/° C$, $dn_y/dT=1.3x10^{-5}/° C$, $dn_z/dT=1.6x10^{-5}/° C$
Absorption	α< 1% cm^{-1} @1064nm and 532nm

Applications for SHG and SFG of Nd:lasers

KTP is the most commonly used material for frequency doubling of Nd:YAG lasers and other Nd-doped lasers, particularly at the low or medium power density. To date, extra- and intra-cavity frequency doubled Nd:lasers using KTP have become a preferred source of pumping visible dye lasers and tunable Ti:Sapphire lasers as well as their amplifiers. Applied to diode-pumped Nd:laser, KTP has provided the basis for the construction of compact visible solid state laser systems.

Recent advances in intracavity-doubled Nd:YAG and Nd:YVO4 lasers, have increased the demand for compact green lasers used in optical disk and laser printer. Over 100mW and 76mW TEM00 green outputs are available from LD pumped Nd:YAG and Nd:YVO4 lasers, respectively. Moreover, 2.5mW green light has derived from 50mW LD pumped and intracavity doubled Nd:YVO4 mini-lasers with a 9mm long cavity.

KTP has also shown its powerful applications in extracavity SHG with conversion efficiency exceeding 60%. The applications of KTP for intracavity mixing of 810nm diode and 1064nm Nd:YAG laser to generate blue light and intracavity SHG of Nd:YAG or Nd:YAP lasers at 1300nm to produce red light are also in progress.

Applications for OPG, OPA and OPO

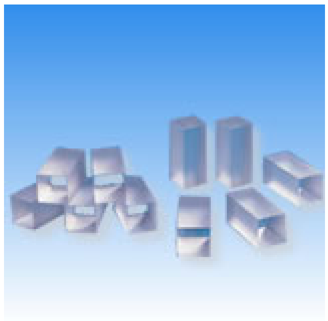
As an efficient OPO crystal pumped by a Nd:laser and its second harmonics, KTP plays an important role for parametric sources for tunable output from visible (600nm) to mid-IR (4500nm). KTP's OPO results in stable, continuous outputs of femtosecond pulse of 108 Hz repetition rate and miliwatt average power levels in both signal and idler output. KTP's OPO pumped by a 1064nm Nd:YAG laser has generated above 66% efficiency for degenerately converting to 2120nm.

KTP Specifications

- Transmitting wavefront distortion: less than λ /4 @ 633 nm
- Dimension tolerance: (W ± 0.1 mm) x (H ± 0.1 mm) x (L + 0.2 mm/-0.1mm)
- Clear aperture: > 90% central area
- Flatness: λ /8 @ 633 nm
- Scratch/Dig code: 10/5 to MIL-O-13830A
- Parallelism: better than 20 arc seconds
- Perpendicularity: 5 arc minutes
- Angle tolerance: $\Delta\theta$ < ± 0.5° , $\Delta\phi$ < ± 0.5°
- AR coating: R< 0.2% at 1064nm and R<1.0% at 532 nm.
- Quality Warranty Period: one year under proper use.

LBO

Lithium Triborate (LiB3O5 or LBO) is an excellent nonlinear optical crystal and it has the following features:



* Broad transparency range from 160nm to 2600nm
* high optical homogeneity (δn≈10-6) and being free of inclusion
* relatively large effective SHG coefficient (about three times that of KDP)
* high damage threshold
* wide acceptance angle and small walk-off
* type I and type II non-critical phase matching (NCPM) in a wide wavelength range
* spectral NCPM near 1300nm.

We can provide LBO crystals:
* large crystal size up to 30x30x30mm^3 and maximum length of 60mm
* AR-coating, mounts and re-polishing services
* a large quantity of crystals in stock
* fast delivery(10 days for polished only, 15 days for AR-coated).

Table 1. Chemical and Structural properties

Crystal Structure	Orthorhombic, Space group Pna21, Point group mm2
Lattice Parameter	a=8.4473Å, b=7.3788Å , c=5.1395Å , Z=2
Melting Point	About 834℃
Mohs Hardness	6
Density	2.47 g/cm3
Thermal Conductivity	3.5W/m/K
Thermal Expansion Coefficient	ax=10.8x10-5/K, ay= -8.8x10-5/K, az=3.4x10-5/K

Table 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 (°C, l in μm)	dnx/dT=-9.3X10-6 dny/dT=-13.6X10-6 dnz/dT=(-6.3-2.1l)X10-6
Absorption Coefficient	<0.1%/cm at 1064nm <0.3%/cm at 532nm
Angle Acceptance	6.54mrad-cm (φ, Type I,1064 SHG) 15.27mrad-cm (q, Type II,1064 SHG)
Temperature Acceptance	4.7°C-cm (Type I, 1064 SHG) 7.5°C-cm (Type II,1064 SHG)
Spectral Acceptance	1.0nm-cm (Type I, 1064 SHG) 1.3nm-cm (Type II,1064 SHG)
Walk-off Angle	0.60° (Type I 1064 SHG) 0.12° (Type II 1064 SHG)
NLO Coefficient	deff(I)=d32cosφ (Type I in XY plane) deff(I)=d31cos2θ+d32sin2θ (Type I in XZ plane) deff(II)=d31cosθ (Type II in YZ plane) deff(II)=d31cos2θ+d32sin2θ (Type II in XZ plane)
Non-vanished NLO susceptibilities	d31=1.05 ± 0.09 pm/V d32= -0.98 ± 0.09 pm/V d33=0.05 ± 0.006 pm/V
Sellmeier Equations(λ in μm)	nx2=2.454140+0.011249/(λ2-0.011350)-0.014591λ2-6.60x10-5λ4 ny2=2.539070+0.012711/(λ2-0.012523)-0.018540λ2+2.0x10-4λ4 nz2=2.586179+0.013099/(λ2-0.011893)-0.017968λ2-2.26x10-4λ4

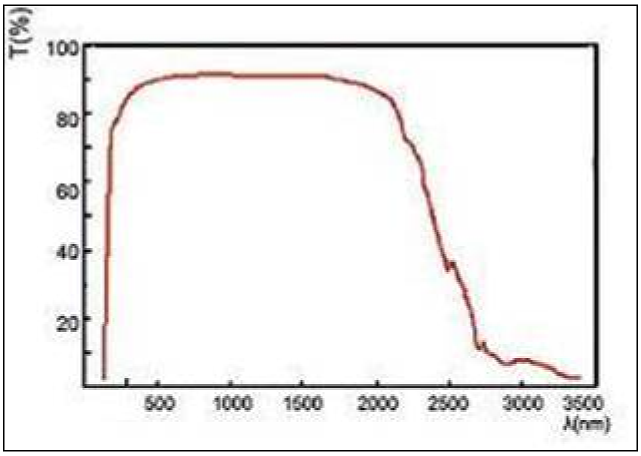


Figure 1. Transparency curve of LBO

SHG and THG at Room Temperature

LBO is phase matchable for the SHG and THG of Nd:YAG and Nd:YLF lasers, using either type I or type II interaction. For the SHG at room temperature, type I phase matching can be reached and has the maximum effective SHG coefficient in the principal XY and XZ planes (see Fig. 2) in a wide wavelength range from 551nm to about 2600nm. The optimum type II phase matching falls in principal YZ and XZ planes(see Fig 2).

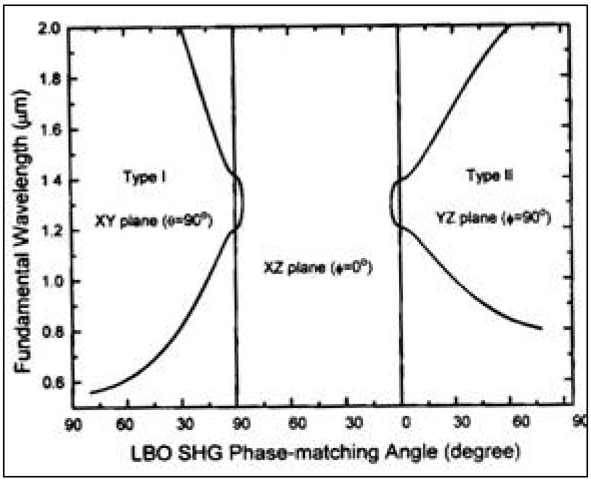


Figure 2. Optimum matching

SHG conversion efficiencies of more than 70% for pulse and 30% for cw Nd:YAG lasers, and THG conversion efficiency over 60% for pulse Nd:YAG laser have been observed.

