

Lithium Triborate (LiB_3O_5 , LBO)

Introduction

Lithium Triborate (LiB_3O_5 or LBO) is an excellent nonlinear optical crystal discovered and developed by FIRSM, CAS (Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences). Fujian CASTECH Crystals, Inc. (**CASTECH**) has the exclusive rights to produce, manufacture and market the patented LBO crystal and its NLO devices. **The patent number is 4,826,283 in USA, 2023845 in Japan and 88 1 02084.2 in China.**

CASTECH's LBO is featured by

- broad transparency range from 160nm to 2600nm (see Figure 1);
- high optical homogeneity ($\delta n \approx 10^{-6}/\text{cm}$) 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.

CASTECH offers

- strict quality control;
- large crystal size up to $30 \times 30 \times 30 \text{mm}^3$ 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 $\text{Pna}2_1$, Point group $\text{mm}2$
Lattice Parameter	$a=8.4473 \text{Å}$, $b=7.3788 \text{Å}$, $c=5.1395 \text{Å}$, $Z=2$
Melting Point	About 834°C
Mohs Hardness	6
Density	2.47 g/cm^3
Thermal Conductivity	3.5 W/m/K
Thermal Expansion Coefficients	$\alpha_x=10.8 \times 10^{-5}/\text{K}$, $\alpha_y=-8.8 \times 10^{-5}/\text{K}$, $\alpha_z=3.4 \times 10^{-5}/\text{K}$

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, λ in μm)	$dn_x/dT=-9.3 \times 10^{-6}$ $dn_y/dT=-13.6 \times 10^{-6}$ $dn_z/dT=(-6.3-2.1\lambda) \times 10^{-6}$
Absorption Coefficients	<0.1%/cm at 1064nm <0.3%/cm at 532nm
Angle Acceptance	6.54mrad·cm (Φ, Type I, 1064 SHG) 15.27mrad·cm (θ, 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 Coefficients	$d_{\text{eff}}(\text{I})=d_{32}\cos\phi$ (Type I in XY plane) $d_{\text{eff}}(\text{I})=d_{31}\cos^2\theta+d_{32}\sin^2\theta$ (Type I in XZ plane) $d_{\text{eff}}(\text{II})=d_{31}\cos\theta$ (Type II in YZ plane) $d_{\text{eff}}(\text{II})=d_{31}\cos^2\theta+d_{32}\sin^2\theta$ (Type II in XZ plane)
Non-vanished NLO susceptibilities	$d_{31}=1.05 \pm 0.09$ pm/V $d_{32}=-0.98 \pm 0.09$ pm/V $d_{33}=0.05 \pm 0.006$ pm/V
Sellmeier Equations (λ in μm)	$n_x^2=2.454140+0.011249/(\lambda^2-0.011350)-0.014591\lambda^2-6.60 \times 10^{-5} \lambda^4$ $n_y^2=2.539070+0.012711/(\lambda^2-0.012523)-0.018540\lambda^2+2.00 \times 10^{-5} \lambda^4$ $n_z^2=2.586179+0.013099/(\lambda^2-0.011893)-0.017968\lambda^2-2.26 \times 10^{-5} \lambda^4$

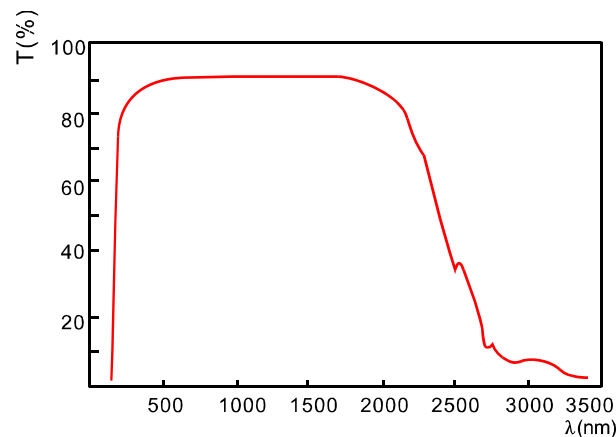


Figure 1. Transparency curve of LBO

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 effective SHG coefficient see Table 2).

The optimum type II phase matching falls in the principal YZ and XZ planes (see Fig. 2), (the effective SHG coefficient see Table 2).

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 by using CASTECH's LBO crystals.

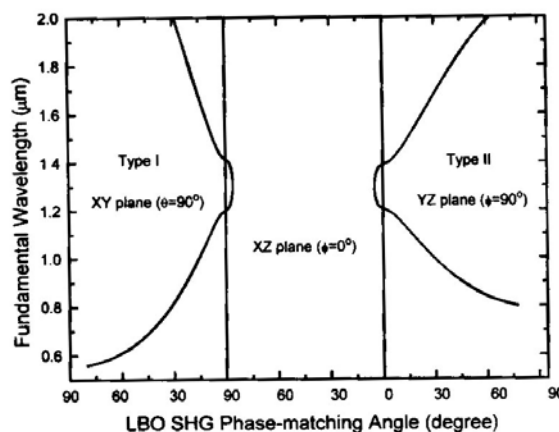


Figure 2. SHG tuning curves of LBO

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 intracavity frequency tripling a Q-switched Nd:YAG laser.

Non-Critical Phase Matching

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.

(CASTECH develops an assembly of oven and temperature controller for NCPM applications. Please refer to Page 69 for more technical data.)

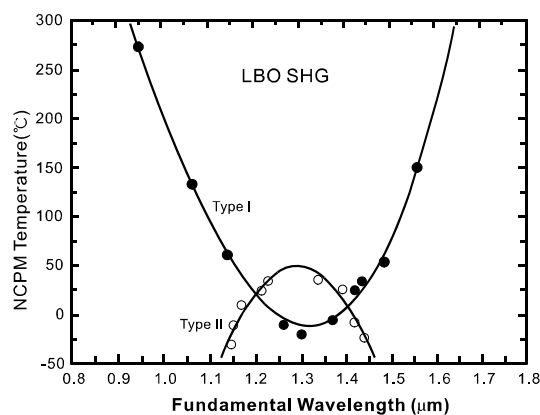


Figure 3. NCPM temperature tuning curves of LBO

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

NCPM Temperature	148°C
Acceptance Angle	52 mrad·cm
Walk-off Angle	0
Temperature Bandwidth	4°C·cm
Effective SHG Coefficient	2.69 x d ₃₆ (KDP)

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. Higher green output is expected with higher input power.

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 which 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 large 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.

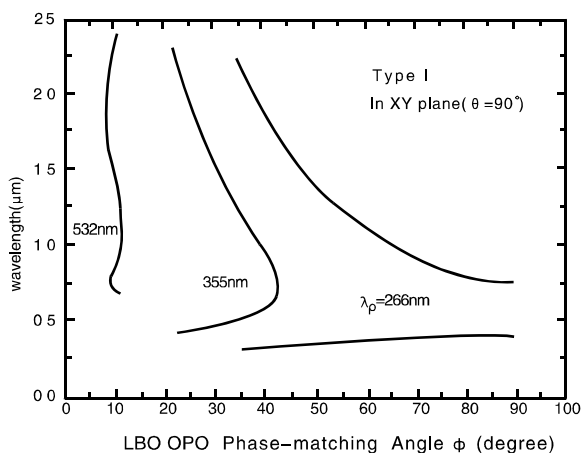


Figure 4. Type I OPO tuning curves of LBO

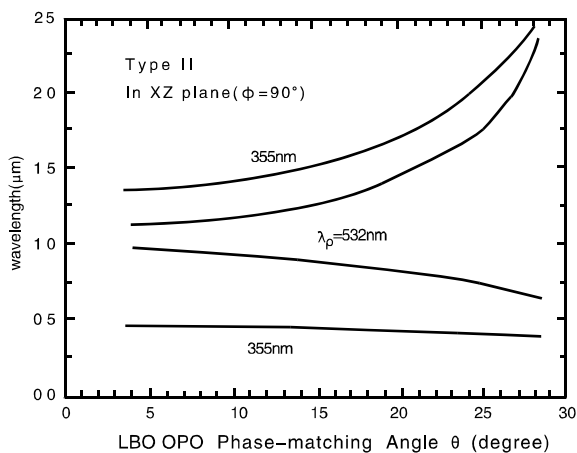


Figure 5. Type II OPO tuning curves of LBO

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 either by increasing the temperature of LBO or by rotating BBO.

LBO's Spectral NCPM

Not only the ordinary non-critical phase matching (NCPM) for angular variation but also the non-critical phase matching for spectral variation (SNCPM) can be achieved in the LBO crystal. As shown in Fig.2, the phase matching retracing positions are $\lambda_1=1.31 \mu\text{m}$ with $\theta =86.4^\circ$, $\phi=0^\circ$ for Type I and $\lambda_2=1.30 \mu\text{m}$ with $\theta =4.8^\circ$, $\phi=0^\circ$ for Type II. The phase matching at these positions possess very large spectral acceptances $\Delta\lambda$. The calculated $\Delta\lambda$ at λ_1 and λ_2 are $57\text{nm}\cdot\text{cm}$ and $74\text{nm}\cdot\text{cm}$ respectively, which are much larger than that of other NLO crystals. These spectral characteristics are very suitable for doubling broadband coherent radiations near $1.3 \mu\text{m}$, such as those from some diode lasers, and some OPA/OPO output without linewidth-narrowing components.

AR-coatings

CASTECH provides the following AR-coatings:

- 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 ($>500\text{MW}/\text{cm}^2$ at both wavelengths);
long durability.
- Broad Band AR-coating (BBAR) of LBO for SHG of tunable lasers.
- Other coatings are available upon request.

CASTECH's Warranty on LBO Specifications

- Dimension tolerance: $(W\pm 0.1\text{mm})\times(H\pm 0.1\text{mm})\times(L+0.5/-0.1\text{mm})$ ($L\geq 2.5\text{mm}$)
 $(W\pm 0.1\text{mm})\times(H\pm 0.1\text{mm})\times(L+0.1/-0.1\text{mm})$ ($L<2.5\text{mm}$)
- Clear aperture: central 90% of the diameter
- No visible scattering paths or centers when inspected by a 50mW green laser
- Flatness: less than $\lambda/8$ @ 633nm
- Transmitting wavefront distortion: less than $\lambda/8$ @ 633nm
- Chamfer: $\leq 0.2\text{mm} \times 45^\circ$
- Chip: $\leq 0.1\text{mm}$
- Scratch/Dig code: better than 10/ 5 to MIL-PRF-13830B
- Parallelism: better than 20 arc seconds
- Perpendicularity: ≤ 5 arc minutes
- Angle tolerance: $\Delta\theta\leq 0.25^\circ$, $\Delta\phi\leq 0.25^\circ$
- Damage threshold [GW/cm^2]: >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.

Notes

- LBO has a low susceptibility to moisture. Users are advised to provide dry conditions for both the use and preservation of LBO.
- Polished surfaces of LBO requires precautions to prevent any damage.
- CASTECH engineers can select and design the best crystal for you, based on the main parameters of your laser, 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.
- For thin crystals, CASTECH can provide free holders for you.

Beta-Barium Borate (β -BaB₂O₄ or BBO)

Introduction

Beta-Barium Borate (β -BaB₂O₄ or BBO), discovered and developed by FIRSM, CAS (Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences), now is manufactured and marketed by Fujian CASTECH Crystals, Inc. (CASTECH). The high-quality crystal boule is steadily available from CASTECH, who holds specialized proprietary techniques (flux-method) of the BBO crystal growth.

CASTECH's BBO is featured by

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

CASTECH offers

- Strict quality control;
- Crystal length from 0.005 mm to 25 mm and size up to 15x15x15 mm³;
- 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 Properties

Table 1. Chemical and Structural Properties

Crystal Structure	Trigonal, Space group R3c
Lattice Parameter	a=b=12.532Å, c=12.717Å, Z=6
Melting Point	About 1095°C
Mohs Hardness	4
Density	3.85 g/cm ³
Thermal Conductivity	1.2W/m/K(\perp c); 1.6W/m/K(//c)
Thermal Expansion Coefficients	$\alpha_{11}=4 \times 10^{-6}/\text{K}$; $\alpha_{33}=36 \times 10^{-6}/\text{K}$

Table 2. Optical and Nonlinear Optical Properties

Transparency Range	190-3500nm
SHG Phase Matchable Range	409.6-3500nm (Type I) 525-3500nm (Type II)
Therm-optic Coefficient (/°C)	$dn_o/dT = -16.6 \times 10^{-6}$ $dn_e/dT = -9.3 \times 10^{-6}$
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	$d_{\text{eff}}(\text{I}) = d_{31} \sin\theta + (d_{11} \cos 3\phi - d_{22} \sin 3\phi) \cos\theta$ $d_{\text{eff}}(\text{II}) = (d_{11} \sin 3\phi + d_{22} \cos 3\phi) \cos^2\theta$
Non-vanished NLO susceptibilities	$d_{11} = 5.8 \times d_{36}(\text{KDP})$ $d_{31} = 0.05 \times d_{11}$ $d_{22} < 0.05 \times d_{11}$
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:	$\chi_{22} = 2.7 \text{ pm/V}$
Half-wave voltage:	7 KV (at 1064 nm, 3x3x20mm ³)
Resistivity:	>10 ¹¹ ohm·cm
Relative Dielectric Constant:	$\epsilon_{11}^s / \epsilon_o : 6.7$ $\epsilon_{33}^s / \epsilon_o : 8.1$ $\text{Tan } \delta < 0.001$

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.

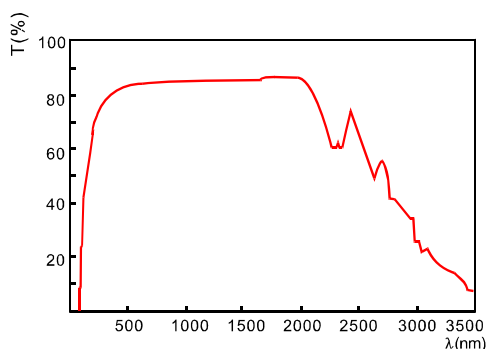


Figure 1. Transparency curve of BBO

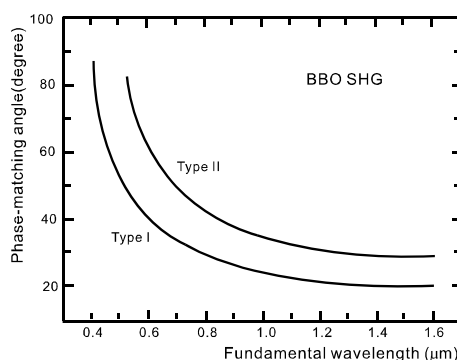


Figure 2. SHG tuning curves of BBO

Application in Nd:YAG Lasers

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

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

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

Applications in Tunable Lasers

1. Dye lasers

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

CASTECH's 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, CASTECH can provide as thin as 0.005mm BBO for this purpose. A laser pulse as short as 10 fs can be efficiently frequency-doubled with a thin BBO, in terms of both phase-velocity and group-velocity matching.

3. Ti:Sapphire and Alexandrite lasers

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

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

4. Argon Ion and Copper-Vapor lasers

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

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

BBO's OPO and OPA

The OPO and OPA of BBO are powerful tools for generating a widely tunable coherent radiation from the UV to IR. The tuning angles of type I and type II BBO OPO and OPA have been calculated, with the results shown in Fig. 3 and Fig. 4, 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 532 nm 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 CASTECH's BBO crystal, the OPO system covers a tuning range from 400nm to 3100nm which guarantees a maximum of 30% and more than 18% conversion efficiency, over the wavelength range from 430nm to 2000nm.

Type II BBO can be used to decrease linewidth near the degenerate points. A linewidth as narrow as 0.05 nm and usable conversion efficiency of 12% were obtained. However, a longer (> 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 355 nm, a narrow-band (< 0.3 nm), high energy (> 200 μ J) and wide tunable (400 nm to 2000 nm) pulse has been produced by BBO's OPAs. This OPA can reach as high as more than 50% conversion efficiency, and therefore is superior to common Dye lasers in many respects, including efficiency, tunable range, maintenance, and easiness in design and operation. Furthermore, coherent radiation from 205 nm to 3500 nm can be also generated by BBO's OPO or OPA plus a BBO for SHG.

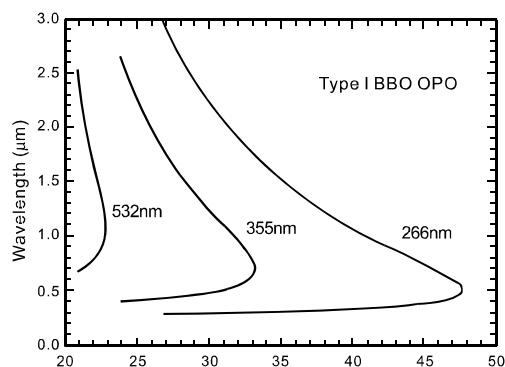


Figure 3. Type I OPO tuning curves of BBO

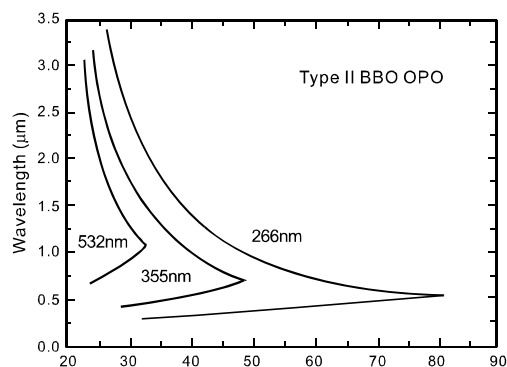


Figure 4. Type II OPO tuning curves of BBO

3.Others

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

When pumped by a 1mJ, 80 fs Dye laser at 615 nm, the OPA with two BBO crystals yields more than 50 μ J (maximum 130 μ J), < 200 fs 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 LiNbO₃. More than 80W output power and 50KHZ repetition rate have been reached by using CASTECH's E-O BBO crystals and Nd:YVO₄ crystals as gain media. At 5K HZ, its pulse has width as short as 6.4ns, and energy of 5.7 mJ 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, and its half-wave voltage is high(7KV at 1064nm, 3x3x20mm³), long and thin BBO can reduce the voltage requirements. CASTECH now can supply 25mm long and 1mm thin high optical quality of BBO crystal with Z-cut, AR-coated and Gold/Chrome plated on the side faces.

Coatings

CASTECH provides the following AR-coatings for BBO:

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

CASTECH's Warranty on BBO Specifications

- Dimension tolerance: (W \pm 0.1mm)x(H \pm 0.1mm)x(L+0.5/-0.1mm) (L \geq 2.5mm)
(W \pm 0.1mm)x(H \pm 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 $\lambda/8$ @ 633nm
- Transmitting wavefront distortion: less than $\lambda/8$ @ 633nm
- Chamfer: \leq 0.2mm x 45°
- Chip: \leq 0.1mm
- Scratch/Dig code: better than 10/ 5 to MIL-PRF-13830B
- Parallelism: \leq 20 arc seconds
- Perpendicularity: \leq 5 arc minutes
- Angle tolerance: \leq 0.25°
- Damage threshold[GW/cm²]: >1 for 1064nm, TEM00, 10ns, 10HZ (polished only)
>0.5 for 1064nm, TEM00, 10ns, 10HZ (AR-coated)
>0.3 for 532nm, TEM00, 10ns, 10HZ (AR-coated)
- Quality Warranty Period: one year under proper use.

Note

- BBO has a low susceptibility to the moisture. Users are advised to provide dry conditions for both application and preservation of BBO.
- BBO is relatively soft and therefore requires precautions to protect its polished surfaces.
- When angle adjusting is necessary, please keep in mind that the acceptance angle of BBO is small.
- CASTECH engineers can select and design the best crystal, based on the main parameters of your laser, 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.
- For thin crystals, CASTECH can provide free holders for you.

Potassium Titanyl Phosphate(KTiOPO₄, KTP)

Introduction

Potassium Titanyl Phosphate (KTiOPO₄ or KTP) is widely used in both commercial and military lasers including laboratory and medical systems, range-finders, lidar, optical communication and industrial systems.

CASTECH's KTP is featured by

- 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
- Nonhygroscopic, chemically and mechanically stable

CASTECH offers

- Strict quality control
- Large crystal size up to 20x20x40mm³ and maximum length of 60mm;
- Quick delivery (2 weeks for polished only, 3 weeks for coated)
- Unbeatable price and quantity discount
- Technical support
- AR-coating, mounting and re-polishing service

Table 1. Chemical and Structural Properties

Crystal Structure	Orthorhombic, space group Pna2 ₁ , point group mm2
Lattice Parameter	a=6.404Å, b=10.616Å, c=12.814Å, Z=8
Melting Point	About 1172°C
Mohs Hardness	5
Density	3.01 g/cm ³
Thermal Conductivity	13W/m/K
Thermal Expansion Coefficient	$\alpha_x=11 \times 10^{-6}/^{\circ}\text{C}$, $\alpha_y=9 \times 10^{-6}/^{\circ}\text{C}$, $\alpha_z=0.6 \times 10^{-6}/^{\circ}\text{C}$

Table 2. Optical and Nonlinear Optical Properties

Transparency Range	350-450nm
SHG Phase Matchable Range	497-1800nm (Type II)
Therm-optic Coefficients (/°C)	$dn_x/dT=1.1 \times 10^{-5}$ $dn_y/dT=1.3 \times 10^{-5}$ $dn_z/dT=1.6 \times 10^{-5}$
Absorption Coefficients	<0.1%/cm at 1064nm <1%/cm at 532nm
For Type II SHG of a Nd:YAG laser at 1064nm	Temperature Acceptance: 24°C·cm Spectral Acceptance: 0.56nm·cm Angular Acceptance: 14.2mrad·cm (Φ); 55.3mrad·cm(θ) Walk-off Angle: 0.55°
NLO Coefficients	$d_{\text{eff}}(\text{II}) \approx (d_{24} - d_{15})\sin 2\phi \sin 2\theta - (d_{15}\sin^2\phi + d_{24}\cos^2\phi)\sin\theta$
Non-vanished NLO susceptibilities	$d_{31}=6.5$ pm/V $d_{24}=7.6$ pm/V $d_{32}=5$ pm/V $d_{15}=6.1$ pm/V $d_{33}=13.7$ pm/V
Sellmeier Equations (λ in μm)	$n_x^2=3.0065+0.03901/(\lambda^2-0.04251)-0.01327\lambda^2$ $n_y^2=3.0333+0.04154/(\lambda^2-0.04547)-0.01408\lambda^2$ $n_z^2=3.0065+0.05694/(\lambda^2-0.05658)-0.01682\lambda^2$
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
Dielectric constant:	$\epsilon_{\text{eff}}=13$

Applications for SHG and SFG of Nd: lasers

KTP is the most commonly used material for frequency doubling of Nd:YAG and other Nd-doped lasers, particularly when the power density is at a low or medium level. To date, extra- and intra-cavity frequency doubled Nd:lasers using KTP have become a preferred pumping source for visible dye lasers and tunable Ti:Sapphire lasers as well as their amplifiers. They are also useful green sources for many research and industry applications.

- More than 80% conversion efficiency and 700mJ green laser were obtained with a 900mJ injection-seeded Q-switch Nd:YAG lasers by using extra-cavity KTP.
- 8W green laser was generated from a 15W LD pumped Nd:YVO₄ with intra-cavity KTP.
- 200mW green outputs are generated from 1W LD pumped Nd:YVO₄ lasers by using CASTECH's 2x2x5mm³ KTP and 3x3x1mm³ Nd:YVO₄.
- 2-5mw green outputs are generated from 180mw LD pumped Nd:YVO₄ and KTP glued crystals. For more details, please refer to P67.

KTP is also being used for intracavity mixing of 0.81 μm diode and 1.064 μm Nd:YAG laser to generate blue light and intracavity SHG of Nd:YAG or Nd:YAP lasers at 1.3 μm to produce red light.

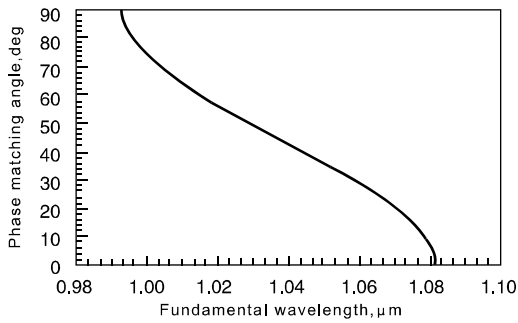


Fig. 1 Type II KTP SHG in XY Plane

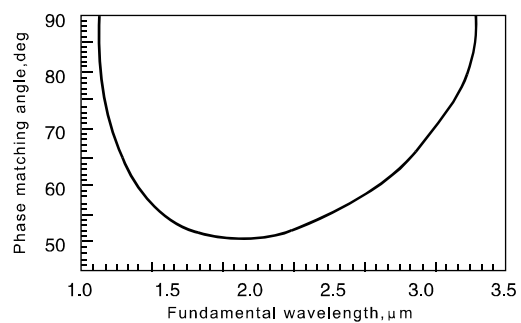


Fig. 2 Type II KTP SHG in XZ Plane

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 outputs from visible (600nm) to mid-IR (4500nm), as shown in Fig. 3 and Fig. 4.

Generally, KTP's OPOs provide stable and continuous pulse outputs (signal and idler) in fs, with 10^8 Hz repetition rate and a milliwatt average power level. A KTP's OPO that are pumped by a 1064nm Nd:YAG laser has generated as high as above 66% efficiency for degenerately converting to 2120nm.

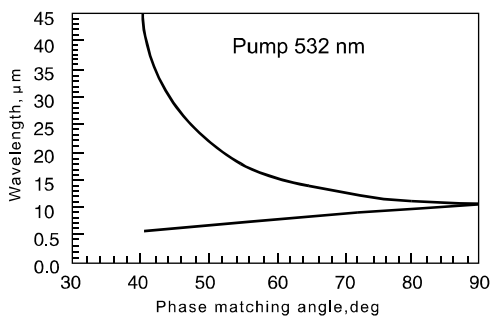


Fig. 3 OPO pumped at 532 in X-Z plane

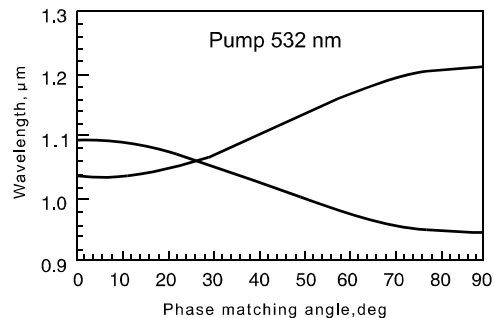


Fig. 4 OPO pumped at 532 in X-Y plane

The novel developed application is the non-critical phase matched (NCPM) KTP's OPO/OPA. As shown in Fig.5, for pumping wavelength range from 0.7μm to 1μm, the output can cover from 1.04μm to 1.45μm (signal) and from 2.15μm to 3.2μm (idler). More than 45% conversion efficiency was obtained with narrow output bandwidth and good beam quality.

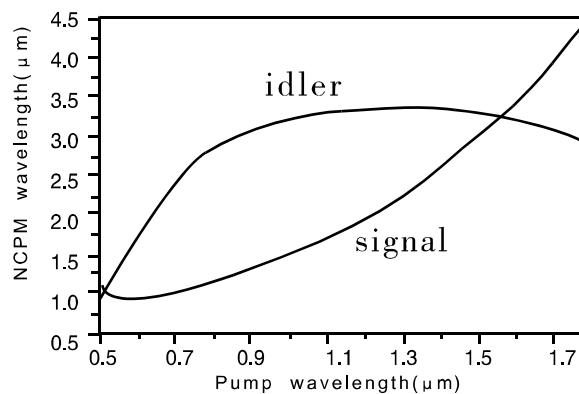


Fig. 5 Type II NCPM OPO

Applications for E-O Devices

In addition to unique NLO features, KTP also has promising E-O and dielectric properties that are comparable to LiNbO₃. These advantaged properties make KTP extremely useful to various E-O devices. Table 1 is a comparison of KTP with other E-O modulator materials commonly used:

Table 1. Electro-Optic Modulator Materials

Material			Phase			Amplitude		
	ϵ	N	R(pm/V)	k(10 ⁻⁶ /°C)	N ⁷ r ² /ε(pm/V) ²	r(pm/V)	k(10 ⁻⁶ /°C)	n ⁷ r 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	8.8	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

From Table 1, clearly, KTP is expected to replace LiNbO₃ crystal in the considerable volume application of E-O modulators, when other merits of KTP are combined into account, such as high damage threshold, wide optical bandwidth (>15GHZ), thermal and mechanical stability, and low loss, etc.

Applications for Optical Waveguides

Based on the ion-exchange process on KTP substrate, low loss optical waveguides developed for KTP have created novel applications in integrated optics. Table 2 gives a comparison of KTP with other optical waveguide materials. Recently, a type II SHG conversion efficiency of 20%/W/cm² was achieved by the balanced phase matching, in which the phase mismatch from one section was balanced against a phase mismatch in the opposite sign from the second. Furthermore, segmented KTP waveguides have been applied to the type I quasi-phase-matchable SHG of a tunable Ti:Sapphire laser in the range of 760-960nm, and directly doubled diode lasers for the 400-430nm outputs.

Table 2. Electro-Optic Waveguide Materials

Materials	r (pm/V)	n	$\epsilon_{\text{eff}} (\epsilon_{11}\epsilon_{33})^{1/2}$	n ³ r/ε _{eff} (pm/V)
KTP	35	1.86	13	17.3
LiNbO ₃	29	2.20	37	8.3
KNbO ₃	25	2.17	30	9.2
BNN	56	2.22	86	7.1
BN	56-1340	2.22	119-3400	5.1-0.14
GaAs	1.2	3.6	14	4.0
BaTiO ₃	28	2.36	373	1.0

AR-coatings

CASTECH provides the following AR-coatings:

- Dual Band AR-coating (DBAR) of KTP for SHG of 1064nm.
low reflectance ($R < 0.2\%$ at 1064nm and $R < 0.5\%$ at 532nm);
high damage threshold ($> 300 \text{ MW/cm}^2$ at both wavelengths);
long durability.
- Broad Band AR-coating (BBAR) of KTP for OPO applications.
- High reflectivity coating: HR1064nm&HT532nm, $R > 99.8\%$ @1064nm, $T > 90\%$ @532nm.
- Other coatings are available upon request.

CASTECH's Warranty on KTP Specifications

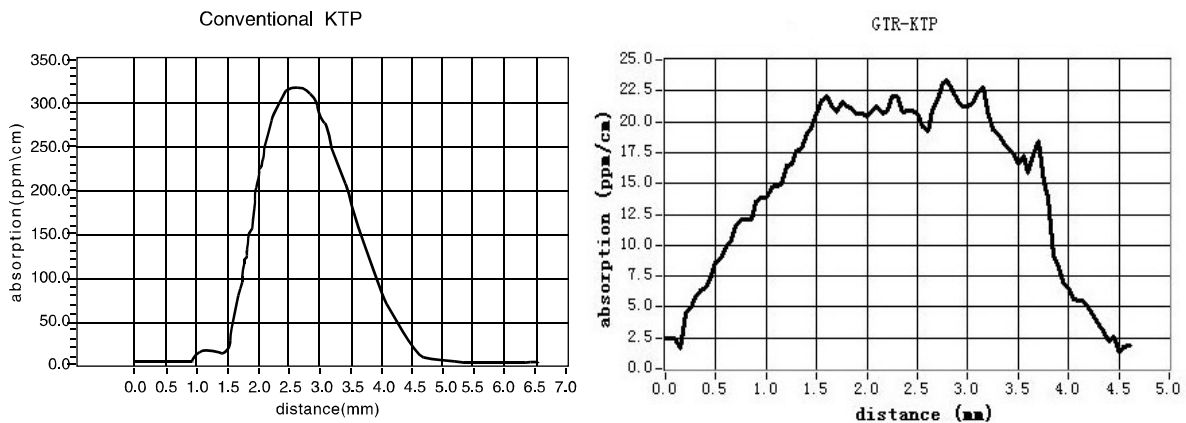
- Dimension tolerance: $(W \pm 0.1 \text{ mm}) \times (H \pm 0.1 \text{ mm}) \times (L + 0.5 / - 0.1 \text{ mm})$ ($L \geq 2.5 \text{ mm}$)
 $(W \pm 0.1 \text{ mm}) \times (H \pm 0.1 \text{ mm}) \times (L + 0.1 / - 0.1 \text{ mm})$ ($L < 2.5 \text{ mm}$)
- Clear aperture: central 90% of the diameter
- No visible scattering paths or centers when inspected by a 50mW green laser
- Flatness: less than $\lambda/8$ @ 633nm
- Transmitting wavefront distortion: less than $\lambda/8$ @ 633nm
- Chamfer: $\leq 0.2 \text{ mm} \times 45^\circ$
- Chip: $\leq 0.1 \text{ mm}$
- Scratch/Dig code: better than 10/ 5 to MIL-PRF-13830B
- Parallelism: better than 20 arc seconds
- Perpendicularity: ≤ 5 arc minutes
- Angle tolerance: $\leq 0.25^\circ$
- Damage threshold [GW/cm^2]: > 0.5 for 1064nm, TEM00, 10ns, 10HZ (AR-coated)
 > 0.3 for 532nm, TEM00, 10ns, 10HZ (AR-coated)
- Quality Warranty Period: one year under proper use.

Gray-track Resistance KTP(KTiOPO₄, GTR-KTP)

Introduction

Potassium Titanyl Phosphate (KTiOPO₄ or KTP) is an excellent NLO crystal, widely used in both commercial and military lasers. However conventional KTP suffer a significant drawbacks. The gray track phenomena in conventional KTP limit its application in high repetition and high power laser system. The occurrence of gray-track can be measured by an increase of bulk absorption by a strong CW 532nm green laser within several minutes. This measurement can be performed with Photo-thermal Common-path interferometer.