Applications:

- More than 480mW output at 395nm is generated by frequency doubling a 2W mode-locked Ti:Sapphire laser (<2ps, 82MHz). The wavelength range of 700-900nm is covered by a 5x3x8mm3 LBO crystal.
- Over 80W green output is obtained by SHG of a Q-switched Nd:YAG laser in a type II 18mm long LBO crystal.
- The frequency doubling of a diode pumped Nd:YLF laser (>500μJ @ 1047nm, <7ns, 0-10KHz) reaches over 40% conversion efficiency in a 9mm long LBO crystal.
- The VUV output at 187.7 nm is obtained by sum-frequency generation.
- 2mJ/pulse diffraction-limited beam at 355nm is obtained by intra-cavity frequency tripling a Q-switched Nd:YAG laser.

Non-Critical Phase-Matching

Table 3. Properties of type I NCPM SHG at 1064nm

NCPM Temperature	148°C
Acceptance Angle	52 mrad-cm1/2
Walk-off Angle	0
Temperature Bandwidth	4°C-cm
Effective SHG Coefficient	2.69 d36(KDP)

AS shown in table 3, 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. 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.

As shown in Fig.3, type I and type II non-critical phase-matching can be reached along x-axis and z-axis at room temperature, respectively.

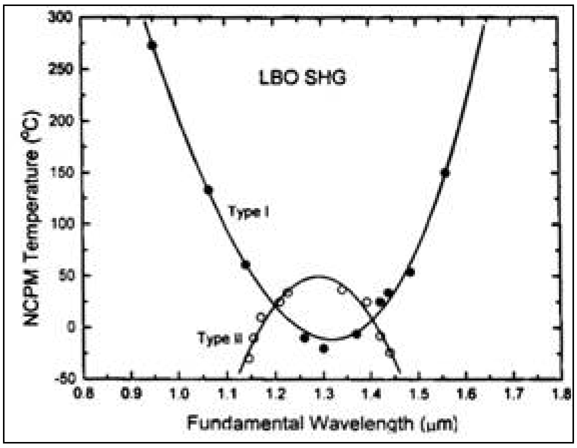


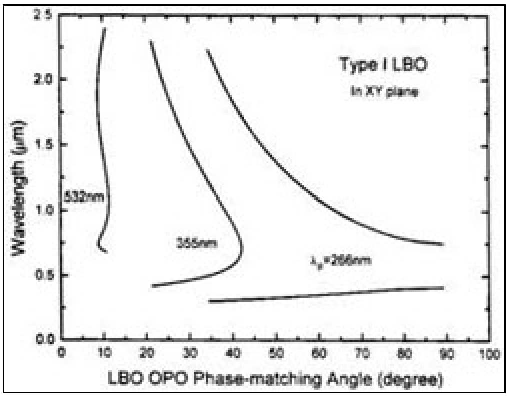
Figure 3.NCPM temperature tuning curves of LBO

Applications:

- Over 11W of average power at 532nm was obtained by extra-cavity SHG of a 25W Antares mode-locked Nd:YAG laser (76MHz, 80ps).
- 20W green output was generated by frequency doubling a medical, multi-mode Q-switched Nd:YAG laser. Much higher green output is expected with higher input.

LBO's OPO and OPA

LBO is an excellent NLO crystal for OPOs and OPAs with a widely tunable wavelength range and high powers. These OPO and OPA that are pumped by the SHG and THG of Nd:YAG laser and XeCl excimer laser at 308nm have been reported. The unique properties of type I and type II phase matching as well as the NCPM leave a big room in the research and applications of LBO's OPO and OPA. Fig.4 shows the calculated type I OPO tuning curves of LBO pumped by the SHG, THG and 4HG of Nd:YAG laser in XY plane at the room temperature. And Fig. 5 illustrates type II OPO tuning curves of LBO pumped by the SHG and THG of Nd:YAG laser in XZ plane.



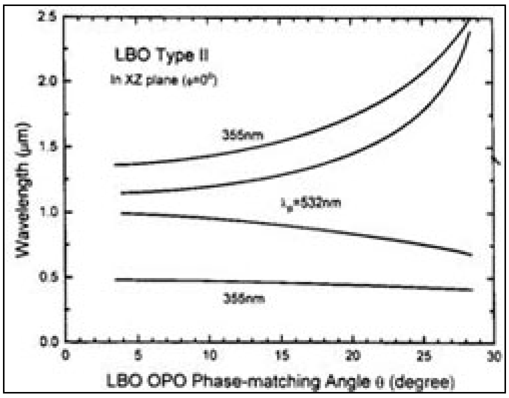


Figure 4. Type I OPO tuning curves of LBO

Figure 5. Type II OPO tuning curves of LBO

Applications:

- A quite high overall conversion efficiency and 540-1030nm tunable wavelength range were obtained with OPO pumped at 355nm.
- Type I OPA pumped at 355nm with the pump-to-signal energy conversion efficiency of 30% has been reported.

- Type II NCPM OPO pumped by a XeCl excimer laser at 308nm has achieved 16.5% conversion efficiency, and moderate tunable wavelength ranges can be obtained with different pumping sources and temperature tuning.
- By using the NCPM technique, type I OPA pumped by the SHG of a Nd:YAG laser at 532nm was also observed to cover a wide tunable range from 750nm to 1800nm 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, a narrow linewidth (0.15nm) and high pump-to-signal energy conversion efficiency (32.7%) were obtained when it is pumped by a 4.8mJ, 30ps laser at 354.7nm. Wavelength tuning range from 482.6nm to 415.9nm was covered by increasing the temperature of LBO or rotating BBO.

LBO's Spectral NCPM

Not only the ordinary non-critical phase matching (NCPM) for angular variation but also the noncritical phase matching for spectral variation (SNCPM) can be achieved in the LBO crystal. As shown in Fig.2, the phase matching retracing positions are λ1=1.31μm with θ =86.4°, φ=0° for Type I and λ2=1.30μm with θ=4.8°, φ=0° for Type II. The phase matching at these positions possess very large spectral acceptances Δλ. The calculated Δλ at λ1 and λ2are 57nm-cm-1/2 and 74nm-cm-1/2 respectively, which are much larger than the other NLO crystals. These spectral characteristics are very suitable for doubling broadband coherent radiations near 1.3μm, such as those from some diode lasers, and some OPA/OPO output without linewidth-narrowing components.

The crystal holder (free) and oven & Temperature Controller (for NCPM,OPO,OPA applications) are available for BBO & LBO.

AR-coating

- Dual Band AR-coating (DBAR) of LBO for SHG of 1064nm.
  · low reflectance (R<0.2% at 1064nm and R<0.5% at 532nm);
  · high damage threshold (>500MW/cm2at both wavelengths);
  · long durability.
  * Broad Band AR-coating (BBAR) of LBO for SHG of tunable lasers.
  * Other coatings are available upon request.
- * Dimension tolerance: (W±0.1mm)x(H±0.1mm)x(L+0.5/-0.1mm) (L≥2.5mm)
  (W±0.1mm)x(H±0.1mm)x(L+0.1/-0.1mm) (L<2.5mm)
- Clear aperture: central 90% of the diameter
- No visible scattering paths or centers when inspected by a 50mW green laser
- Flatness: less than λ/8 @ 633nm
- Transmitting wavefront distortion: less than λ/8 @ 633nm
- Chamfer: ≤0.2mm@450
- Chip: ≤0.1mm
- Scratch/Dig code: better than 10/ 5 to MIL-O-13830A
- Parallelism: better than 20 arc seconds
- Perpendicularity: ≤5 arc minutes
- Angle tolerance: Δθ≤0.25°, Δφ≤0.25°
- Damage threshold[GW/cm]: >10 for 1064nm, TEM00, 10ns, 10HZ (polished only)
  >1 for 1064nm, TEM00, 10ns, 10HZ (AR-coated)
  >0.5 for 532nm, TEM00, 10ns, 10HZ (AR-coated)
- Quality Warranty Period: one year under proper use.