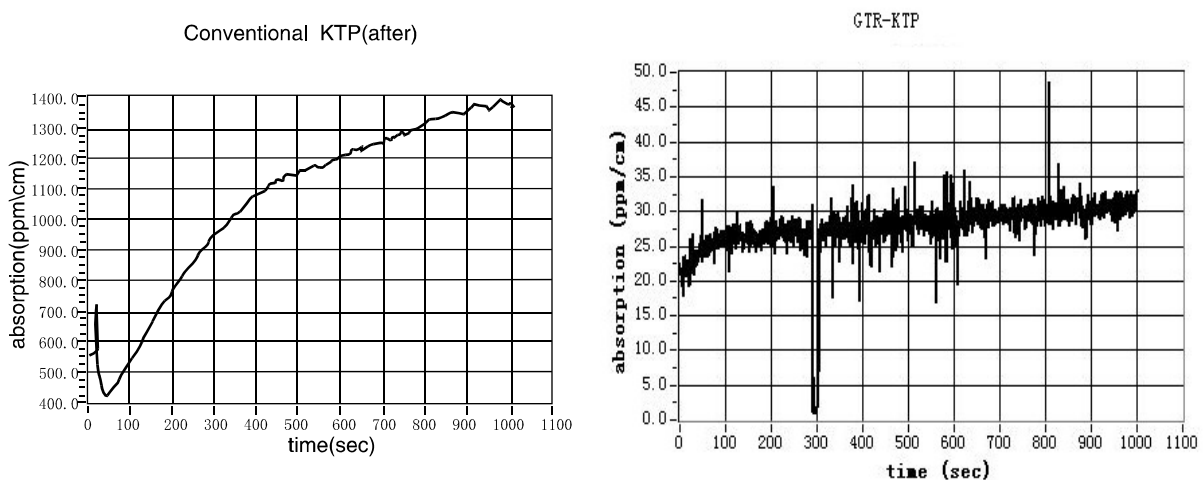
1. Longitudinal Test (Before Gray Tracking Test):



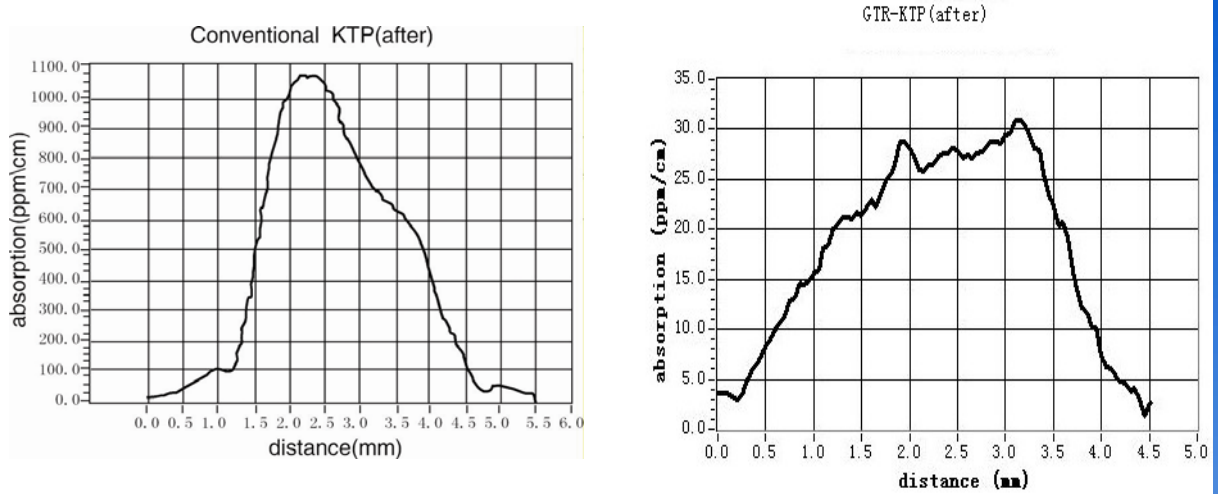
It appears that the absorption of GTR-KTP at 1064nm is only 1/10 of conventional KTP.

2. Gray Tracking Test:

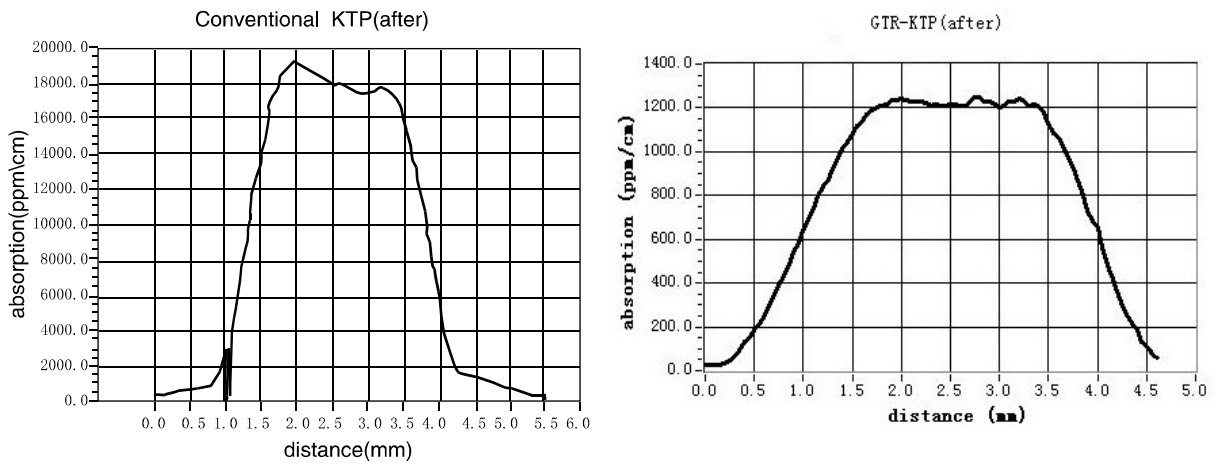
When a green laser beam(400mW, beam diameter 0.07mm, power density 10KW/cm²) goes through the crystal, it causes an increase in the IR absorption of the crystal. This phenomenon is correlated with “gray tracking effect”. The following graphs show the different absorption levels at 1064nm between CASTECH’s GTR KTP and the conventional KTP.



3. Transverse scan after gray tracking test (at 1064 nm):



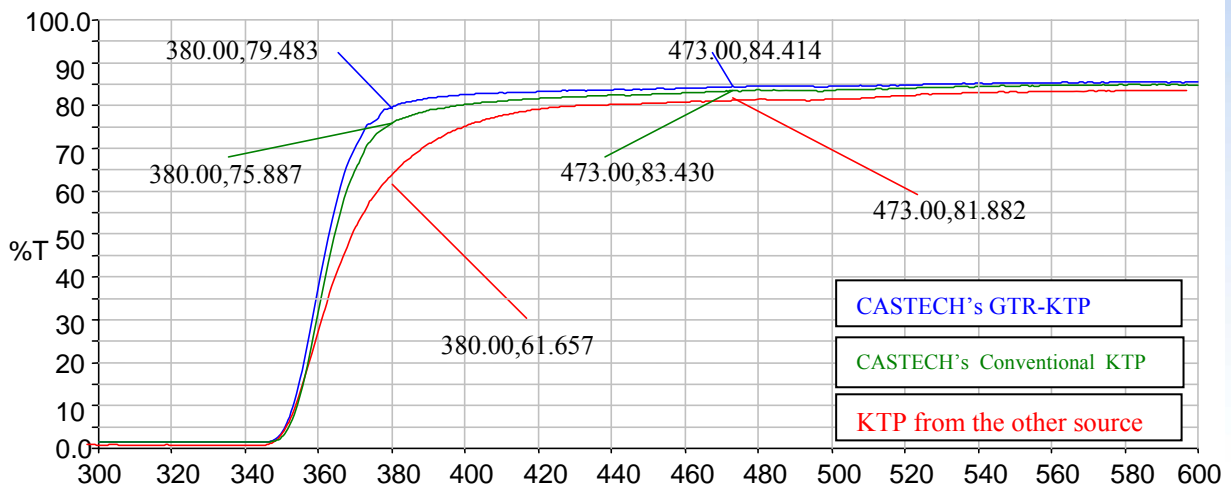
4. Transverse scan after gray tracking test (at 532 nm) :



5. Damage threshold testing:

After testing a group of GTR-KTP and the conventional KTP crystals (polished only) with laser condition of 10ns, 1 HZ, we found that CASTECH's GTR-KTP has laser damage threshold around 1.8GW/cm² at 1064nm, which is much higher than the conventional KTP(450MW/cm² in the same condition).

6. Transmission curve in the visible and UV region:



Apparently CASTECH's GTR-KTP has lower absorption than the conventional KTP in the range of 350-550nm.

We can conclude that CASTECH's GTR-KTP is expected to have a higher gray track resistance than the regular flux grown KTP crystals.

CASTECH provides the following AR-coatings

- IBS, IAD or E-beam coating methods are available upon request.
- Dual Band AR-coating (DBAR) of GTR-KTP for SHG of 1064nm.
low reflectance ($R < 0.2\%$ at 1064nm and $R < 0.5\%$ at 532nm);
high damage threshold ($> 1.2\text{GW}/\text{cm}^2$ at 1064nm, $> 300\text{MW}/\text{cm}^2$ at 532nm, at 10ns, 2.5HZ)
long durability.
- Broad Band AR-coating (BBAR) of GTR-KTP for OPO applications.
- High reflectivity coating: HR1064nm&HT532nm, $R > 99.8\%$ @1064nm, $T > 95\%$ @532nm.
- Other coatings are available upon request.

CASTECH offers GTR-KTP with

- Strict quality control
- Large crystal size up to $7 \times 7 \times 20\text{mm}^3$
- Quick delivery(2 weeks for polished only, 3 weeks for coated)
- Unbeatable price and quantity discount
- Technical support
- AR, HR-coating, mounting and re-polishing service

CASTECH's Warranty on GTR-KTP Specifications

- Dimension tolerance: $(W \pm 0.1\text{mm}) \times (H \pm 0.1\text{mm}) \times (L + 0.5/-0.1\text{mm})$ ($L \geq 2.5\text{mm}$)
 $(W \pm 0.1\text{mm}) \times (H \pm 0.1\text{mm}) \times (L + 0.1/-0.1\text{mm})$ ($L < 2.5\text{mm}$)
- Clear aperture: central 90% of the diameter
- No visible scattering paths or centers when inspected by a 50mW green laser
- Flatness: less than $\lambda/8$ @ 633nm
- Transmitting wavefront distortion: less than $\lambda/8$ @ 633nm
- Chamfer: $\leq 0.2\text{mm} \times 45^\circ$
- Chip: $\leq 0.1\text{mm}$
- Scratch/Dig code: better than 10/5(polished only) to MIL-PRF-13830B
better than 20/10(AR-coated) to MIL-PRF-13830B
better than 40/20(HR-coated) to MIL-PRF-13830B
- Parallelism: better than 20 arc seconds
- Perpendicularity: ≤ 5 arc minutes
- Angle tolerance: $\leq 0.25^\circ$

RTP Crystal

Introduction

RTP (Rubidium Titanyle Phosphate – RbTiOPO_4) is an isomorph of KTP crystal which is used in nonlinear and Electro-Optical applications. It has advantages of high damage threshold (about 1.8 times of KTP), high resistivity, high repetition rate, no hygroscopic and no induced piezo-electric effect with electrical signals up to 60 kHz. Its transmission range is 350nm to 4500nm.

Basic Properties

Crystal structure	Orthorhombic
Cell Parameters	$a = 12.96 \text{ \AA}$; $b = 10.56 \text{ \AA}$; $c = 6.49 \text{ \AA}$
Mohs hardness	About 5
Density (g/cm^3)	3.6
Melting Point:	About 1000°C
Thermal Expansion Coefficients (/K)	$\alpha_x = 1.01 \times 10^{-5}$, $\alpha_y = 1.37 \times 10^{-5}$ $\alpha_z = -4.17 \times 10^{-6}$
Sellmeier equations (λ in μm)	$n_x^2 = 2.15559 + 0.93307[1 - (0.20994/\lambda)^2] - 0.01452 \lambda^2$ $n_y^2 = 2.38494 + 0.73603[1 - (0.23891/\lambda)^2] - 0.01583 \lambda^2$ $n_z^2 = 2.27723 + 1.11030[1 - (0.23454/\lambda)^2] - 0.01995 \lambda^2$
Thermo-optical coefficients ($d\lambda/dT$)	$-0.029 \text{ nm}/^\circ\text{C}$
Electro-optic constants(Y-cut) (X-cut)	$r_{33} = 38.5 \text{ pm/V}$ $r_{33} = 35 \text{ pm/V}$, $r_{23} = 12.5 \text{ pm/V}$, $r_{13} = 10.6 \text{ pm/V}$
Electrical Resistivity	About 10^{11} - $10^{12} \text{ ohm}\cdot\text{cm}$
Static Half Wave Voltage at 1064 nm	4x4x20 mm: 1,600 V 6x6x20 mm: 2,400 V 9x9x20 mm: 3,600 V
Extinction Ratio	$>20\text{dB}@633\text{nm}$

Specifications

Growing Orientation	Along Y-axis
Maximum length(5x5mm ² aperture)	25mm
Length tolerance (mm)	+0.5 / -0.1
Width and height tolerance (mm)	± 0.1
Parallelism	$< 30''$
Perpendicularity	$< 15'$
Surface quality	20/10
Coating	AR-coatings

Potassium Titanyle Arsenate(KTiOAsO₄, KTA)

Introduction

Potassium Titanyle Arsenate(KTiOAsO₄), or KTA crystal, is an excellent nonlinear optical crystal for Optical Parametric Oscillation (OPO) application. It has better non-linear optical and electro-optical coefficients, significantly reduced absorption in the 2.0-5.0 μm region, broad angular and temperature bandwidth, low dielectric constants. And its low ionic conductivities result in higher damage threshold compared with KTP .

CASTECH offers KTA

- Crystal length from 0.1mm to 30mm and size up to 10x10x30mm
- AR-coating from visible to 3300nm
- Re-polishing, re-coating service
- Fast delivery(10 working days for polished only, 15 working days for AR-coated)

Table 1. Basic properties

Crystal Structure	Orthorhombic, point group mm2,
Lattice parameter	a=13.125Å, b=6.5716Å, c=10.786Å
Melting point	1130 °C
Mohs Hardness	near 5
Density	3.454g/cm ³
Thermal conductivity	K1:1.8W/m/K; K2: 1.9W/m/K; K3: 2.1W/m/K

Table 2. Optical and Nonlinear Optical Properties

Transparency Range	350-5300nm				
Absorption Coefficients	@ 1064 nm <0.05 %/cm @ 1533 nm <0.05 %/cm @ 3475 nm <5%/cm				
NLO susceptibilities (pm/V)	d ₃₁ = 2.76, d ₃₂ = 4.74, d ₃₃ = 18.5 , d ₁₅ = 2.3, d ₂₄ = 3.2				
Sellmeier Equation $n_i^2 = A_i + B_i \lambda^2 / (\lambda^2 - C_i^2) - D_i \lambda^2$ (λ in μm)	index	A	B	C	D
	n _x	1.90713	1.23522	0.19692	0.01025
	n _y	2.15912	1.00099	0.21844	0.01096
	n _z	2.14768	1.29559	0.22719	0.01436
Electro-optical constants (pm/V) (low frequency)	r ₃₃ =37.5; r ₂₃ =15.4; r ₁₃ =11.5				
SHG Phase Matchable Range	1083-3789nm				

BiB₃O₆ (BIBO) Crystal

Introduction

BiB₃O₆ (BIBO) is a newly developed nonlinear optical crystal. It possesses large effective nonlinear coefficient, high damage threshold and inertness with respect to moisture. Its nonlinear coefficient is 3.5 - 4 times higher than that of LBO, 1.5 - 2 times higher than that of BBO. It is a promising doubling crystal to produce blue laser. The top-seeded solution growth (TSSG) technique is used at CASTECH for the growth of BIBO single crystals.

CASTECH offers

- Strict quality control;
- Large crystal size up to 10x10x15mm³ ;
- AR-coating, mounts and repolishing services;
- Fast delivery.