NOTE

1. LBO has a very low susceptibility to moisture. Users are advised to provide dry conditions for both the use and preservation of LBO.
2. Polished surfaces of LBO requires precautions to prevent any damage.
3. We can select and design the best crystal for you, if the main parameters of your laser are provided, such as energy per pulse, pulse width and repetition rate for a pulsed laser, power for a cw laser, laser beam diameter, mode condition, divergence, wavelength tuning range, etc.

Beta-Barium Borate (β-BaB_2O_4,BBO)

Main features are:

- Broad phase-matchable range from 409.6 nm to 3500nm;
- Wide transmission region from 190 nm to 3500nm;
- Large effective second-harmonic-generation (SHG) coefficient about 6 times greater than that of KDP crystal;
- High damage threshold of 10GW/cm^2 for 100ps pulse-width at 1064nm;
- High optical homogeneity with $\delta n \approx 10^{-6}$/cm;
- Wide temperature-bandwidth of about 55℃.

We offer:

- Strict quality control;
- Crystal length from 0.02mm to 25mm and size up to 15x15x15 mm^3;
- P-coatings, AR-coatings, mounts and re-polishing services;
- A large quantity of crystals in stock
- Fast delivery (10 days for polished only,15 days for AR-coated).

Basic Properites

Table 1.Chemical and Structural properties

Crystal Structure:	Trigonal, space group R3c
Lattics Parameters:	a=b=12.532Å, c=12.717Å, Z=6
Melting point	About 1095°C
Mohs Hardness	4
Density	3.85g/cm^3
Thermal Conductivity	1.2W/m/K(⊥c): 1.6w/m/K(//c)
Thermal Expansion Coefficients	α,4x10^{-6}/K; c,36x10^{-6}/K

Table 2.Optical and Nontinear Optical Properties

Transparency Range:	190-3500nm
SHG Phase Matchable Range	409.6-3500nm(Type I) 525-3500nm(Type II)
therm-optic Coefficients(/°C)	dn_o/dT=-9.3x 10^{-6}/°C dn_e/dT=-16.6x 10^{-6}/°C
Absorption Coefficients	<0.1%/cm at 1064nm <1%/cm at 532nm
Angle Acceptance	0.8mrad-cm (θ, Type I,1064 SHG) 1.27mrad-cm (θ, Type II,1064 SHG)
Temperature Acceptance	55°C -cm
Spectral Acceptance	1.1nm-cm
Walk-off Angle	2.7° (Type I 1064 SHG) 3.2° (Type II 1064 SHG)
NLO Coefficients	$d_{eff}(I)=d_{31}\sin\theta+(d_{11}\cos\Phi-d_{22}\sin3\Phi)\cos\theta$ $d_{eff}(II)=(d_{11}\sin3\Phi+d_{22}\cos3\Phi)\cos^2\theta$
Non-vanished NLO susceptibilities	$d_{11}=5.8xd_{36}$(KDP) $d_{31}=0.05xd_{11}$ $d_{22}<0.05xd_{11}$
sellmeier Equations(λ in μm)	$n_o^2=2.7359+0.01878 / (\lambda^2-0.01822) -0.01354 \lambda^2$ $n_e^2=2.3753+0.01224 / (\lambda^2-0.01667) -0.01516 \lambda^2$
Electro-optic coefficients:	r_{11}=2.7pm/V, r_{22}, $r_{31}<0.1\gamma_{11}$
Half-wave voltage:	7KV (at 1064nm,3*3*20mm3)
Resistivity:	>10^{11} ohm-cm
Relative Dielectric Constant:	$\varepsilon^s_{11}/\varepsilon_o$:6.7 $\varepsilon^s_{33}/\varepsilon_o$:8.1 Tan δ<0.001

BBO is a negative uniaxial crystal, with ordinary refractive-index(n_o) larger than extraordinary refractive-index(n_e).Both type I and type II phase-matching can be reached by angle-tuning.The phase matching angles of frequency doubling are shown in Fig.2.

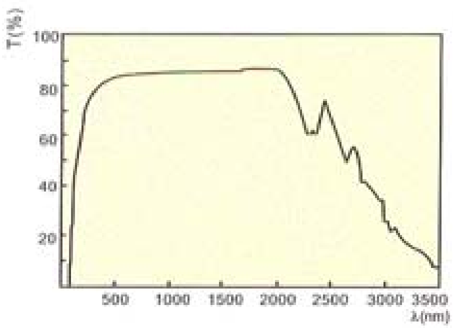


Figure 1.Transparency curve of BBO

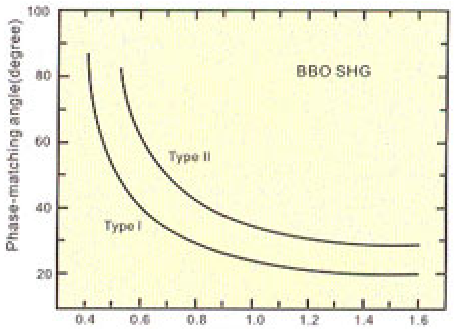


Figure 2.SHG tuning curves of BBO

Application in Nd:YAG Lasers

BBO is an efficient NLO cyrstal for the second, third and fourth harmonic generation of Nd:YAG lasers,and the best NLO crystal for the fifth harmonic generation at 213nm. Conversion efficiencies of more than 70% for SHG,60% for THG and 50% for 4HG,and 200mW output at 213 nm(5HG)have been obtained,respectively.

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

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

Applications in Tunable Lasers

1. Dye lasers

Efficient UV output (205nm-310nm) with a SHG efficiency of over 10% at wavelength of ≥206nm was obtained in type I BBO, and 36% conversion efficiency was achieved for a XeC1-laser pumped Dye laser with power 150KW which is about 4-6 times higher than that in ADP. The shortest SHG wavelength of 204.97 nm with efficiency of about 1% has been generated.

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

2.Ultrafast Pulse Laser

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

3.Ti:Sapphire and Alexandrite lasers

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

More than 50% of SHG conversion efficiency in a Ti:Sapphire laser has been obtained. High conversion efficienies have been also obtained for the THG and FHG of Ti:Sapphire lasers.

4. Argon Ion and Copper-Vapor lasers

By employing the intracavit frequency-doubling technique in an Argon Ion laser with all lines output power of 2W, maximum 33 mW at 250.4 nm and thirty-six lines of deep UV wavelengths ranging from 228.9 nm to 257.2 nm were generated in a Brewster-angle-cut BBO crystal.

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

BBO's OPO and OPA
The OPO and OPA of BBO are powerful tools for generating a widely tunable coherent radiation from the UV to IR. The tuning angles of type I and type II BBO OPO and OPA have been calculated, with the results shown in Fig.5 and Fig.6, respectively.

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

2.OPO and OPA pumped at 355 nm
In the case of Nd:YAG pumping,BBO's OPOs can generate more than 100mJ,with wavelength tunable from 400nm to 2000nm. Using our BBO crystal, the OPO system covers a tuning range from 400nm to 3100nm which guarantees a maximum of 30% and more than 18% conversion efficiency, over the wavelength range from 430nm to 2000nm.

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

Pumping with a picosecond Nd:YAG at 355nm, a narrow-band(<0.3nm), high energy (>200μJ) and wide tunable (400nm to 2000nm) pulse has been produced by BBO's OPAs. This OPA can reach as high as more than 50% conversion efficiency, and therefore is superior to common Dye lasers in many respects, including efficiency, tunable range, maintenance, and easiness in design and operation. Furthermore, coherent radiation from 205 nm to 3500 nm can be also generated by BBO's OPO or OPA plus a BBO for SHG.

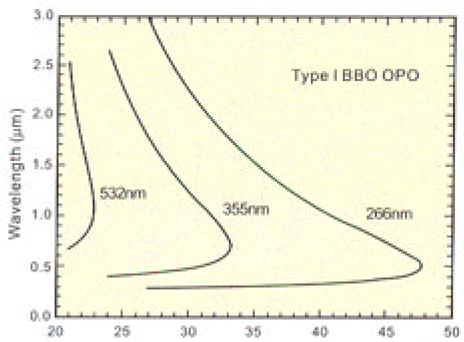


Figure3.Type I OPO turning curves of BBO

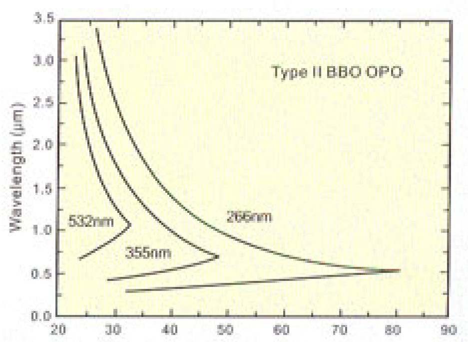


Figure4,Type Ii OPO tuning curves of BBO

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

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

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 repitition rate have been reached by using our E-O BBO crystals and Nd:YVO_4 crystals as gain media. At 5K Hz, 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 high (7KV at 1064nm,3*3*20mm3),long and thin BBO can reduce the voltage requirements. We now can supply 25mm long and 1mm thin high optica quality of BBO crystal with Z-cut, AR-coated and Gold/Chrome plated on the side faces.