Table 1. Chemical and Structural Properties

Crystal Structure	Monoclinic, Point group 2
Lattice Parameter	a=7.116 Å , b=4.993 Å , c=6.508 Å , β=105.62°, Z=2
Melting Point	726°C
Mohs Hardness	5-5.5
Density	5.033 g/cm ³
Thermal Expansion Coefficient	α _a =4.8 x 10 ⁻⁵ /K , α _b = 4.4 x 10 ⁻⁶ /K, α _c =-2.69 x 10 ⁻⁵ /K

Table 2. Optical and Nonlinear Optical Properties

Transparency Range	286- 2500 nm
Absorption Coefficient	<0.1%/cm at 1064nm
Physical Axis	X // b, (Z,a)=31.6° ,(Y,c)=47.2°
SHG of 1064/532nm	Phase matching angle: 168.9° from Z axis in YZ plane Deff : 3.0 ± 0.1 pm/V Angular acceptance: 2.32 mrad·cm Walk-off angle: 25.6 mrad Temperature acceptance: 2.17 °C·cm

Sellmeier coefficients	$n^2_i(\lambda) = A + B/(\lambda^2 - C) - D \lambda^2$ (λ in μm)			
	A	B	C	D
n ₁	3.6545(4)	0.0511(2)	0.0371(3)	0.0226(1)
n ₂	3.0740(3)	0.0323(1)	0.0316(3)	0.01337(6)
n ₃	3.1685(3)	0.0373(1)	0.0346(3)	0.01750(8)

CASTECH's Warranty on BIBO Specifications

- Dimension tolerance: $(W \pm 0.1\text{mm}) \times (H \pm 0.1\text{mm}) \times (L + 0.5/-0.1\text{mm})$ ($L \geq 2.5\text{mm}$)
 $(W \pm 0.1\text{mm}) \times (H \pm 0.1\text{mm}) \times (L + 0.1/-0.1\text{mm})$ ($L < 2.5\text{mm}$)
- Clear aperture: central 90% of the diameter
- Flatness: less than $\lambda/8$ @ 633nm
- Transmitting wavefront distortion: less than $\lambda/8$ @ 633nm
- Chamfer: $\leq 0.2\text{mm} \times 45^\circ$
- Chip: $\leq 0.1\text{mm}$
- Scratch/Dig code: better than 10/ 5 to MIL-PRF-13830B
- Parallelism: better than 20 arc seconds
- Perpendicularity: ≤ 5 arc minutes
- Angle tolerance: $\Delta\theta \leq 0.25^\circ$, $\Delta\phi \leq 0.25^\circ$
- Damage threshold[GW/cm²]: >0.3 for 1064nm, TEM00, 10ns, 10HZ
- Quality Warranty Period: one year under proper use.

Lithium Niobate Crystal (LiNbO₃)

Introduction

LiNbO₃ 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. Additionally due to its large Electro-Optic(E-O) and Acousto-Optic(A-O) coefficients, LiNbO₃ crystal is the most commonly used material for Pockel Cells, Q-switches and phase modulators, waveguide substrate, and surface acoustic wave(SAW) wafers, etc. **CASTECH** can provide LiNbO₃ crystals with high quality and large size for all these applications.

Structural and Physical Properties of LiNbO₃

Crystal Structure:	Trigonal, Space group R3c, Point group 3m
Cell Parameters:	a=5.148 Å , c=13.863 Å
Melting Point:	1253°C
Curie Temperature:	1140°C
Mohs Hardness:	5
Density:	4.64 g/cm ³
Elastic Stiffness Coefficients	$C_{11}^E = 2.33(\times 10^{11} \text{N/m}^2)$ $C_{33}^E = 2.77(\times 10^{11} \text{N/m}^2)$

Optical and Electro-optical Properties of LiNbO₃

Transparency Range:	420-5200nm
Optical Homogeneity:	$\sim 5 \times 10^{-5} / \text{cm}$
Refractive indices at 1064nm:	$n_e = 2.146, n_o = 2.220 @ 1300 \text{ nm}$ $n_e = 2.156, n_o = 2.232 @ 1064 \text{ nm}$ $n_e = 2.203, n_o = 2.286 @ 632.8 \text{ nm}$
NLO Coefficients:	$d_{33} = 86 \times d_{36} \text{ (KDP)}$ $d_{31} = 11.6 \times d_{36} \text{ (KDP)}$ $d_{22} = 5.6 \times d_{36} \text{ (KDP)}$
Effective NLO Coefficients:	$d_{\text{eff}}(\text{I}) = d_{31} \sin\theta - d_{22} \cos\theta \sin 3\phi$ $d_{\text{eff}}(\text{II}) = d_{22} \cos^2\theta \cos 3\phi$
Electro-Optic Coefficients	$\gamma_{33}^T = 32 \text{ pm/V}, \gamma_{33}^S = 31 \text{ pm/V},$ $\gamma_{31}^T = 10 \text{ pm/V}, \gamma_{31}^S = 8.6 \text{ pm/V},$ $\gamma_{22}^T = 6.8 \text{ pm/V}, \gamma_{22}^S = 3.4 \text{ pm/V},$
Half-Wave Voltage, DC Electrical field // z, light ⊥ z: Electrical field // x or y, light // z:	3.03 KV 4.02 KV
Damage Threshold	100 MW/cm ² (10 ns, 1064nm)

Thermal and Electrical Properties of LiNbO₃

Melting Point:	1250°C
Curie Temperature:	1140°C
Thermal Conductivity:	38W/m/K @25°C
Thermal Expansion Coefficients (at 25°C):	//a, $2.0 \times 10^{-6}/K$ //c, $2.2 \times 10^{-6}/K$
Resistivity:	$2 \times 10^{-6} \Omega \cdot \text{cm}$ @200°C
Dielectric Constants:	$\epsilon_{11}^S / \epsilon_0 = 43$ $\epsilon_{11}^T / \epsilon_0 = 78$ $\epsilon_{33}^S / \epsilon_0 = 28$ $\epsilon_{33}^T / \epsilon_0 = 32$
Piezoelectric Strain Constant:	$D_{22} = 2.04 (\times 10^{-11} \text{ C/N})$ $D_{33} = 19.22 (\times 10^{-11} \text{ C/N})$

The Sellmeier equations (λ in μm) :

$$n_o^2 = 4.9048 + 0.11768 / (\lambda^2 - 0.04750) - 0.027169\lambda^2$$

$$n_c^2 = 4.5820 + 0.099169 / (\lambda^2 - 0.04443) - 0.02195\lambda^2$$

Specifications

- Transmitting wavefront distortion: less than $\lambda/4$ @ 633 nm
- Dimension tolerance: (W \pm 0.1 mm) x (H \pm 0.1 mm) x (L \pm 0.2mm)
- Clear aperture: > 90% central area
- Flatness: $\lambda/8$ @ 633 nm
- Scratch/Dig code: 20/10 to MIL-PRF-13830B
- Parallelism: better than 20 arc seconds
- Perpendicularity: 5 arc minutes
- Angle tolerance: $< \pm 0.5^\circ$
- AR coating: dual wave band AR coating at 1064/532 nm on both surfaces, with R < 0.2% at 1064nm and R < 0.5% at 532nm per surface.

Other coatings are available upon request.

Magnesium Doped Lithium Niobate MgO:LiNbO₃

Introduction

Compared with LiNbO₃ crystal, MgO:LiNbO₃ crystal exhibits its particular advantages for NCPM frequency doubling (SHG) of Nd:Lasers, mixing (SFG) and optical parametric oscillators (OPOs). The SHG efficiencies of over 65% for pulsed Nd:YAG lasers and 45% for cw Nd:YAG lasers have been achieved by MgO:LiNbO₃ crystals, respectively. MgO:LiNbO₃ is also a good crystal for optical parametric oscillators (OPOs) and amplifiers (OPAs), quasi-phase-matched doublers and integrated waveguide.

MgO:LiNbO₃ is characterized by

- High damage threshold
- Noncritical phase matching (NCPM) at room temperature
- Broad transparency range
- Excellent E-O and NLO properties
- Good mechanical and chemical properties

MgO:LiNbO₃ has similar effective nonlinear coefficient to pure LiNbO₃. Its Sellmeier equations (for 5mol% MgO dopant) are (λ in μm):

$$n_o^2(\lambda) = 4.8762 + 0.11554 / (\lambda^2 - 0.04674) - 0.033119 \times \lambda^2$$

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

Different dimensions of MgO:LiNbO₃ with high quality are available from CASTECH. The AR coating is available upon request.

Potassium Dihydrogen Phosphate (KDP) and Potassium Dideuterium Phosphate (DKDP or KD*P)

Introduction

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 under 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.

CASTECH's KDP & KD*P products

CASTECH supplies high quality KDP and KD*P crystals in large quantities for these applications. Because their polished surfaces are easier to be moistened, the user is advised to provide the dry condition (<50%) and the sealed housing for preservation. For this purpose, CASTECH 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.

Basic Properties

	KDP	KD*P
Chemical Formula	KH_2PO_4	KD_2PO_4
Transparency Range	200-1500nm	200-1600nm
Nonlinear Coefficients	$d_{36}=0.44\text{pm/V}$	$d_{36}=0.40\text{pm/V}$
Refractive index (at 1064nm)	$n_o=1.4938, n_e=1.4599$	$n_o=1.4948, n_e=1.4554$
Electro-optical Coefficients	$r_{41}=8.8\text{pm/V}$ $r_{63}=10.3\text{pm/V}$	$r_{41}=8.8\text{pm/V}$ $r_{63}=25\text{pm/V}$
Longitudinal half-wave voltage:	$V_\pi=7.65\text{KV}(\lambda=546\text{nm})$	$V_\pi=2.98\text{KV}(\lambda=546\text{nm})$
Absorptance:	0.07/cm	0.006/cm
Optical damage threshold:	>5 GW/cm ²	>3 GW/cm ²
Extinction ratio:		30dB
Sellmeier equations of KDP: (λ in μm)		
$n_o^2 = 2.259276 + 0.01008956 / (\lambda^2 - 0.012942625) + 13.00522 \lambda^2 / (\lambda^2 - 400)$ $n_e^2 = 2.132668 + 0.008637494 / (\lambda^2 - 0.012281043) + 3.2279924 \lambda^2 / (\lambda^2 - 400)$		
Sellmeier equations of DKDP: (λ in μm)		
$n_o^2 = 1.9575544 + 0.2901391 \lambda^2 / (\lambda^2 - 0.0281399) - 0.02824391 \lambda^2 + 0.004977826 \lambda^4$ $n_e^2 = 1.5005779 + 0.6276034 \lambda^2 / (\lambda^2 - 0.0131558) - 0.01054063 \lambda^2 + 0.002243821 \lambda^4$		

Lithium Iodate (LiIO₃)

Introduction

LiIO₃ crystal is one of the oldest commercial NLO crystals. For the high NLO coefficient. LiIO₃ is used for frequency-doubling, tripling and mixing of low and medium power lasers.

CASTECH provides large size of LiIO₃ crystals with high optical homogeneity. They may be as-cut and polished. And sealed housing with AR-coated windows is also available.

Basic Properties

Point Group	6
Transparency Range	300-5000nm
Nonlinear coefficient	$d_{15} = -5.5 \times 10^{-12} \text{m/V}$
Refractive Index	negative uniaxial $n_o = 1.8571, n_e = 1.7165 (\lambda = 1064 \text{nm})$
Sellmeier Equations: (λ in μm)	
$n_o^2 = 3415716 + 0047031 / (\lambda^2 - 0035306) - 0008801\lambda^2$ $n_e^2 = 2918692 + 0035145 / (\lambda^2 - 0028224) - 0003641\lambda^2$	

Notes to the user of LiIO₃

- LiIO₃ is highly hygroscopic. Please keep it in a dry environment, and sealed housing is recommended. CASTECH provide both polishing and sealed housing for LiIO₃ crystal.
- LiIO₃ is not recommended for high power applications, because of the low damage threshold.

Crystal Specifications

- Transmitting wavefront distortion: less than $\lambda/4$ @ 633 nm
- Dimension tolerance: (W \pm 0.2 mm) x (H \pm 0.2 mm) x (L + 0.5 /-0.2mm)
- Clear aperture: > 90% central area
- Flatness: $\lambda/4$ @ 633 nm
- Scratch/Dig code: 20/10 to MIL-PRF-13830B
- Parallelism: better than 20 arc seconds
- Perpendicularity: 5 arc minutes
- Angle tolerance: $< \pm 0.5^\circ$
- Quality Warranty Period: one year under proper use.

Neodymium Doped Yttrium Orthovanadate (Nd:YVO₄)

Introduction

Nd:YVO₄ is the most efficient laser host crystal for diode pumping among the current commercial laser crystals, especially, for low to middle power density. This is mainly for its absorption and emission features surpassing Nd:YAG. Pumped by laser diodes, Nd:YVO₄ crystal has been incorporated with high NLO coefficient crystals (LBO, BBO, or KTP) to frequency-shift the output from the near infrared to green, blue, or even UV. This incorporation to construct all solid state lasers is an ideal laser tool that can cover the most widespread applications of lasers, including machining, material processing, spectroscopy, wafer inspection, light displays, medical diagnostics, laser printing, and data storage, etc. It has been shown that Nd:YVO₄ based diode pumped solid state lasers are rapidly occupying the markets traditionally dominated by water-cooled ion lasers and lamp-pumped lasers, especially when compact design and single-longitudinal-mode outputs are required.

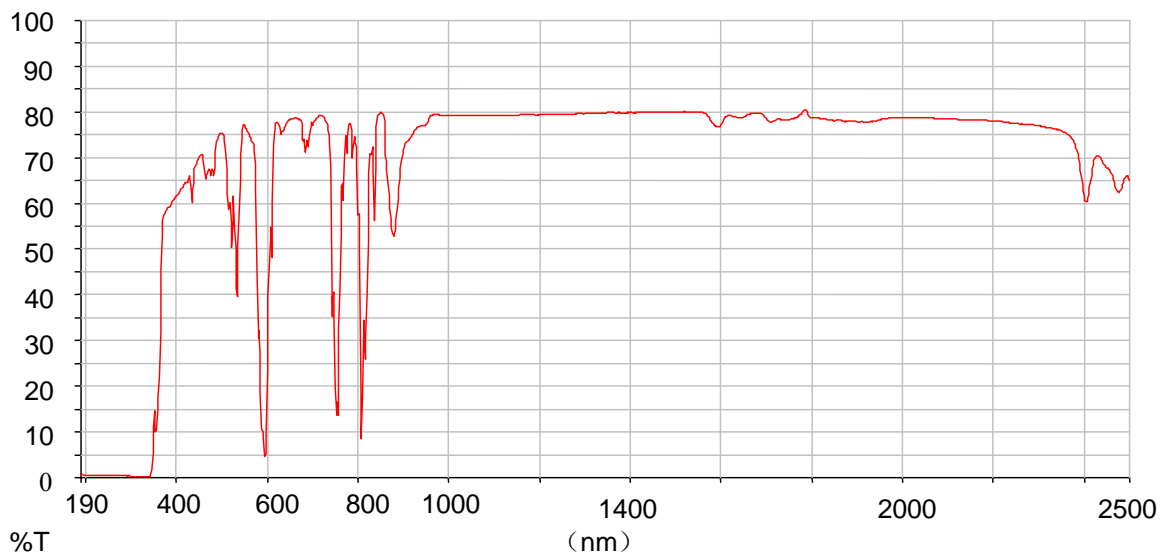
Nd:YVO₄ 's advantages over Nd:YAG

- As high as about five times larger absorption efficient over a wide pumping bandwidth around 808 nm (therefore, the dependency on pumping wavelength is much lower and a strong tendency to the single mode output)
- As large as three times larger stimulated emission cross-section at the lasing wavelength of 1064nm
- Lower lasing threshold and higher slope efficiency
- As a uniaxial crystal with a large birefringence, the emission is only a linearly polarized.

CASTECH Provides

- Various doping concentration from 0.1% to 3%.
- Doping concentration tolerance: $\pm 0.05\%$ (atm% $\leq 1\%$), $\pm 0.1\%$ (atm% $\geq 1\%$)
- Various size bulk and finished high quality Nd:YVO₄ crystals up to $\phi 35 \times 50 \text{mm}^3$ and $\phi 20 \times 20 \text{mm}^3$, respectively;
- 10,000 pcs of Nd:YVO₄ devices per month in sizes 3x3x0.5 to 4x4x8mm
- With quick delivery
- With competitive price.