Coatings

We provide the following AR-coatings for BBO:

- Dual Band AR-coating (DBAR)of BBO for SHG of 1064nm
    1. low reflectance (R<0.2% at 1064nm and R<0.5% at 532nm);
    2. high damage threshold (>300MW/cm^2 at both wqvelengths);
    3. long durability;
- Broad Band AR-coating (BBAR) of BBO for SHG of tunable lasers.
- Broad Band P-coating of BBO for OPO applications.
- Other coatings are available upon request.

Warranty on BBO Specifications

- Dimension tolerance:
  (W±0.1mm)x(H±0.1mm)x(L+0.5/-0.1mm) (L≥22.2.5mm)
  (W±0.1mm)x(H±0.1mm)x(L+0.1/-0.1mm) (L<2.5mm)
- Clear aperture :central 90% or the diameter
- No visible scattering paths or centers when inspected by a 50mW green Laser
- Flatness: less than λ/8 @ 633nm
- Transmitting wavefront distortion: less than λ/8 @ 633nm
- Chamfer: ≤0.2mm@45°
- Chip: ≤0.1mm
- Scratch/Dig code: better than 10/5 to MIL-O-13830A
- Parallelism: ≤20 arc seconds
- Perpendicularity:≤5 arc minutes
- Angle tolerance:≤0.25°, ≤0.25°
- Damage threshold{GW/cm}:
  >1for1064nm,TEM00,10ns,10HZ (polished only),
  >0.5 for 1064nm,TEM00,10ns,10HZ(AR-coated) ;
  >0.3 for 532nm,TEM00,10ns,10HZ(AR-coatd)

Note

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

KTA (Potassium Titanyl Arsenate, KTiOAsO4)

KTA crystal features large non-linear optical and electro-optical coefficients in comparison to KTP and has the added benefit of significantly reduced absorption in the 2 to 5 µm region. It has found more and more applications in second harmonic generation (SHG), sum and difference frequency generation (SFG)/(DFG), optical parametric oscillation/ amplification (OPO/OPA), and electro-optical Q-switching.

KTA features

- Large nonlinear optical coefficients
- Wide angular bandwidth and small walk-off angle
- Broad temperature and spectral bandwidth
- Large electro-optic coefficients
- Lower absorption in the 3-4 µm range than KTP.
- Nonhydroscopic, chemically and mechanically stable
- High thermal conductivity
- High damage threshold

KTA is a positive biaxial crystal, with the principal axes X, Y, and Z (nz>ny>nx) parallel to the crystallographic axes a, b, and c, respectively.

Structural and Physical Properties

Crystal Structure	Orthorhombic, space group Pna21, point group mm2
Cell Parameters	a=13.125Å, b=6.5716Å, c=10.786 Å, Z=8
Melting Point	1130°C
Curie Point	880°C
Mohs Hardness	~ 5
Density	3.45 g/cm3
Color	colorless
Hygroscopic Susceptibility	No
Specific Heat	0.687 J/g/K
Thermal Conductivity	1.8 W/m/K
Electrical Conductivity	0.7-3.4 x10-6 s/cm (c-axis, @22°C, 1KHz)

Linear Optical Properties:

Transmitting Range	350 nm - 5500 nm
Refractive Indices: 1064nm 532nm	nx ny nz 1.7818 1.7866 1.8680 1.8264 1.8331 1.9310
Sellmeier Equations (l in µm)	nx2=1.90713+1.23522l2 /(l2-0.19692)-0.01025l2 ny2=2.15912+1.00099l2 /(l2-0.21844)-0.01096l2 nz2=2.14768+1.29559l2/(l2-0.22719)-0.01436l2
Thermo-optic Coefficients	dnx/dT=1.1x10-5/°C, dny/dT=1.3x10-5/°C dnz/dT=1.6x10-5/°C
Absorption Coefficient	a < 1% cm-1 @1064nm and 532nm

Nonlinear Optical Properties:

Phasematchable SHG Range	542 - 1800nm
Nonlinear Optical Coefficients	d31=2.8pm/v, d32=4.2pm/v, d33=16.2pm/v,d24=3.2pm/v, d15=2.3pm/v
Effective Nonlinearity Expressions	deff(II)= (d24-d15)sin2fsin2q-(d15sin2f+d24cos2f)sinq
Electro-optic Coefficients (Low frequency)	r13= 11.5pm/V, r23=15.4pm/V, r33=37.5pm/V
Dielectric Constant	eeff=42

Specifications for finished KTA
Wavefront distortion: less than l/4 @ 633 nm
Dimension tolerance: (W +/- 0.1 mm) x (H +/- 0.1 mm) x (L + 0.2 mm/-0.1mm)
Clear aperture: > 90% central area
Flatness: l/8 @ 633 nm
Scratch/dig: 10/5 to MIL-O-13830A
Parallelism: better than 20 arc seconds
Perpendicularity: 5 arc minutes
Angle tolerance: Dq< +/-0.25o, Df< +/-0.25o

Coating and Mount
Standard dual band anti-reflection (DBAR) coatings at 1064nm/1530 nm, 1064/3200nm, or 1320nm/660nm are available. Other coatings are also available upon request. Mounts may be provided free of charge.

KTP Elements for SHG, SFM, DFM and OPO

We produce high quality single domain KTP NLO elements. Our controlled growth methods ensure a reliable supply of KTP crystals of consistent quality.

KTP Crystals

- Absorption coefficient: α< 50 ppm cm^{-1} at 1064 nm, and α < 2000 ppm cm^{-1} at 532 nm
- Domain structure: Single domain
- Guaranteed Damage threshold: 600 MW/cm^2 (with coating) at 1064 nm, for 10 ns pulses

NLO Elements

- Fabrication: Cut from single growth sector
- Apertures: up to 30 x 30 mm^2
- Length: up to 40 mm along X axis
- AR coatings: dual band R < 0.2 %
- Wave front distortion control
- Certified frequency conversion efficiency (upon request)

Optical Polishing Capabilities

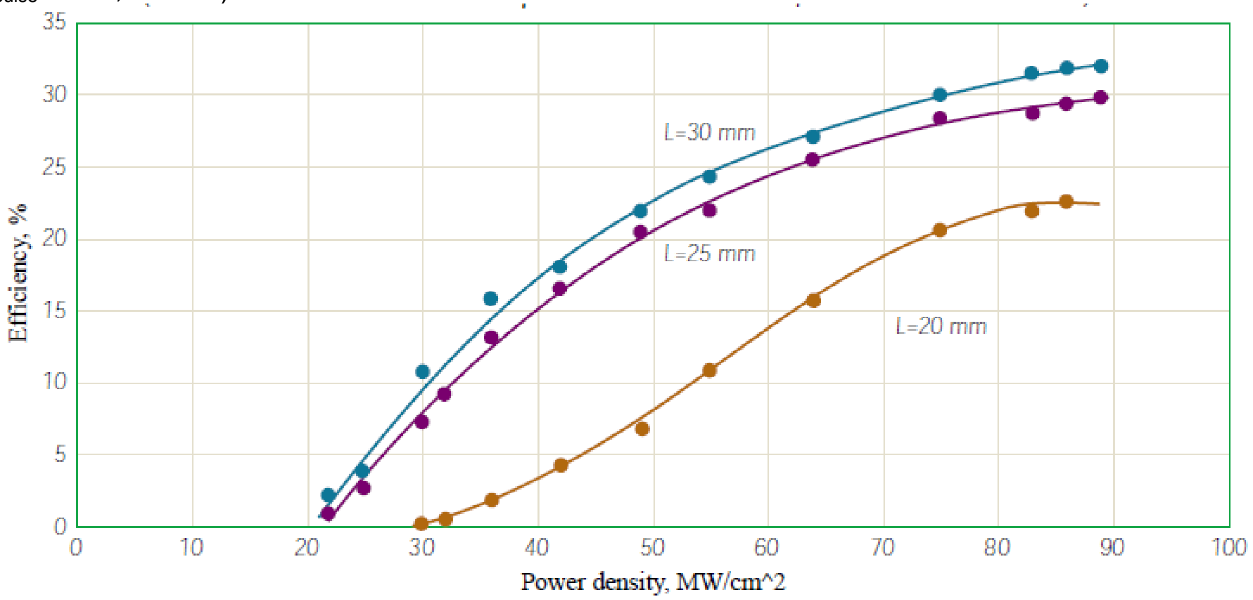
- Flatness: λ/10
- Parallelism: 5 arc sec
- Perpendicularity: 5 arc min.
- Scratch/dig: None at x 100 magnification