Figure 1. Absorption Curve of 0.5% Nd:YVO₄(thickness 4mm)



Basic Properties

Crystal Structure: Cell Parameter:	Zircon Tetragonal, space group D_{4h}^{-14}/amd $a=b=7.1193 \text{ \AA}$, $c=6.2892 \text{ \AA}$
Density:	4.22g/cm ³
Atomic Density:	1.26×10^{20} atoms/cm ³ (Nd 1.0%)
Mohs Hardness:	4-5 (Glass-like)
Thermal Expansion Coefficient (300K):	$\alpha_a=4.43 \times 10^{-6}/K$ $\alpha_c=11.37 \times 10^{-6}/K$
Thermal Conductivity Coefficient (300K):	//C: 0.0523W/cm/K ⊥C: 0.0510W/cm/K
Lasing wavelength:	1064nm, 1342nm
Thermal optical coefficient (300K):	$dn_o/dT=8.5 \times 10^{-6}/K$ $dn_e/dT=2.9 \times 10^{-6}/K$
Stimulated emission cross-section:	$25 \times 10^{-19} \text{ cm}^2$ @1064nm
Fluorescent lifetime:	90μs (1% Nd doped)
Absorption coefficient:	31.4 cm^{-1} @810nm
Intrinsic loss:	0.02 cm^{-1} @1064nm
Gain bandwidth:	0.96nm @1064nm
Polarized laser emission:	π polarization; parallel to optical axis (c-axis)
Diode pumped optical to optical efficiency:	>60%
Sellmeier equations (λ in μm)	$n_o^2=3.77834+0.069736/(\lambda^2-0.04724)-0.010813 \lambda^2$ $n_e^2=4.59905+0.110534/(\lambda^2-0.04813)-0.012676 \lambda^2$

Laser Properties of Nd:YVO₄

1. One most attractive character of Nd:YVO₄ is, compared with Nd:YAG, its 5 times larger absorption coefficient in a broader absorption bandwidth around the 808nm peak pump wavelength, which just matches the standard of high power laser diodes currently available. This means a smaller crystal that could be used for the laser, leading to a more compact laser system. For a given output power, this also means a lower power level at which the laser diode operates, thus extending the lifetime of the expensive laser diode. The broader absorption bandwidth of Nd:YVO₄ which may reaches 2.4 to 6.3 times that of Nd:YAG. Besides more efficient pumping, it also means a broader range of selection of diode specifications. This will be helpful to laser system makers for wider tolerance for lower cost choice.
2. Nd:YVO₄ crystal has larger stimulated emission cross-sections, both at 1064nm and 1342nm. When a-axis cut Nd:YVO₄ crystal lasing at 1064nm, it is about 4 times higher than that of Nd:YAG, while at 1340nm the stimulated cross-section is 18 times larger, which leads to a CW operation completely outperforming Nd:YAG at 1320nm. These make Nd:YVO₄ laser be easy to maintain a strong single line emission at the two wavelengths.
3. Another important character of Nd:YVO₄ lasers is, because it is an uniaxial rather than a high symmetry of cubic as Nd:YAG, it only emits a linearly polarized laser, thus avoiding undesired birefringent effects on the frequency conversion. Although the lifetime of Nd:YVO₄ is about 2.7 times shorter than that of Nd:YAG, its slope efficiency can be still quite high for a proper design of laser cavity, because of its high pump quantum efficiency.

The major laser properties of Nd:YVO₄ vs Nd:YAG are listed in Table below, including stimulated emission cross-sections (σ), absorption coefficient (α), fluorescent lifetime (τ), absorption length (L_α), threshold power (P_{th}) and pump quantum efficiency (η_s).

Laser Properties of Nd:YVO₄ vs Nd:YAG

LASER CRYSTAL	DOPING (atm%)	σ ($\times 10^{-19} \text{cm}^2$)	α (cm^{-1})	τ (μs)	L_α (mm)	P_{th} (mW)	η_s (%)
Nd:YVO ₄ (a-cut)	1.0	25	31.2	90	0.32	30	52
	2.0	25	72.4	50	0.14	78	48.6
Nd:YVO ₄ (c-cut)	1.1	7	9.2	90		231	45.5
Nd:YAG	0.85	6	7.1	230	1.41	115	38.6

Typical Results

- Diode pumped Nd:YVO₄ laser output comparing with diode pumped Nd:YAG laser.

Crystals	Size (mm ³)	Pump Power	Output (at 1064nm)
Nd:YVO ₄	3x3x1	850mW	350mW
Nd:YVO ₄	3x3x5	15W	6W
Nd:YAG	3x3x2	850mW	34mW

- Diode pumped Nd:YVO₄+KTP green laser.
- 8W green laser was generated from a 15W LD pumped 0.5%Nd:YVO₄ with intracavity KTP.
- 200mW green outputs are generated from 1 W LD pumped 2%Nd:YVO₄ lasers by using CASTECH's 2x2x5mm KTP and 3x3x1mm Nd:YVO₄.

CASTECH provides the following coatings

- Both ends AR/AR-1064/808nm, R<0.2%@1064nm,R<2%@808nm
- S1:HR@1064&532 nm,HT808 nm, R>99.8%@1064&532nm,T>90%@808nm
S2:AR@1064&532 nm, R<0.2%@1064nm,R<0.5%@532nm
- S1:HR@1064,HT808, R>99.8%@1064nm,T>95%@808nm
S2:AR@1064, R<0.1%@1064nm.
- S1,S2 AR-coated, S3:gold/chrome plated.
- Both ends AR/AR-1064 nm; S3:AR-808 nm
- Other coatings are available upon request.

CASTECH's Warranty on Nd:YVO₄ Specifications

- Dimension tolerance: (W±0.1mm)x(H±0.1mm)x(L+0.5/-0.1mm) (L≥2.5mm)
(W±0.1mm)x(H±0.1mm)x(L+0.2/-0.1mm) (L<2.5mm)
- Clear aperture: central 90% of the diameter
- Flatness: less than $\lambda/8$ @ 633nm (L≥2.5mm); less than $\lambda/4$ @ 633nm (L<2.5mm)
- Transmitting wavefront distortion: less than $\lambda/4$ @ 633nm
- Chamfer: $\leq 0.2\text{mm}@45^\circ$
- Chip: $\leq 0.1\text{mm}$
- Scratch/Dig code: better than 10/ 5 to MIL-PRF-13830B
- Parallelism: better than 20 arc seconds
- Perpendicularity: ≤ 5 arc minutes
- Angle tolerance: $\leq 0.5^\circ$
- Damage threshold[GW/cm²]: >1 for 1064nm, TEM00, 10ns, 10Hz (AR-coated)
- Quality Warranty Period: one year under proper use.

Neodymium Doped Gadolinium Orthovanadate (Nd:GdVO₄)

CASTECH's Nd:GdVO₄ is featured by

- Large stimulated emission cross section at laser wavelength;
- High absorption coefficient and wide bandwidth at pump wavelength;
- Low dependency on pump wavelength;
- Good thermal conductivity;
- Low lasing threshold and high slope efficiency;
- High laser induced damage threshold;
- Strongly-polarized laser output.

Specifications

Crystal structure	Tetragonal
Space Group	I4 ₁ /amd
Lattice parameter	a=0.721nm, b=0.635nm
Lasing Transition	⁴ F _{3/2} → ⁴ I _{11/2}
Lasing wavelength	1062.9nm
Emission Cross Section (at 1064nm)	7.6x10 ⁻¹⁹ cm ²
Absorption Cross Section (at 808nm)	4.9x10 ⁻¹⁹ cm ²
Absorption Coefficient (at 808nm)	74cm ⁻¹
Index of Refractivity (at 1064nm)	n _o =1.972, n _e =2.192
Thermal Conductivity (<110>)	11.7W/m/K
Density	5.47g/cm ³
Nd Dopant level (atomic)	0.1%, 0.2%, 0.3%, 0.5%, 0.7%, 1.0%...

Material Properties: Comparing Nd:GdVO₄ and Nd:YVO₄

Crystal	Nd:GdVO ₄		Nd:YVO ₄	
Crystal Structure, Space Group	Tetragonal, I4 ₁ /amd		Tetragonal, I4 ₁ /amd	
Lattice constants (nm)	a:0.721	b:0.635	a:0.721	b:0.629
Melting temperature(°C)	1780		1825	
Thermal expansion @25°C, x10 ⁻⁶ /°C	a	1.5	a	4.43
	b	7.3	b	11.4
Specific heat @25°C, cal/mol·K	32.6		24.6	
dn / dT, x10 ⁻⁶ /°C	4.7		2.7	

Information Regarding Neodymium Laser Host Crystals

Crystal	Nd:YVO ₄	Nd:GdVO ₄	Nd:YAG
Laser wavelengths	1064.3nm,1342.0 nm	1062.9 nm,1340 nm	1064.2 nm,1338.2 nm
Emission bandwidth (linewidth at 1064 nm)	0.8nm	No data	0.45nm
Effective laser cross section (emission cross section at 1064 nm)	$15.6 \times 10^{-19} \text{ cm}^2$	$7.6 \times 10^{-19} \text{ cm}^2$	$6.5 \times 10^{-19} \text{ cm}^2$
Polarization	Parallel to c-axis	Parallel to c-axis	unpolarized
Radioactive lifetime (microseconds) at 1% Nd doping	~ 100 μs	~ 95 μs	230 μs
Pump wavelength	808.5 nm	808.4 nm	807.5 nm
Peak pump absorption at 1% doping	~ 41 cm^{-1}	~ 57 cm^{-1}	
Thermal conductivity, W/m/K	5.1	11.7	14
Doping concentration range	0.1 - 3.0%	0.1 - 3.0%	0.1-2.0%

CASTECH Warranty on Nd:YVO₄ Specifications

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

Neodymium Doped Yttrium Aluminum Garnet (Nd:YAG) Crystal

Introduction

Nd:YAG is the earliest and most famous laser host crystal. Since it combines great advantages in many basic properties, Nd:YAG is the ubiquitous presence for near-infrared solid-state lasers and their frequency-doubler, tripler, and higher order multiplier.

Advantages Of Nd:YAG

- High gain
- Low threshold
- High efficiency
- Low loss at 1.06 μm
- Good thermal conductivity and thermal shock characteristics
- Mechanical strength
- High optical quality
- Material characteristics that allow for various modes of operation (CW, pulsed, Q-switched, mode locked)

Basic Properties

Crystal structure:	Cubic
Lattice constant:	12.01 \AA
Melting point:	1970 $^{\circ}\text{C}$
Density:	4.5g/cm ³
Reflective Index:	1.82
Thermal Expansion Coefficient:	7.8x10 ⁻⁶ /K <111>, 0-250 $^{\circ}\text{C}$
Thermal Conductivity (W/m/K):	14, 20 $^{\circ}\text{C}$ 10.5, 100 $^{\circ}\text{C}$
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

Specifications of Nd:YAG crystal from CASTECH

- Dimension: size up to dia.15x180mm and maximum diameter of dia.40mmx2mm
- Nd Dopant Level: 0.3~2.0(\pm 0.1)atm%
- Diameter tolerance: \pm 0.05mm
- Length tolerance: \pm 0.5mm
- Perpendicularity: < 5 arc minutes
- Parallelism: <10 arc seconds
- Wavefront distortion: $\lambda/8$
- Flatness: $\lambda/10$
- Scratch/Dig: 10/5 @MIL-PRF-13830B
- Chamfer: 0.1mmx45°
- HR-Coating: R>99.8%@1064nm and R<5%@808nm
- AR-Coating (Single layer MgF2): R<0.25%@1064nm
- Other HR coatings, such as HR@1064/532 nm, HR@946 nm, HR@1319 nm and other wavelengths are also available.
- Damage Threshold: >500MW/cm²

Optical Parameter of Nd:YAG crystal			
Diameter (mm)	Standard grade	Excellence grade	Superexcellence grade
φ 3-6.35	≤0.5 fringes/inch	≤0.25 fringes/inch	≤0.1 fringes/inch
	≥25dB	≥28dB	≥30dB
φ 7-10	≤0.7 fringes/inch	≤0.4 fringes/inch	≤0.16 fringes/inch
	≥22dB	≥25dB	≥28dB
φ 11-13	≤1 fringes/inch	≤0.6 fringes/inch	≤0.2 fringes/inch
	≥20dB	≥23dB	≥26dB
φ 14-16	≤1.2 fringes/inch	≤0.8 fringes/inch	≤0.25 fringes/inch
	≥18dB	≥20dB	≥23dB

Higher grade or specific Nd:YAG rods or slabs, and Nd:YAG rods for 946 nm and 1319 nm lasers can be provided. Er:YAG, Yb:YAG and other ion doped YAG crystals are also available upon request.

Chromium Doped Yttrium Aluminum Garnet Crystal (Cr⁴⁺:YAG)

Introduction

Cr⁴⁺:YAG Crystal is an excellent crystal for passively Q-switching diode pumped or lamp-pumped Nd:YAG, Nd:YLF, Nd:YVO₄ or other Nd and Yb doped lasers at wavelength from 0.8 to 1.2 μm. Because of its chemically stable, durable, UV resistant, good thermal conductivity and high damage threshold (> 500 MW/cm²) and being easy to be operated, it will replace traditional materials, such as LiF, organic Dye and color centers.

CASTECH provides Cr⁴⁺:YAG with Cr⁴⁺ doping level from 0.5mol% to 3mol%. The size could be from 2×2mm² to 14×14mm² with length from 0.1mm to 12mm available. We can control the initial transmission from 10% to 92% according to customers' requirements.

Basic Properties of Cr⁴⁺:YAG

Crystal Structure	Cubic
Dopant Level	0.5 mol% ~ 3 mol%
Hardness	8.5
Damage Threshold	> 500 MW/cm ²
Refractive Index	1.82 @ 1064 nm

The preliminary experiments of CASTECH's Cr⁴⁺:YAG showed that the pulse width of passively Q-switched lasers could be as short as 5ns for diode pumped Nd:YAG lasers and repetition as high as 10kHz for diode pumped Nd:YVO₄ lasers. Furthermore, an efficient green output @ 532nm, and UV output @ 355nm and 266nm were generated, after a subsequent intracavity SHG in KTP or LBO, THG and 4HG in LBO and BBO for diode pumped and passive Q-switched Nd:YAG and Nd:YVO₄ lasers.

Cr⁴⁺:YAG is also a laser crystal with tunable output from 1.35 μm to 1.55 μm. It can generate ultrashort pulse laser (to fs pulsed) when pumped by Nd:YAG laser at 1.064 μm.

Note:

When ordering Cr⁴⁺:YAG crystal, please specify the size, initial transmission and coatings. For further information, please contact CASTECH.

Nd:Ce:Tb:YAG

Introduction

Now CASTECH can offer Nd:Ce:Tb:YAG crystal. Besides all the advantages of Nd:Ce:YAG, Nd:Ce:Tb:YAG crystal has more outstanding advantages, such as high beam quality, high thermal stability which is especially suitable to high repetition laser machine.

Material and Specifications

Application	1.064 μm pulse/CW solid lasers
Nd Dopant Concentration	0.6-1.2 at%
Parameters of Laser Rod	Interference Fringes $\leq 0.25/\text{inch}$ Extinction Ratio $\geq 30\text{dB}$
Rod Sizes	Rod: Dia.: 3~10mm, Length: 30~140 mm; Slab: (3~12)X(6~24)X(60~140)mm
Parallelism	$\leq 10''$
Perpendicularity	$\leq 5'$
Flatness	$\lambda / 10 @ 589.3\text{nm}$
Coating Reflectivity	PR coating @1064nm, Reflectivity could be 10~99.85% (upon user's request); AR coating @1064nm, $R \leq 0.2\%$

Ho:Cr:Tm:YAG

Introduction

Ho:Cr:Tm:YAG is a high efficient laser material which lases at 2.1 μm . It has wide applications in surgery, dentistry, atmospheric testing, etc.

Advantages of Ho:Cr:Tm:YAG Crystal

- High slope efficiency
- Pumped by flash lamp or diode
- Operates well at room temperature
- Operates in a relatively eye-safe wavelength range

Optical and Spectral Properties of Ho:Cr:Tm:YAG Crystals

Laser Transition	$^5I_7 \rightarrow ^5I_8$
Laser Wavelength	2.097 μm
Photon Energy	$9.55 \times 10^{-20}\text{J}$
Emission Cross Section	$7 \times 10^{-21}\text{cm}^2$
Fluorescence Lifetime	8.5 ms
Index of Refraction	1.80 @2.08 μm
Absorption Linewidth	4 nm
Diode Pump Band	781 nm
Major Pump Bands	400~800 nm

Specifications of Ho:Cr:Tm:YAG crystal from CASTECH

Dopant concentration	Ho:~0.35 at%, Tm:~5.8at%, Cr:~1.5at%
Wavefront Distortion	$\leq 0.125 \lambda$ /inch(@1064nm)
Extinction Ratio	≥ 25 dB
Rod Sizes	Diameter:3~6mm,Length:50~120mm Upon request of customer
Dimensional Tolerances	Diameter:+0.00/-0.05mm, Length: ± 0.5 mm
Barrel Finish	Ground Finish: 400# Grit
Parallelism	$\leq 30''$
Perpendicularity	$\leq 5'$
Flatness	$\lambda / 10$
Surface Quality	10/5
Chamfer	0.006" \pm 0.002" at $45^\circ \pm 5^\circ$
AR Coating Reflectivity	$\leq 0.25\%$ (@2094nm)

Nd:Ce:YAG

Introduction

In double doped Nd:Ce:YAG crystals, Cerium are chosen as sensitizer for Nd³⁺ ions because of its strong absorption in UV spectral region at flash lamp pumping and efficient energy transfer to the Nd³⁺ excited state. As a result, thermal distortion in Nd:Ce:YAG is appreciably less and the output laser energy is greater than that in Nd:YAG by the same pumping. Therefore it is possible to realize high power lasers with good beam quality. Lasing wavelength at 1064 nm, laser damage threshold and thermal conductivity of the Nd:Ce:YAG crystals are the same as for Nd:YAG.