KTP Substrates for Optical Waveguides and PPKTP

- Area: Z-cut, up to 40 x 40 mm^2
- Domain structure: Single domain

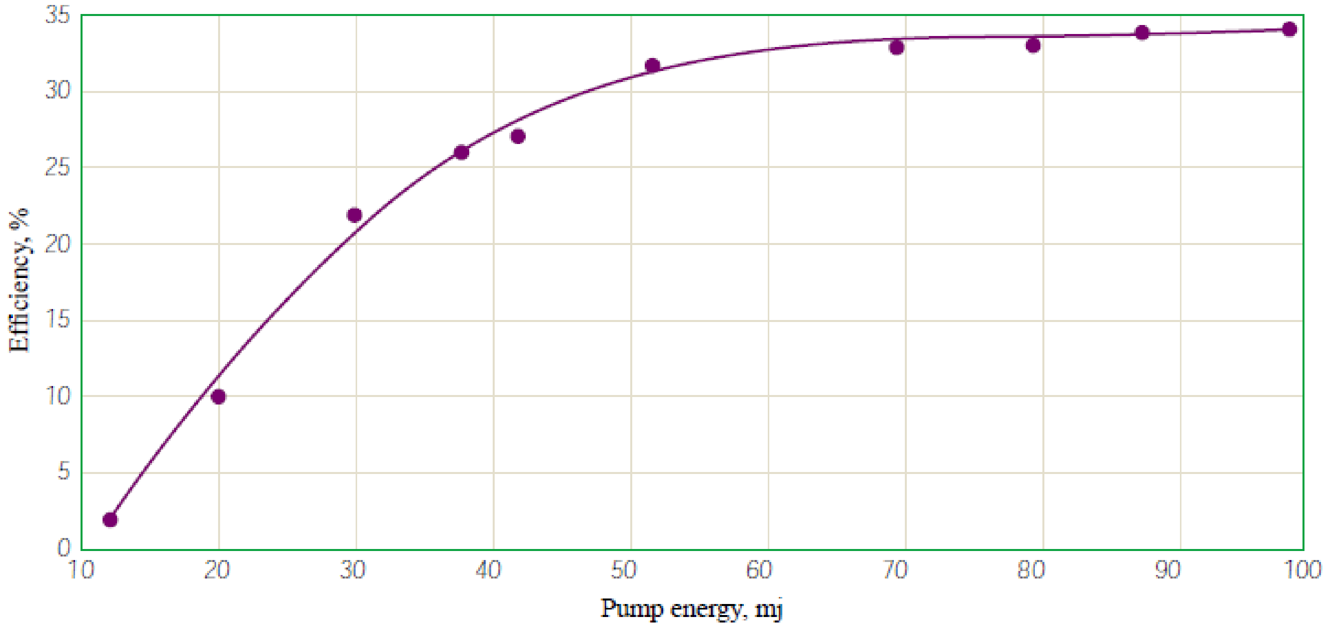
Index	A	B	C	D
nx	3.006700	0.039500	0.042510	0.012470
ny	3.031900	0.041520	0.045860	0.013370
nz	3.313400	0.056940	0.059410	0.016713

Efficiency of KTP elements in OPO 1064-1570 nm (Resonator L=35mm, output mirror- 50%, τ_{pulse}=10ns, f=25Hz)



The above graph shows the increase in efficiency in OPO conversion achieved with increased KTP element length. In the past, OPO efficiency levelled off with 20 mm long elements, and actually dropped with longer elements. This was due to imperfections in the KTP elements. Our crystal growth technology can provide long elements with few imperfections, which results in higher OPO efficiency.

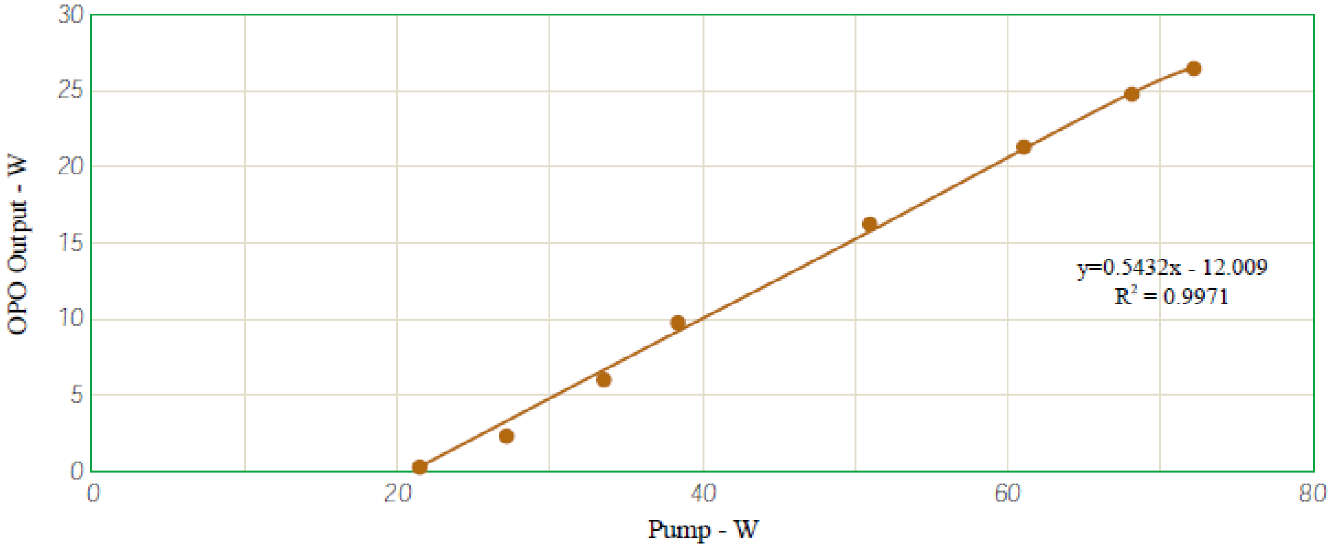
Efficiency of KTP element (L =35.4 mm) in OPO 1064 -1570 nm