Advantages of Nd:Ce:YAG Crystal

- High efficiency
- Low threshold
- Good anti-violet radiation property
- Good thermal stability
- High optical quality

Optical and Spectral Properties of Nd:Ce:YAG Crystal

Laser Transition	$^4F_{3/2} \rightarrow ^4I_{11/2}$
Laser Wavelength	1.064 μm
Photon Energy	$1.86 \times 10^{-19} \text{J} @ 1.064 \mu\text{m}$
Emission Linewidth	4.5 \AA @ 1.064 μm
Emission Cross Section (Nd 1.0at%)	$2.7 \sim 8.8 \times 10^{-19} \text{cm}^2$
Fluorescence Lifetime (Nd 1.0at%)	230 μs
Index of Refraction	1.8197 @ 1064nm

Specifications of Nd:Ce:YAG crystal from CASTECH

Dopant concentration	Nd:1.1~1.4at%,Ce:0.05~0.1at%
Wavefront distortion	$\leq 0.2 \lambda$ /inch
Extinction Ratio	≥ 28 dB
Rod Sizes	Diameter:3~6mm,Length:40~80mm Upon request of customer
Dimensional Tolerances	Diameter+0.000"/-0.002",Length ± 0.02 "
Barrel Finish	Ground Finish: 400# Grit
Parallelism	≤ 10 "
Perpendicularity	$\leq 5'$
Flatness	$\lambda / 10$
Surface quality	10-5(MIL-PRF-13830B)
Chamfer	0.006" \pm 0.002" at $45^\circ \pm 5^\circ$
AR coating reflectivity	$\leq 0.25\%$ (@1064nm)

Yb:YAG

Introduction

Yb:YAG is one of the most promising laser-active materials and more suitable for diode-pumping than the traditional Nd-doped systems. Compared with the commonly used Nd:YAG crystal, Yb:YAG crystal has a much larger absorption bandwidth to reduce thermal management requirements for diode lasers, a longer upper-laser level lifetime, three to four times lower thermal loading per unit pump power. Yb:YAG crystal at 1030nm is a good substitute for a Nd:YAG crystal at 1064nm and its second harmonic at 515nm may replace Ar-ion laser (with a large volume), which emit at 514nm.

Advantages of Yb:YAG Crystal

- Very low fractional heating, less than 11%
- Very high slope efficiency
- Broad absorption bands, about 8nm@940nm
- No excited-state absorption or up-conversion
- Conveniently pumped by reliable InGaAs diodes at 940nm(or 970nm)
- High thermal conductivity and large mechanical strength
- High optical quality

Material and Specifications

Dopant concentration	Yb: 5~15 at%
Wavefront Distortion	$\leq 0.125 \lambda$ /inch
Extinction Ratio	≥ 28 dB
Rod Sizes	Diameter:2~20mm, Length:5~150mm Upon request of customer
Dimensional Tolerances	Diameter:+0.00"/-0.002"mm, Length: ± 0.02 "
Barrel Finish	Ground Finish: 400# Grit
Parallelism	$\leq 10''$
Perpendicularity	$\leq 5'$
Flatness	$\lambda / 10$
Surface Quality	10-5(MIL-PRF-13830B)
Chamfer	0.006" \pm 0.002" at $45^\circ \pm 5^\circ$
AR Coating Reflectivity	$\leq 0.25\%$ (@1030nm)
Single pass loss	$< 3 \times 10^{-3} \text{cm}^{-1}$

Optical and Spectral Properties of Yb:YAG Crystal

Laser Transition	${}^2F_{5/2} \rightarrow {}^2F_{7/2}$
Laser Wavelength	1030nm
Photon Energy	$1.93 \times 10^{-19} \text{J} (@1030\text{nm})$
Emission Linewidth	9nm
Emission Cross Section	$2.0 \times 10^{-20} \text{cm}^2$
Fluorescence Lifetime	1.2 ms
Diode Pump Band	940nm or 970nm
Pump Absorption Band Width	8 nm
Index of Refraction	1.82
Thermal Optical Coefficient	$9 \times 10^{-6}/^\circ\text{C}$
Loss Coefficient	0.003 cm^{-1}

Er:YAG

Introduction

Er:YAG is an excellent laser crystal which lases at 2940 nm. This wavelength is the most readily absorbed into water and hydroxylapatite of all existing wavelengths and is considered a highly surface cutting laser. It has wide applications in medical applications, such as dental (hard tissues), orthopedics, etc.

Advantages of Er:YAG Crystal

- High slope efficiency
- Operate well at room temperature
- Operate in a relatively eye-safe wavelength range

Material and Specifications

Dopant concentration	Er: ~50 at%
Wavefront Distortion	$\leq 0.125 \lambda$ /inch(@1064nm)
Extinction Ratio	≥ 25 dB
Rod Sizes	Diameter:3~6mm, Length:50~120 mm Upon request of customer
Dimensional Tolerances	Diameter:+0.000"/-0.002", Length: ± 0.02 "
Barrel Finish	Ground Finish: 400# Grit
Parallelism	≤ 10 "
Perpendicularity	$\leq 5'$
Flatness	$\lambda /10$
Surface Quality	10-5(MIL-PRF-13830B)
Chamfer	0.006" \pm 0.002" at $45^\circ \pm 5^\circ$
AR Coating Reflectivity	$\leq 0.25\%$ (@2940nm)

Optical and Spectral Properties of Er:YAG Crystal

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

Nd:YLF Crystal

Introduction

CASTECH grows Nd:YLF crystals using Czochralski method. The use of high quality starting materials for crystal growth, whole boule interferometry, and precise inspection of scattering particle in crystal using He-Ne laser assures that each crystal will perform well.

Optical Properties

Transparency Range:	180 - 6700 nm
Peak Stimulated Emission Cross Section	$1.8 \times 10^{-19}/\text{cm}^2$ (E c) at 1047nm $1.2 \times 10^{-19}/\text{cm}^2$ (E \perp c) at 1053nm
Spontaneous Fluorescence Lifetime	485 μs for 1% Nd doping
Scatter Losses	<0.2%/cm
Peak Absorption Coefficient(for 1.2% Nd)	$\alpha = 10.8\text{cm}^{-1}$ (792.0 nm E c) $\alpha = 3.59\text{cm}^{-1}$ (797.0 nm E \perp c)
Laser Wavelength	1047nm (c, a-cut crystal) 1053nm(\perp c, a or c-cut crystal)

Physical Properties

Chemical Formula	$\text{LiY}_{1.0-x}\text{Nd}_x\text{F}_4$
Space Group	$I4_1/a$
Nd atoms/cm ³	1.40×10^{20} atoms/cm ³ for 1% Nd doping
Modulus of Elasticity	85 GPa
Crystal Structure:	Tetragonal
Cell Parameters:	a=5.16 Å , c=10.85 Å
Melting Point:	819°C
Mohs Hardness:	4~5
Density:	3.99 g/cm ³
Thermal Conductivity	0.063 W/cm/K
Specific Heat	0.79 J/g/K
Thermal Expansion Coefficients	$8.3 \times 10^{-6}/\text{k}$ c $13.3 \times 10^{-6}/\text{k}$ \perp c

Index of Refraction

Wavelength(nm)	n_o	n_e
262	1.485	1.511
350	1.473	1.491
525	1.456	1.479
1050	1.448	1.470
2065	1.442	1.464

dn/dT

Wavelength(nm)	$E \parallel c$	$E \perp c$
436	$-2.44 \times 10^{-6}/^{\circ}C$	$-0.54 \times 10^{-6}/^{\circ}C$
578	$-2.86 \times 10^{-6}/^{\circ}C$	$-0.91 \times 10^{-6}/^{\circ}C$
1060	$-4.30 \times 10^{-6}/^{\circ}C$	$-2.00 \times 10^{-6}/^{\circ}C$

The Sellmeier equations (λ in μm):

$$n_o^2 = 1.38757 + 0.70757\lambda^2 / (\lambda^2 - 0.00931) + 0.18849\lambda^2 / (\lambda^2 - 50.99741)$$

$$n_e^2 = 1.31021 + 0.84903\lambda^2 / (\lambda^2 - 0.00876) + 0.53607\lambda^2 / (\lambda^2 - 134.9566)$$

CASTECH's general Nd:YLF production capabilities including

- Rod sizes from 2mm to 10mm in diameter and from 1mm to 150mm in length
- Orientation of rod axis to crystal axis within 1 degree
- Polished only or AR coated rods
- Nd dopant concentrations between 0.4 and 1.2at%
- Large rod and slab dimensions and non-standard dopant concentrations are available upon request

Specifications

Standard Dopant	$1.1 \pm 0.1\%$
Wavefront Distortion	$< \lambda / 4$ per inch @633nm
Parallelism	< 10 arc seconds
Perpendicularity	< 5 arc minutes
Chamfer	0.13 ± 0.07 mm @45°
Surface Quality	10/5
End Coating	$R < 0.15\%$ @1047/1053nm
Surface Flatness	$\lambda / 8$ @632.8nm

Titanium Doped Sapphire Crystal (Ti:Sapphire)

Introduction

Titanium doped Sapphire (Ti:Sapphire) is the most widely used laser crystal for widely tunable and ultrashort pulsed lasers with high gain and power outputs. CASTECH possesses the advanced growth method of Temperature Gradient Technique (TGT), and it supplies large-sized (Dia.30x30mm) Ti:Sapphire crystal in high quality free of light scatter, with the dislocation density less than 10^2cm^{-2} . The TGT grown sapphire crystal is characterized by the (0001) oriented growth, high doping level ($\alpha_{490} = 4.0\text{cm}^{-1}$), high gain and laser damage threshold.

Main Applications

- The tunable wavelengths that cover a broad range from 700 to 1000 nm make Ti:Sapphire an excellent substitute for dye lasers in many applications.
- Doubling by NLO crystals such as BBO in an ultra-thin, Ti:Sapphire can be used to generate UV and DUV (up to 193 nm) laser with ultrafast pulses below 10fs.
- Ti:Sapphire is also widely used as the pump source of OPOs to expand the tunable range.

Basic Properties

Chemical formula:	$\text{Ti}^{3+}:\text{Al}_2\text{O}_3$
Crystal structure:	Hexagonal
Lattice constants:	$a=4.758\text{\AA}$, $c=12.991\text{\AA}$
Density:	3.98 g/cm^3
Melting point:	2040°C
Mohs hardness:	9
Thermal conductivity:	52 W/m/k
Specific heat:	0.42 J/g/K
Laser action:	4-Level Vibronic
Fluorescence lifetime:	$3.2\ \mu\text{s}$ (T=300K)
Tuning range:	660 - 1050 nm
Absorption range:	400 - 600 nm
Emission peak:	795 nm
Absorption peak:	488 nm
Refractive index:	1.76 @ 800 nm
Peak Cross-section:	$3\sim 4 \times 10^{-19}\text{cm}^2$
Thermal Expansion:	$8.40 \times 10^{-6}/^\circ\text{C}$

Standard product specifications

- Orientation: Optical axis C normal to rod axis
- Ti_2O_3 concentration: 0.06 - 0.26atm %
- Figure Of Merit (FOM): 100~250 (>250 available upon special requests)
- α_{490} : 1.0~4.0 cm^{-1}
- Diameter: 2~30mm or specified
- Path Length: 2~30mm or specified
- End configurations: Flat/Flat or Brewster/Brewster ends
- Flatness: $<\lambda/10$ @ 633 nm
- Parallelism: <10 arc sec
- Surface finishing: $<40/20$ scratch/dig to MIL-PRF-13830B
- Wavefront distortion: $<\lambda/4$ per inch

Note: AR Coating is available upon request.

Cr-doped Colquiriite (Cr:LiSAF)

Introduction

CASTECH provides high quality, Cr-doped Colquiriite crystal (Cr:LiSAF) using the Czochralski technique. It is excellent laser material with high energy storage and high slope efficiency. It is also ideal working material under conditions of ultra short pulse and ultra high power. Currently, Cr:LiSAF related products such as flashlight pumping and diode pumping laser have been widely used.

Physical and Optical Properties

Physical Properties

Chemical Formula	$\text{Cr}^{3+}:\text{LiSrAlF}_6$
Lattice Parameters(Å)	a=5.084
	c=10.21
Crystal structure	trigonal
Space Group	$P\bar{3}1c$
Cr atoms/cm ³ for 1% doping	8.75×10^{19}
Fracture Toughness(Mpam)	0.40(c)
Melting Point (°C)	766
Density(g/cm ³)	3.45
Modulus of Elasticity(GPa)	109
Thermal Expansion	-10(c)
Coefficient (10 ⁻⁶ /K)	25(⊥c)
Thermal Conductivity (W/m/K)	3.3(c)
	3.0(⊥ c)
Specific Heat(J/g·K) (@25°C)	0.842

Optical Properties

Emission Peak(nm)	846
Peak Stimulated Emission Cross Section($\times 10^{-20}\text{cm}^2$)	4.8(c)
Spontaneous Fluorescence Lifetime(μs)	67
Scatter Losses(%/cm)	<0.2
dn/dT($\times 10^{-6}/^\circ\text{C}$)	-4.8(c)
	-2.5(⊥c)

The Sellmeier equations (λ in μm)

$$n_c^2 = 1.98448 + 0.00235 / (\lambda^2 - 0.010936) - 0.01057 \lambda^2$$

$$n_a^2 = 1.97673 + 0.00309 / (\lambda^2 - 0.00935) - 0.00828 \lambda^2$$

Crystal	Wavelength(nm)	n_c	n_a
Cr:LiSAF	846	1.407	1.405
	670	1.409	1.407
	423	1.413	1.412
	290	1.420	1.420
	266	1.422	1.424

Specifications of Cr:LiSAF

- Size: Rod sizes from 2mm to 16mm in diameter and from 1mm to 180mm in length
- Cr dopant concentrations: 0.5~1.0 mol%
- Parallelism: <10 arc seconds
- Perpendicularity: <5 arc minutes
- Chamfer: $0.13 \pm 0.07\text{mm} \times 45^\circ$
- Scratch/Dig code: 10/5 to MIL-PRF-13830B
- Flatness: $\lambda/8 @ 632.8\text{nm}$
- AR coating: $R < 0.10\% @ 850\text{nm}$

Large rod and slab dimensions and non-standard dopant concentrations are available upon request.

Nd:KGW

Introduction

Neodymium doped Potassium-Gadolinium Tungstate crystals (Nd:KGd(WO₄)₂ or Nd:KGW) is an excellent laser gain material which has low laser oscillations threshold and higher emission section. The fluorescent concentration quench effect of the Nd³⁺ ion in the KGW crystal may be weakened due to the W-O covalent bond, so this crystal has a higher doping concentration of active ion. Furthermore, the absorption band at 808nm of Nd³⁺ in the KGW which has 12nm FWHM is well matched with the emission wavelength of current commercial laser diode.