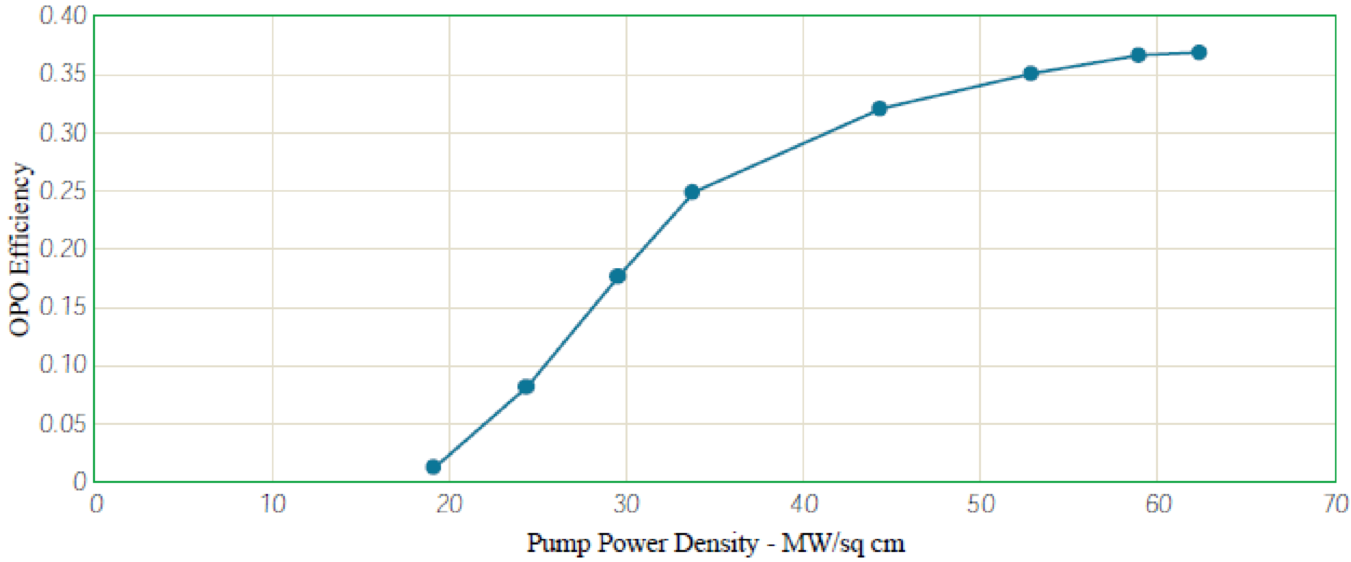


The increased efficiency of OPO conversion with a 35 mm long KTP element is shown above.
We can provide KTP OPO elements up to 50 mm long. Large apertures are also available.

High Average Power KTP Ring OPO

Three 10x10x20 mm, DBAR 1.06 & 1.57, 100 pps rate, 2 hrs. Run time, No degradation





High Gray Track Resistance KTP Elements (HGTR KTP)

We produce KTP crystals with gray track resistance up to ten times greater than typical flux grown KTP. This is possible due to advances in the controlled growth of KTP crystals, using proprietary modified fluxes and heat treatment. These HGTR KTP elements are suitable for high power density applications, where many other KTP elements would suffer from gray tracks or photorefractive breakdown.

KTP Crystals

- Absorption coefficient: α< 10-5 cm^{-1} at 1064 nm and α< 0.01 cm^{-1} at 532 nm
- Domain structure: Single domain
- Guaranteed Damage threshold: 600 MW/ cm^2 (with coating) at 1064 nm, for 10 ns pulses

KTP Elements for SHG, SFM, DFM and OPO

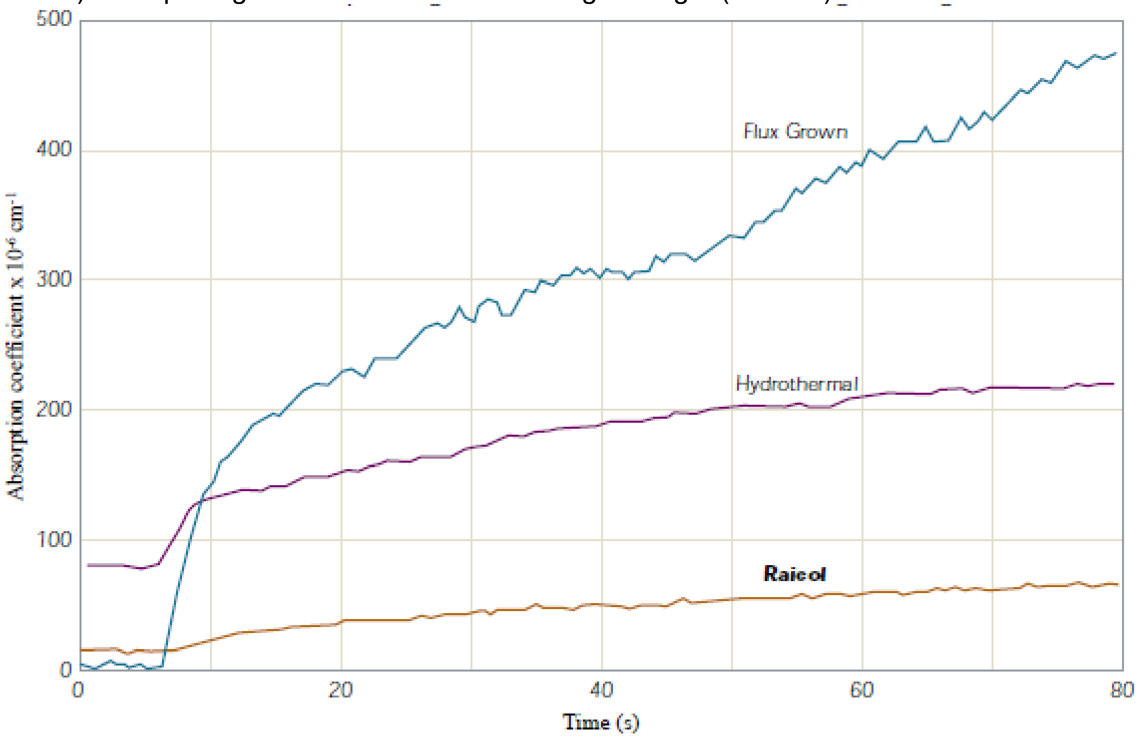
- Fabrication: Cut from single growth sector
- Apertures: up to 8 x 8 mm^2
- Length: up to 12 mm along X axis
- AR coatings: dual band R<0.2 %

Optical Polishing Capabilities

- Flatness: λ/10
- Parallelism: 5 arc sec
- Perpendicularity: 5 arc min.
- Scratch/dig: None at x100 magnification

Gray-tracking Effect in KPT Crystals

IR (1064 nm) absorption growth under 10 KW/cm^2 of green light (514 nm)



In the GRIIRA (Green Induced Infrared Absorption) test, an infrared laser beam passes through the KTP element.

The initial measurement (at time 0) is the infrared absorption of the crystal. After a few seconds, a green laser beam is allowed to go through the crystal as well. The green light causes an increase in the IR absorption of the crystal. This effect has been show to correlate with gray tracking in KTP crystals.

The above graph shows that the HGTR KTP elements have both a lower initial IR absorption, and are affected less by the green laser. Thus, the HGTR KTP is expected to have a higher gray track resistance than regular flux grown crystals or hydrothermally grown crystals.

Periodically Poled KTP (PPKTP)

Periodically Poled KTP is an entirely new type of non-linear material. It can be tailor- made for all non-linear applications within the transparency range of KTP, without the phase matching limitations of bulk KTP. Its effective non linear coefficient is about three times larger than that of bulk KTP. We offer PPKTP in large production quantities, as well as small quantities for development work.

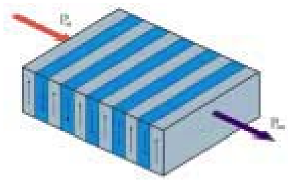
KTP is a ferroelectric crystal. In the classic use of bulk KTP, it is important to have a single domain crystal. In PPKTP, a periodic domain structure is artificially induced in the crystal. The exact spacing of these periods depends on the application, and ranges from a few microns to tens of microns. The period is induced in the direction in the crystal that has the highest non-linear coefficient, as opposed to the bulk crystal, where the direction is dictated by the phase matching constraints. Some degree of crystal temperature control is necessary in using PPKTP.

PPKTP is produced in a multi-step process. An electrode of the desired structure is deposited on the surface of a KTP wafer, using micro lithographic techniques. An electric field is applied to the crystal under carefully controlled conditions, thus inducing the desired change in domain structure. The resulting KTP is then tested, cut into appropriate pieces, polished and coated. The technique lends itself to mass production at a reasonable cost.

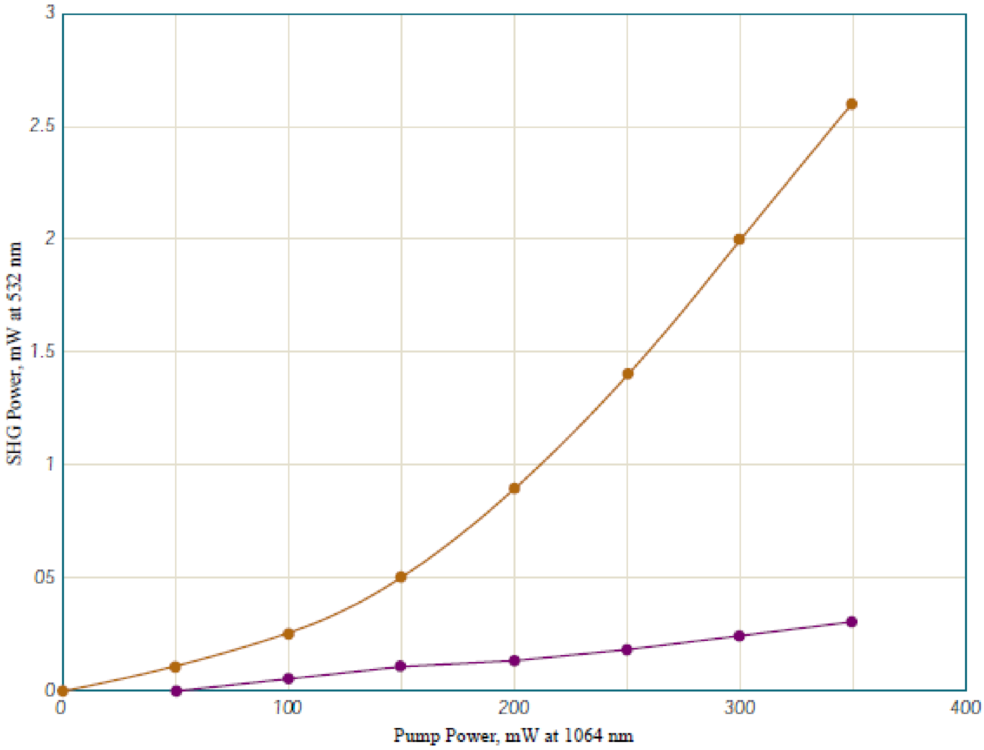
PPKTP is available in standard elements for some common applications, such as second harmonic generation of 1064 nm and 946 nm. It can also be specially designed and manufactured for specific applications.

Typical specifications:

- Wavelength Range: 0.400 to 4.0 micron
- Dimensions:
  - Thickness (typical): 1 mm
  - Width (typical): 2 mm
  - Length: up to 30 mm



Second Harmonic Generation in Periodically Poled and Bulk KTP



Test Conditions: Crystal length = 10 mm, τ= 10 ns, Pulse frequency = 2 kHz

Rubidium Titanyl Phosphate (RTP)

RTP, which has only recently become commercially available, is the material of choice for many NLO and electro-optic applications. Its high optical damage threshold makes it especially useful in high power SHG and OPO applications. RTP's high electrical resistivity is important for many electro-optic applications, and in the production of Periodically Poled RTP elements.

RTP vs. KTP Comparison Chart

Property Type II SHG at 1064 nm	**KTP**	**RTP**
Phase matchable range (nm)	980-1080	1050-1140
Nonlinear coefficients (pm/V)		
d_{33}	16.9	17.1
d_{31}	2.5	3.3
d_{32}	4.4	4.1
d_{eff}	3.34	2.45
Phase matching angle (deg)	22-25	58
Walk-off angle (deg)	0.26	0.4
Angular acceptance (mrad cm)	20	20
Temperature acceptance (°C cm)	25	40
Transparency range (nm)	350-4500	350-4500
Other Properties		
Wavelength of noncritical OPO 1064nm (nm)	1570/3300	1600/3200
Electro optical coefficients (pm/V)		
r_{33}	36.3	39.6
r_{13}	9.5	12.5
r_{23}	15.7	17.1
Dielectric constant ε_{eff}	13	13
Optical damage ratio (to KTP)	1	1.8
Electrical conductivity along Z axis (Ω^{-1} cm^{-1})	10^{-6}-10^{-7}	10^{-11}-10^{-12}
Pyroelectric coefficient (C/cm^2 K)	7 x 10^{-9}	4 x 10^{-9}

Monolithic KTP / OPO

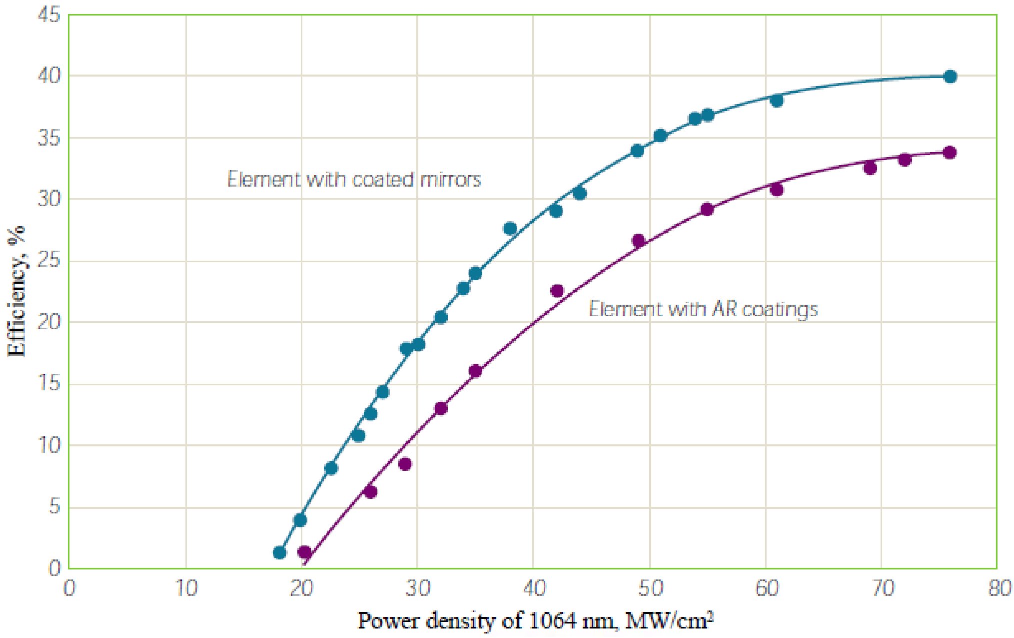
Some applications of OPO require compact size and vibrationless operation, which may be achieved by using a monolithic design of the OPO element. External (cavity) mirrors are eliminated in this design, and the mirrors are evaporated onto the KTP crystal input and output faces directly. In addition, higher frequency conversion efficiency can be achieved (see a figure below).

Elements with flat mirrors are a standard product. A curved mirrors design is under development and it is aimed to achieve a narrower divergence angle of the monolithic OPO element.

Specifications:

- Apertures: up to 10 x 10 mm^2
- Length: up to 35 mm along X-axis
- Flatness: l/10
- Parallelism: < 5 arc sec
- Input mirror: > 99.5 % @ wavelength upon request
- Output mirror: upon request

Efficiency of KTP elements (L = 35 mm) by OPO 1064/1576 nm



Comparison of Electrooptic Materials

Property	Units	RTP	KD*P	$LiNbO_3$	$LiTaO_3$	BBO	KTP	RTA
Transparency range	µm	0.35-4.3	0.2-2.15	0.35-5.5	0.3-5.5	0.19-2.6	0.35-4.3	0.35-5.3
Refractive index		1.9	1.5	2.2	2.2	1.6	1.9	1.9
$V_{\lambda/2}$ (1064nm) (L=d) - static	kV	8*	9	8.5	5	46	8*	8*
Temperature coefficient of $V_{\lambda/2}$	%/°C	small	large	small	small	0.1	small	small
Dielectric constant, ε		11	48	27.9	45	6.7	15.4	11
Laser damage threshold (AR coatd)	MW/ cm2	600	500	280	400	1000	600	400
Conductivity, σ_{33}	S/cm	$\sim 10^{-11}$	$<10^{-12}$	$<10^{-12}$	$<10^{-12}$	$<10^{-12}$	$<10^{-6}$	$<10^{-9}$
Optical Homogeneity		good	excellent	fair	fair	excellent	good	good
Acoustic ringing		no	yes	yes	no	small	no	no
Temperature stability		good	problem	problem	good	good	good	good
Hygroscopic		no	yes	no	no	slight	no	no

* $V_{\lambda/2}$ measured for light propagating in the x direction.

Cr4+:YAG Crystal - Passive Q-Switch

Cr4+:YAG is an ideal material for Q-switching of Nd:YAG, and other Nd and Yb doped lasers. The crystals are effective Q-switches in the wavelength range of 0.9 to 1.2 m. Cr4+:YAG is also a useful lasing material, with output from 1.35µto 1.6µ (tunable).