Basic Properties

Crystal structure	monoclinic
Space group	C _{2h} (2/c)-C2/c
Cell Parameters	a = 8.087 Å; b = 10.374 Å; c = 7.588 Å β=94.41°
Refractive index, at 1067 nm	n _q = 2.049; n _p = 1.978; n _m = 2.014
Mohs hardness	5
Density, g/cm ³	7.27
Melting Point	1075 °C
Thermal conductivity at 373K, W x cm ⁻¹ x K ⁻¹	K _[100] = 0.026; K _[010] = 0.038; K _[001] = 0.034
Young's modulus, GPa	E _[100] = 115.8; E _[010] = 152.5; E _[001] = 92.4
Thermal expansion coefficient, at 373K	α _[100] = 4 x 10 ⁻⁶ K ⁻¹ ; α _[010] = 1.6 x 10 ⁻⁶ K ⁻¹ ; α _[001] = 8.5 x 10 ⁻⁶ K ⁻¹
Lasing Wavelength	911nm, 1067nm, 1351nm
Absorption band	808nm (FWHM 12nm)
Fluorescent lifetime	110 μs (3% doping), 90 μs (8% doping)

Laser Properties

3%Nd:KGW	Emission wavelength	1070nm
	Emission bandwidth	15nm
	Stimulated emission cross-section σ _e (x10 ⁻²⁰ cm ²)	1.48
	Fluorescent lifetime (μs)	109
	Gain bandwidth	15nm
	Absorption wavelength	810nm
	Absorption bandwidth	14nm
	Absorption cross-section σ _a (x10 ⁻²⁰ cm ²)	1.28

Specifications of Nd:KGW

Orientation	[010]
Standard Dopant concentration (at. %)	3%, 5%, 8%
Maximum length	50mm
Length tolerance, mm	+1.0 / -0.0
Diameter tolerance, mm	+/-0.1
Parallelism	< 30''
Perpendicularity	< 15'
Surface quality	20/10
coating	AR-coated

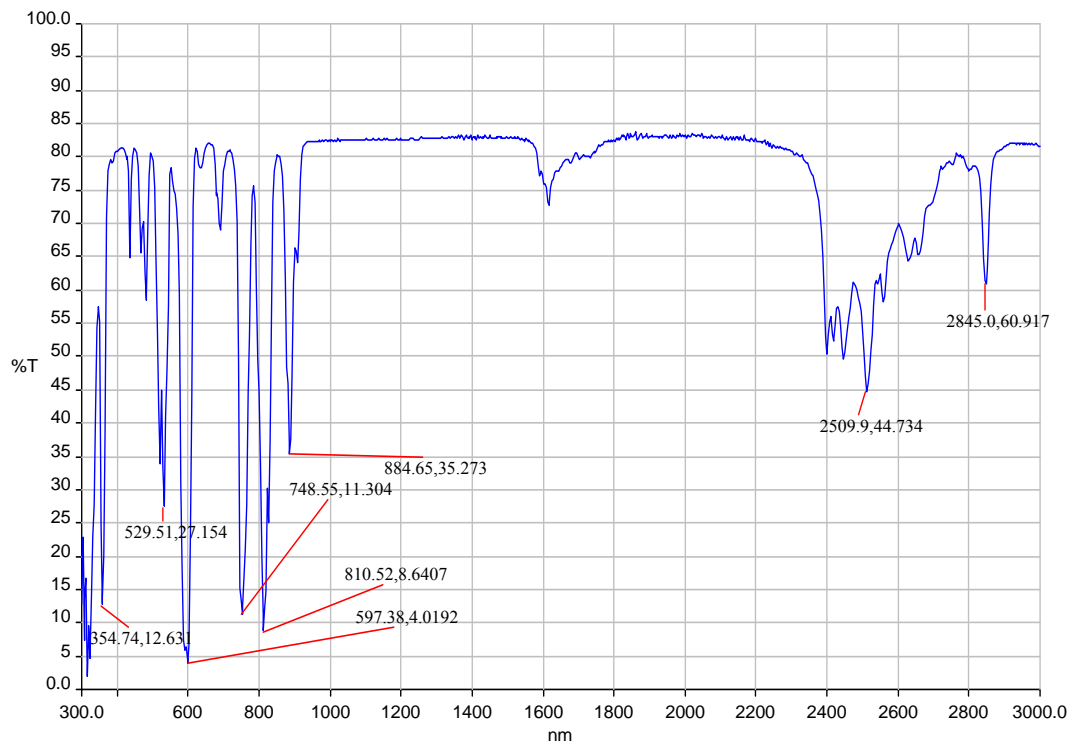


Figure 1. Transparency curve of Nd:KGW

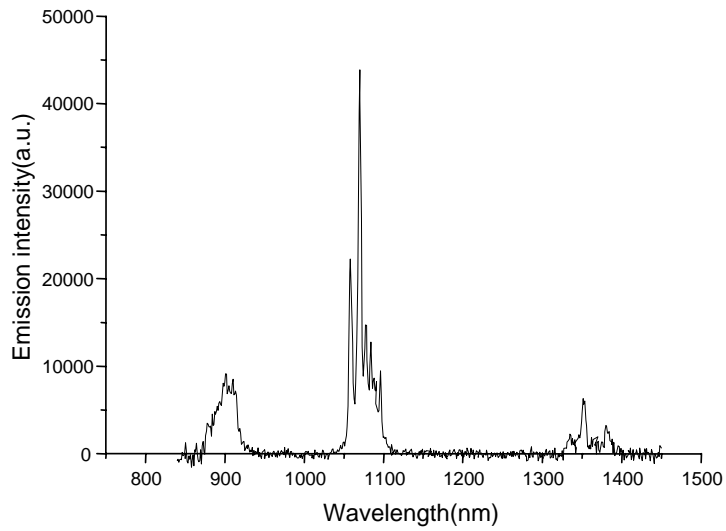


Figure 2. Emission spectra of 3%Nd:KGW

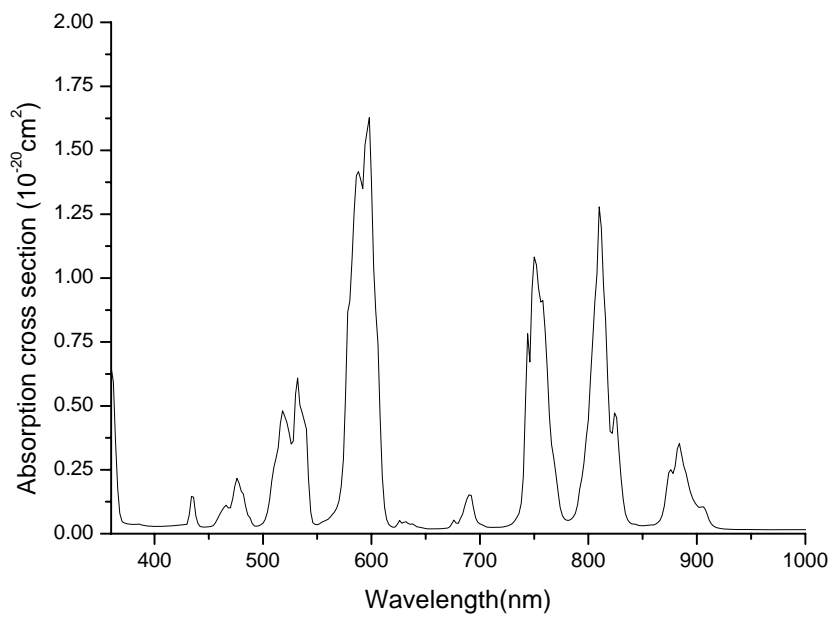


Figure 3. Absorption spectra of 3%Nd:KGW

Yb:KGW

Introduction

Ytterbium doped Potassium-Gadolinium Tungstate crystals - (Yb:KGd(WO₄)₂ or Yb:KGW) is an excellent laser gain material which has important advantages over the widely used Nd³⁺ doped materials. Its broad spectral emission band 1023-1060nm allows the generation of short (ps or fs) laser pulses. Its wide absorption spectrum at 980 nm and high absorption of pump radiation allow an efficient use of diode laser pumping. Compared with YAG used as hosts for Yb³⁺, KGW has the advantage of larger absorption cross section, which decreases the minimum pump intensity necessary to achieve transparency in the quasi-two-level system of ytterbium.

Basic Properties:

Crystal structure	monoclinic
Point group	C2/c
Cell Parameters	a = 8.09Å; b = 10.43Å; c = 7.588Å β = 94.4°
Refractive index, at 1067 nm	n _q = 2.033; n _p = 2.037; n _m = 1.986
Mohs hardness	5
Density, g/cm ³	7.27
Melting Point	1075°C
Thermal conductivity at 373K, W x cm ⁻¹ x K ⁻¹	K _[100] = 0.026; K _[010] = 0.038; K _[001] = 0.034
Thermal expansion coefficient, at 373K	α _[100] = 4 x 10 ⁻⁶ K ⁻¹ ; α _[010] = 1.6 x 10 ⁻⁶ K ⁻¹ ; α _[001] = 8.5 x 10 ⁻⁶ K ⁻¹
Lasing Wavelength	1023-1060nm
Absorption band	981nm (FWHM 3.7nm)
Fluorescent lifetime	600 μs (5% doping)

Specifications of Yb:KGW

Orientation	[010]
Standard Dopant concentration (at. %)	5%
Maximum length	50mm
Length tolerance, mm	+1.0 / -0.0
Diameter tolerance, mm	+/-0.1
Parallelism	< 30''
Perpendicularity	< 15'
Surface quality	20/10
coating	AR-coated

Diffusion Bonded Crystals

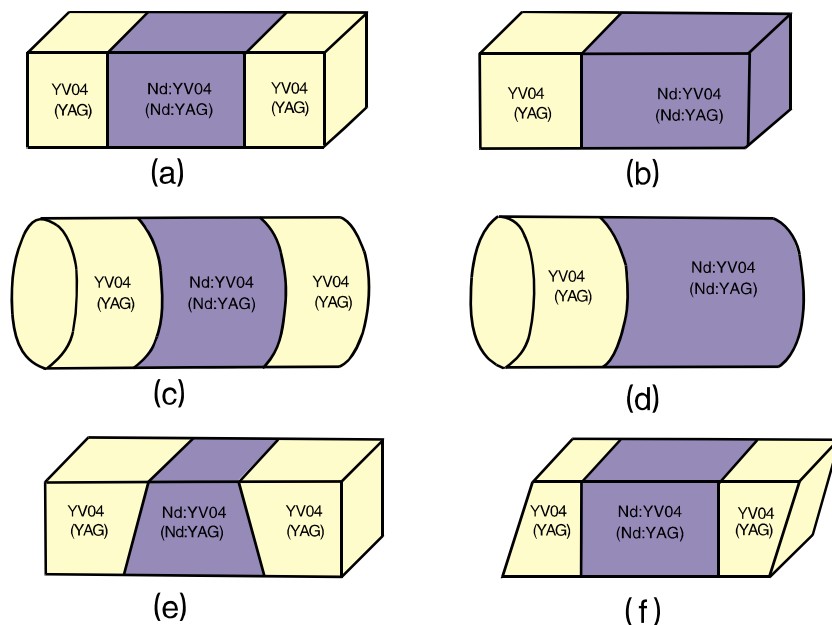
Introduction

Diffusion Bonded Crystals consist of one laser crystal and one or two undoped material. They are combined by optical contact method and further bonded under high temperature. Diffusion Bonded Crystal helps to decrease thermal lensing effect considerably.

CASTECH can supply 2 kinds of Diffusion Bonded Crystals: $YVO_4+Nd:YVO_4+YVO_4$ and $YAG+Nd:YAG+YAG$.

Material	Doping concentration	Aperture (mm ²)	Length of laser crystal (mm)
$YVO_4+Nd:YVO_4+YVO_4$	0.1-3%	2x2-10x10	1-20
$YVO_4+Nd:YVO_4+YVO_4$	0.1-3%	φ 2-10	3-20
$YAG+Nd:YAG+YAG$	0.5-1.1%	2x2-10x10	1-30
$YAG+Nd:YAG+YAG$	0.5-1.1%	φ 2-10	3-30

We have several assembly types as follows



For other assembly type please contact us for more information.

LiTaO₃ Crystal

Introduction

LiTaO₃ is an E-O crystal widely used for E-O devices, due to its good optical NLO and E-O properties, as well as high damage threshold. **CASTECH** supplies high quality LiTaO₃ boules and wafers with the following specifications for standard applications. We can also offer other specifications upon request:

Basic Properties of LiTaO₃

Crystal Structure	Trigonal, Space group R3c, Point group 3m
Cell Parameters	a=5.154 Å , c=13.781 Å
Melting Point	1650°C
Curie Temperature	607°C
Mohs Hardness	5.5
Density	7.46g/cm ³
Dielectric Constants	ϵ_{11}/ϵ_0 : 51.7 ϵ_{33}/ϵ_0 : 44.5
Elastic Stiffness Coefficients	C_{11}^E : 2.33 (x 10 ¹¹ N/m ²) C_{33}^E : 2.77 (x 10 ¹¹ N/m ²)
Piezoelectric Strain Constants	d_{22} : 2.4 (x 10 ⁻¹¹ C/N) d_{33} : 0.8 (x 10 ⁻¹¹ C/N)
Transmission range	400 - 4500nm
Electro-optical coefficients	r_{33} =30.4pm/V
Refractive index at 632.8nm	n_o =2.176, n_e =2.180

Typical Specifications

Type Specifications	Boule		Wafer	
	Diameter	φ3"	φ4"	φ3"
Length or Thickness	≤100mm	≤50mm	0.35-0.5 mm	
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	

LiNbO₃ Crystal

Introduction

LiNbO₃ is widely used as electro-optic modulators and Q-switches for Nd:YAG, Nd:YLF and Ti:Sapphire lasers as well as modulators for fiber optics. The following table list the specifications of a typical LiNbO₃ crystal used as Q-switch with transverse E-O modulation. The light propagates in z-axis and electric field applies to x-axis. The electro-optic coefficients of LiNbO₃ are: $r_{33} = 32$ pm/V, $r_{31} = 10$ pm/V, $r_{22} = 6.8$ pm/V at low frequency and $r_{33} = 31$ pm/V, $r_{31} = 8.6$ pm/V, $r_{22} = 3.4$ pm/V at high electric frequency. The half-wave voltage: $V_{\pi} = \lambda d/n_o^3 \gamma_c$, $\gamma_c = (n_e/n_o)^3 \gamma_{33} - \gamma_{13}$.

LiNbO₃ Q-Switch Specifications

Size	9 X 9 X 25 mm ³ or 4 X 4 X 15 mm ³
	Other size is available upon request
Tolerance of size	Z-axis: ± 0.2 mm
	X-axis and Y-axis: ± 0.1 mm
Chamfer	less than 0.5 mm at 45°
Accuracy of orientation	Z-axis: $< \pm 5'$, X-axis and Y-axis: $< \pm 10'$
Parallelism	$< 20''$
Finish	10/5 scratch/dig
Flatness	$\lambda / 8$ at 633 nm
AR-coating	R $< 0.2\%$ @ 1064 nm
Electrodes	Gold/Chrome plated on X-faces
Wavefront distortion	$< \lambda / 4$ @ 633 nm
Extinction ratio	$> 400:1$ @ 633 nm, ϕ 6 mm beam

LiNbO₃ is also a good acousto-optic crystal and used for surface acoustic wave (SAW) wafer and A-O modulators. CASTECH provides acoustic (SAW) grade LiNbO₃ crystals in wafers, as-cut boules, finished components and custom fabricated elements.

Typical SAW Properties

Cut Type	SAW Velocity v_s (m/s)	Electromechanical Coupling Factor κ_s^2 (%)	Temperature Coefficient of Velocity TCV ($10^{-6}/^{\circ}\text{C}$)	Temperature Coefficient of Delay TCD ($10^{-6}/^{\circ}\text{C}$)
127.86° Y-X	3970	5.5	-60	78
Y-X	3485	4.3	-85	95

Typical Specifications

Specifications	Type	Boule		Wafer	
	Diameter		φ3"	φ4"	φ3"
Length or Thickness (mm)		≤ 100	≤ 50	0.35-0.5	
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	

CASTECH can offer other sizes and specifications of wafers upon request.

Yttrium Vanadate (YVO₄) Crystal

Introduction

The Yttrium Orthovanadate (YVO₄) is a positive uniaxial crystal grown with Czochralski method. It has good temperature stability and physical and mechanical properties. It is ideal for optical polarizing components because of its wide transparency range and large birefringence. It is an excellent synthetic substitute for Calcite (CaCO₃) and Rutile (TiO₂) crystals in many applications including fiber optic isolators and circulators, interleavers, beam displacers and other polarizing optics (refer to Table 1).

Table 1. Comparison of basic properties between YVO₄ and other Birefringent Crystals

		YVO ₄	TiO ₂	CaCO ₃	LiNbO ₃
Thermal Expansion (/°C)	c-axis	11.4x10 ⁻⁶	9.2x10 ⁻⁶	26.3x10 ⁻⁶	16.7x10 ⁻⁶
	a-axis	4.4x10 ⁻⁶	7.1x10 ⁻⁶	5.4x10 ⁻⁶	7x10 ⁻⁶
Refractive Index	n _o	1.9447@1550nm	2.454@1530nm	1.6346@ 1497nm	2.2151@ 1440nm
	n _e	2.1486@1550nm	2.710@1530nm	1.4774@ 1497nm	2.1413@ 1440nm
Birefringence (n _e -n _o)		0.2039@1550nm	0.256@1530nm	-0.1572@ 1497nm	-0.0738@ 1440nm
Mohs Hardness		5	6.5	3	5
Deliquescence		None	None	Weak	None
Transparency range		0.4-5μm	0.4-5μm	0.35-2.3μm	0.4-5μm

A reliable supplier of YVO₄ crystals

CASTECH is one of the earliest companies who have mastered the advanced growth technique of YVO₄ crystal. Now CASTECH has completed its strong mass-production line that can provide:

- Various size of bulk and finished high quality YVO₄ crystals up to φ35x50mm³ and φ20x20mm³, respectively;
- Large quantity YVO₄ wedges and displacers used for fiber optical isolators and circulators, interleavers, in size of 1.25x1.25x0.5mm³ to 3x3x15mm³ to meet OEM customer's requirement;
- Quick delivery;
- Very competitive price;
- Strict quality control;
- Technical support;

Basic Properties of YVO₄ crystal

Transparency Range:	High transmittance from 0.4 to 5μm
Crystal Symmetry:	Zircon Tetragonal, space group D _{4h}
Crystal Cell:	a=b=7.12Å; c=6.29Å
Density:	4.22 g/cm ³

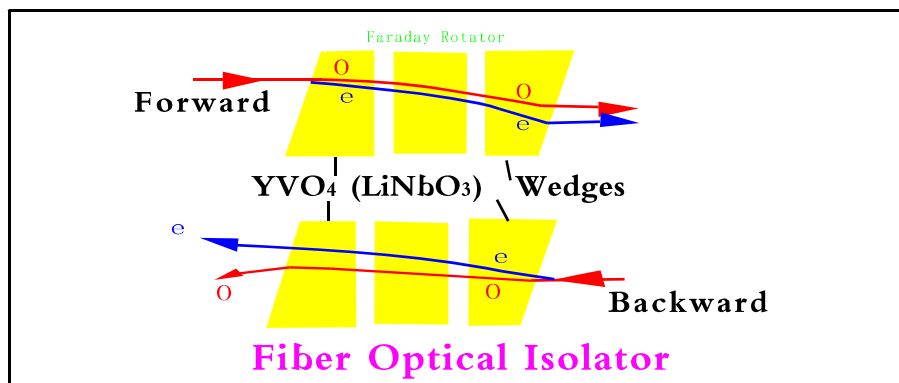
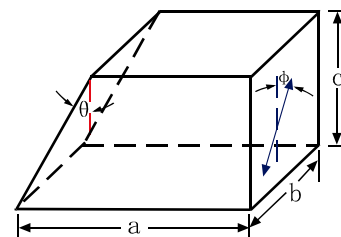
Mohs Hardness:	5, glass-like
Hygroscopic Susceptibility:	Non-hygroscopic
Thermal Expansion Coefficient:	$\alpha_a = 4.43 \times 10^{-6}/K$; $\alpha_c = 11.37 \times 10^{-6}/K$
Thermal Conductivity Coefficient :	//C: 5.23 W/m/K; \perp C: 5.10 W/m/K
Crystal Class:	Positive uniaxial with $n_o=n_a=n_b$, $n_e=n_c$
Thermal Optical Coefficient:	$dn_a/dT = 8.5 \times 10^{-6}/K$; $dn_c/dT = 3.0 \times 10^{-6}/K$
Refractive Indices, Birefringence ($\Delta n = n_e - n_o$) and Walk-off Angle at 45° (ρ):	$n_o = 1.9929$, $n_e = 2.2154$, $\Delta n = 0.2225$, $\rho = 6.04^\circ$ at 630nm $n_o = 1.9500$, $n_e = 2.1554$, $\Delta n = 0.2054$, $\rho = 5.72^\circ$ at 1300nm $n_o = 1.9447$, $n_e = 2.1486$, $\Delta n = 0.2039$, $\rho = 5.69^\circ$ at 1550nm
Sellmeier Equation (λ in μm):	$n_o^2 = 3.77834 + 0.069736/(\lambda^2 - 0.04724) - 0.0108133 \lambda^2$ $n_e^2 = 4.59905 + 0.110534/(\lambda^2 - 0.04813) - 0.0122676 \lambda^2$

YVO₄ crystal application

YVO₄ crystals are widely used in fiber-optic isolators, beam displacers and optical circulators, etc.