Specifications:

- Doping level: up to 4 mole %
- Size: up to 12 x12 mm aperture
- Flatness: λ/10
- Parallelism: 5 arc sec
- Scratch/dig: None at x100 magnification
- AR Coating: < 0.15% @1064 nm
- Initial Transmission: 1% to 99%, per customer specification
- Damage Threshold: 1 GW/cm^2 at 1064 nm, τ= 10 ns

BBO Elements

BBO crystals combine very wide transparency, moderately high nonlinear coupling, high damage threshold and good chemical and mechanical properties. BBO phase matches over a wide range, yielding SHG from 0.19 to 1.75 microns.

Applications:

- 2nd, 3rd, 4th and 5th Harmonic Generation of Nd lasers
- 2nd, 3rd and 4th Harmonic Generation of Ti: Sapphire and Alexandrite Lasers
- SHG of Argon, Cu vapor and Ruby lasers
- OPO and OPA

Specifications - BBO Elements

- Wave front Distortion: λ/5 at λ= 0.633μ
- Absorption coefficient: α< 0.005 cm^{-1} from 0.2μ to 3.5μ
- Damage threshold: 1 GW/cm^2 at 1.064m, τ= 1 ns
- Bubbles, inclusions, etc.: none
- Apertures: up to 20 x 20 mm^2
- Length: up to 20 mm
- AR coatings: dual band R < 0.2%, Damage Threshold 1GW/cm^2, 10 ns pulse, 10Hz
- Certified frequency conversion efficiency (upon request)

Optical Polishing Capabilities

- Flatness: λ/10
- Parallelism: 5 arc sec
- Perpendicularity: 5 arc min.
- Scratch/dig: None at x 100 magnification

LBO (Lithium Triborate) Elements

LBO crystals combine wide transparency, moderately high nonlinear coupling, high damage threshold and good chemical and mechanical properties.

Applications (SHG) of:

- Nd: TAG
- Alexandrite
- Ti:Sapphire
- Nd:YLF
- Cr:LiSAF
- Dye Lasers
- Ultrashort Pulses
- Third Harmonic Generation of Nd:YAG and Nd:YLF
- OPO and OPA

Specifications - LBO Elements

- Wavefront Distortion: λ/10 at λ= 0.633m
- Absorption coefficient: α< 0.005 cm-1 from 0.2μ to 2.5μ
- Bubbles, inclusions, etc.: none
- Apertures: up to 20 x 20 mm^2
- Length: up to 20 mm along X axis
- AR coatings: dual band R < 0.2%
- Damage threshold, coating: 1 GW/cm^2 at 1064 nm, τ= 10 ns
- Damage threshold, crystal: > 10 GW/ cm^2
- Certified frequency conversion efficiency (upon request)

Optical Polishing Capabilities

- Flatness: λ/10
- Parallelism: 5 arc sec
- Perpendicularity: 5 arc min.
- Scratch/dig: None at x 100 magnification

Barium Nitrate (BN) Raman Crystals

Barium Nitrate mono-crystals are one of the best solid state materials for shifting the emission frequency of lasers to different spectral region using Stimulated Raman Scattering effect. Our advanced crystal growing technique based on the water solution method yields large transparent BN crystals.

Basic properties:

- Chemical formula: $Ba(NO_3)_2$
- Crystal structure: Cubic, space group $P2_13$
- Cell parameter: 8.11 A
- Density: 3.244 g/cm^3
- Mohs Hardness: 2.5-3
- Thermal Conductivity: 1.17 W/m/°C @ 25°C
- Thermal Expansion Coefficient: 1.3 x 10^{-5}/°C @ 25°C

Optical and Raman properties:

- Transmitting range: 350 - 1800 nm
- Refractive indexes: 1.575 @ 532 nm, 1.555 @ 1064 nm
- Raman frequency Stokes shift: 1047.3 cm^{-1}
- Raman Linewidth: 0.4 cm^{-1}
- The wavelengths of Stock components for Nd:YAG lasers
  @ 532 nm: 504 nm, 563 nm, 599 nm, 639 nm
  @ 1064 nm: 957 nm, 1197 nm, 1369 nm, 1598 nm
  @ 1319 nm: 1159 nm, 1530 nm, 1822 nm, 2252 nm
- Conversion efficiency: up to 60%
- Laser damage threshold: > 500 MW/cm2 for 10 ns pulse @ 1064 nm

Specifications:

- Aperture: up to 15 x 15 mm
- Length: up to 100 mm
- Flatness: λ/4
- Parallelism: 30 arc sec
- Perpendicularity: 5 arc min
- Scrath/dig: 20/10
- Extinction ratio: > 20 dB
- AR coating: on request

Ovens and Temperature Controllers

We provide ovens and precision temperature controllers to hold crystals and maintain them at a given temperature. Such a high temperature is often required for noncritical phase matching (NCPM) or to avoid optical damage of crystals.

Part Number: OVN6421
Power Consumption: 50W
AC Voltage : 110V (220/110V voltage converter will be provided for customers out side of North America)
Temperature Sensor: RTD Pt100
Operating Temperature Range: Room Temperature - 200°C
Temperature Stability: 0.1°C @148°C (Standard Deviation)
Host Crystal Dimension: 2x2x5mm to 7x7x20mm
Oven External Size: φ50x55mm

Crystals may be pre-mounted in the oven upon customer's request. Custom-made oven and temperature controller are also available for your specific applications. Specifications are subject to change without notice.

Application Examples:
Noncritical Phasematching
LBO: SHG of Nd:YAG/YLF/YVO4 lasers (148-170°C),
OPO pumped by SHG of Nd:YAG/YLF/YVO4 or Ti:Sapphire lasers (RT-200°C)
KNbO3: SHG of 860-950nm (y-cut) (20-180°C), SHG of 990-1064nm (z-cut) (20-188°C)
LiNbO3: SHG of Nd:YAG/YLF/YVO4 lasers (120°C)
KD*P: SHG of 532 nm (52.1 °C), ADP: SHG of 532 nm (51.2°C)

Reduction of optical damage
KTP, LiNbO3: Kept warm at 80°C

Protection from moisture
BBO, KD*P, KDP: Kept warm at well above the room temperature.

Sintec Optronics

Fluoride Powder

In extremely low concentrations (ppm), fluoride compounds are used in health applications. Fluoride compounds also have significant uses in synthetic organic chemistry. They are commonly used to alloy metal and for optical deposition. Certain fluoride compounds can be produced at nano-scale and in ultra high purity forms.

Cadmium Fluoride is a water insoluble Cadmium source for use in oxygen-sensitive applications, such as metal production. Cadmium Fluoride is generally immediately available in most volumes. High purity, submicron and nano-powder forms may be considered. American Elements produces to many standard grades when applicable, including Mil Spec (military grade); ACS, Reagent and Technical Grade; Food, Agricultural and Pharmaceutical Grade; Optical Grade, USP and EP/BP (European Pharmacopoeia/British Pharmacopoeia) and follows applicable ASTM testing standards. Typical and custom packaging is available. Additional technical, research and safety (MSDS) information is available as is a Reference Calculator for converting relevant units of measurement.

MgF2 is commonly used for optical lens coating, ceramics, electronic industry, manufacturing ceramics, glass, metallurgy magnesium metal flux, optical instrument of lenses and filters coating, cathode rays of the screen fluorescent material, flux, etc.

CaF2

MgF2

Specifications:

Product	**Calcium Fluoride**
Molecular Formula	CaF2
Grade	Fluorescent Grade
Appearance	White Powder
Purity (%)	≥99.92
Chloride (Cl) (%)	≤0.01
Na (%)	≤0.001
Plumbum (Pb) (%)	≤0.001
Fe (%)	≤0.001
Mg (%)	≤0.005
Sr (%)	≤0.005

Product	**Magnesium Fluoride**
Molecular Formula	MgF2
Grade	Fluorescent Grade
Appearance	White Powder
Ni (%)	≤0.02
Si (%)	≤0.003
Purity (%)	≥99.9
AL (%)	≤0.007
Mn (%)	≤0.002
Fe (%)	≤0.008
Cu (%)	≤0.007
Cr (%)	≤0.0