1. Specifications of birefringent wedges for fiber-optic isolators

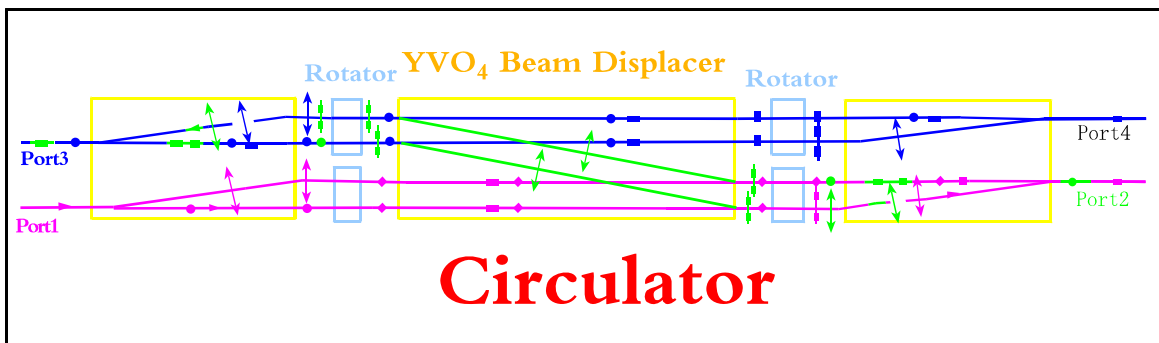
Aperture	1.0 x 1.0 mm ² to 4 x 4 mm ²
Dimension tolerance	+/-0.05mm
Wedge Angle tolerance	+/-0.1°
Optical axis orientation	+/-0.5°
Flatness	$\lambda/4$ @ 632.8 nm
Surface Quality	20-10
AR-coating	R<0.2% @1550 or 1310nm
Standard Size	1.25mmx1.25mmx0.5mm with 13° or 15° wedge, $\phi=22.5^\circ$



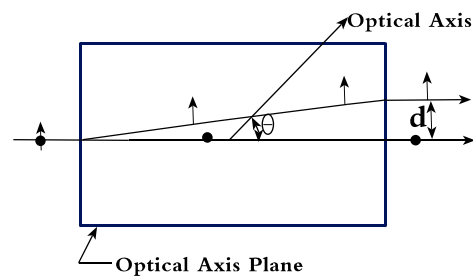
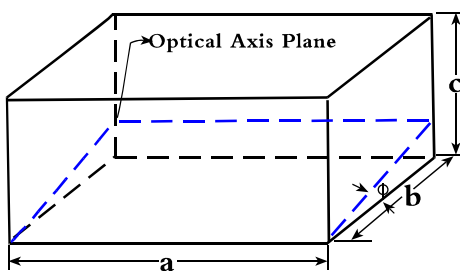
Specifications of YVO₄ beam displacers for fiber-optic circulators or interleaver

Dimension tolerance	W ($\pm 0.05\text{mm}$)xH ($\pm 0.05\text{mm}$) xL ($\pm 0.1\text{mm}$)
Optical axis orientation	$\pm 0.5^\circ$
Parallelism	<15 arc sec
Perpendicularity	<10 arc min
Flatness	$\lambda/4$ @ 632.8 nm
Surface Quality	20/10
AR-coating	R<0.2% @ 1550 nm or 1310nm \pm 40 nm
Standard Size	2.6x2.6x10mm, $\theta=45^\circ$, $\phi=0^\circ$

Note: Other sizes and specifications are available upon request



YVO₄ Beam Displacer for Circulator



LiNbO₃

Introduction

LiNbO₃ crystal combines low cost, good mechanical and physical properties as well as high optical homogeneity. Therefore, LiNbO₃ wedges have been widely used in fiber isolators and circulators.

CASTECH provides

- 50,000 to 100,000 pcs/month of LiNbO₃ wedges used for fiber optical isolators and circulators
- Reliable Delivery
- Strict quality control
- Technical support
- Very competitive price

Basic Properties of LiNbO₃

Crystal Structure:	Trigonal, Space group R3c, Point group 3m
Melting Point:	1253°C
Mohs Hardness:	5
Density:	4.64 g/cm ³
Deliquescence	None
Optical Homogeneity	~5x10 ⁻⁵ /cm
Transparency Range	420nm-5200nm
Absorption Coefficient:	~0.1%/cm @1064nm
Refractive indices at 1064nm:	n _e = 2.146, n _o = 2.220 @ 1300 nm n _e = 2.156, n _o = 2.232 @ 1064 nm n _e = 2.203, n _o = 2.286 @ 632.8 nm
Thermal Expansion Coefficients (at 25 ⁰ C)	//a, 2.0x10 ⁻⁶ /K //c, 2.2x10 ⁻⁶ /K
Thermal Conductivity Coefficient:	38 W/m/K at 25 ⁰ C
Thermal Optical Coefficient:	dn _o /dT=-0.874x10 ⁻⁶ /K at 1.4μm dn _e /dT=39.073x10 ⁻⁶ /K at 1.4μm
The Sellmeier equations (λ in μm)	n _o ² = 4.9048 + 0.11768/(λ ² -0.04750) - 0.027169λ ² n _e ² = 4.5820 + 0.099169/(λ ² -0.04443) - 0.02195λ ²

Specifications of LiNbO₃ wedges

Aperture	1.0 x 1.0 mm ² to 4 x 4 mm ²
Dimension tolerance	±0.05mm
Wedge Angle tolerance	±0.1°
Optical axis orientation	±0.5°
Flatness	λ/4 @ 632.8 nm
Surface Quality	20-10
AR-coating	R<0.2% @1550nm±40nm
Standard Size	1.25mmx1.25mmx0.5mm with 13° or 15° wedge, phi=22.5°

Note: Other sizes and coatings are available upon request.

BaTiO₃ (BTO) crystal

Introduction

Barium Titanate single crystal is an excellent photorefractive material which has high SPPC (Self Pumped Phase Conjugation) reflection and two wave mixing (optical amplification) efficiency, it is important for information processing and image storage. Besides that it is also an important substrate material for some special film as its unique ferroelectric and other properties.

The followings are important for the use of BaTiO₃, both for the bulk device and substrate

- The tetragonal BaTiO₃ single crystal (the useful phase for both photorefractive effect and substrate) will change the phase when its temperature is lower than 13°C or higher than 125°C. So it is necessary to keep its temperature in the safe range during its using, storage and transportation.
- The extra force such as compacting, cracking will cause a phase transition.
- Poling is needed for (001) orientation substrate, while is not necessary for (100), (110), (111) orientations.
- Normally the maximum size for BaTiO₃ substrate is 10x10mm; the thinnest thickness is 0.3mm.

Note: Rh doped BaTiO₃ crystal is also available from CASTECH.

Bi₄Ge₃O₁₂ (BGO) Crystal

Introduction

Now CASTECH can supply Bismuth germanate (Bi₄Ge₃O₁₂) crystal. BGO is an inorganic oxide with cubic eulytine structure, colorless, transparent and insoluble in water. Because of its high stopping power, high photopeak efficiency, non-hygroscopic, low afterglow and easy to be fabricated, BGO is a good scintillator material and has been found a wide applications in high energy physics, nuclear physics, space physics, nuclear medicine, geological prospecting and other industries.

Properties of CASTECH's BGO crystal

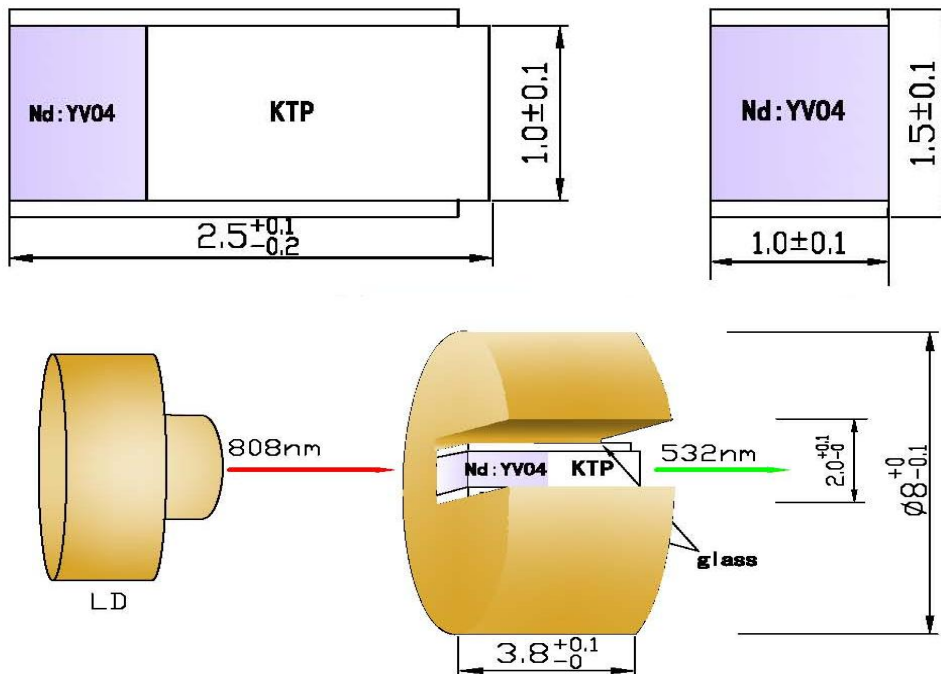
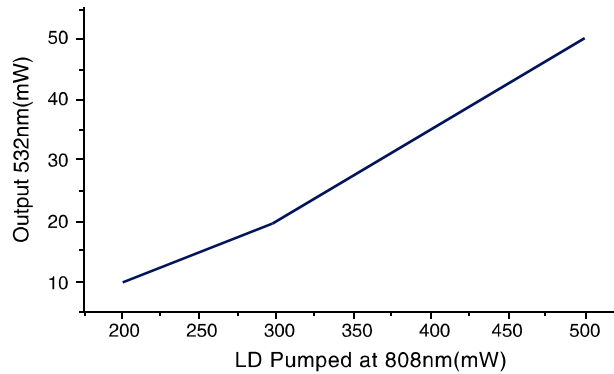
Crystal Structure	cubic
Density (g/cm ³)	7.13
Melting point (°C)	1045
Hardness	5
Parameter of crystal cell (Å)	10.518
Refractive index	2.15
Radiation length (cm)	1.1
Peak of fluorescence spectra (nm)	480
Decay time (ns)	300
Relative light output (%)	10-14 NaI(Tl)
Energy resolution (511 Kev,%)	20

Optical-contact Composites (Green Laser)

Introduction

Optical-contact composites are consisted of laser crystal Nd:YVO_4 and non-linear optical crystal KTP. They are combined together by optical-contact method without cement and can generate as high as 70mW 532nm green laser with 500mW diode pumping. They have the advantages of high conversion efficiency, compact design and low cost etc.

CASTECH is able to steadily supply Optical-contact composites (Nd:YVO_4 +KTP) with large amount (more than 30000pcs/month). The main dimension options are: $1.8 \times 1.3 \times 2.5\text{mm}$ and $1.5 \times 1.0 \times 2.5\text{mm}$. We can also supply free copper holder (Dia.8mm) upon request. For the other size of copper holder please inquire our sales people.



We have 3 kinds of Optical-contact composites (Nd:YVO_4 +KTP) according to the output 532nm power:

- A. 500mW LD pumped, output 532nm power > 70mW
- B. 500mW LD pumped, output 532nm power > 50mW
- C. 500mW LD pumped, output 532nm power > 30mW

Crystal Kit for Blue Laser

Introduction

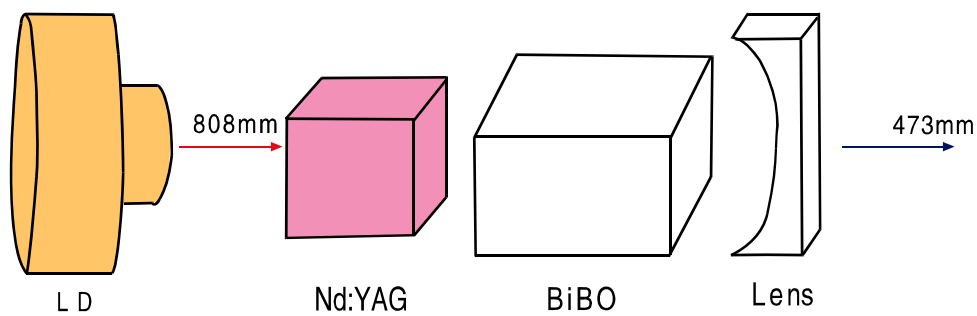
In order to meet the demand for low power blue laser, CASTECH bought the authorization of BIBO patent from FEE, a German company, and developed the low power crystal kit for blue laser. With 2 W LD pumping, such a crystal kit can generate as high as 70mW 473nm blue laser.

A set of blue laser kit include

Nd:YAG: 3x3x2mm, S1: HR-946&473nm, HT-1319/1064/808nm; S2: AR-946&473nm

BIBO: 2x2x5mm, AR/AR-946/473nm

Output Mirror: phi10x3mm, S1: HR-946nm, HT-473nm; S2: AR-473nm



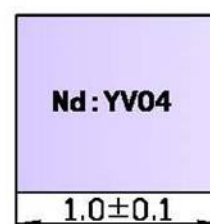
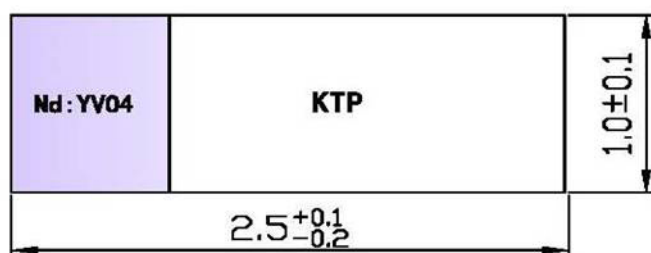
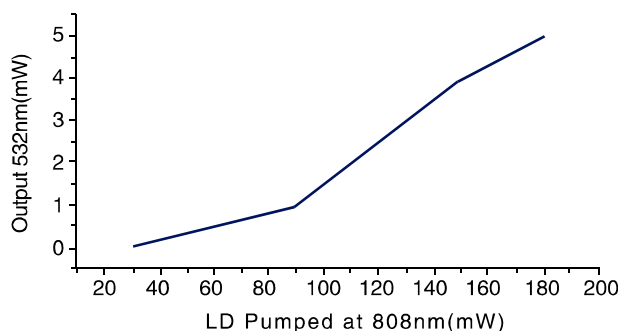
Glued Crystals (Green Laser)

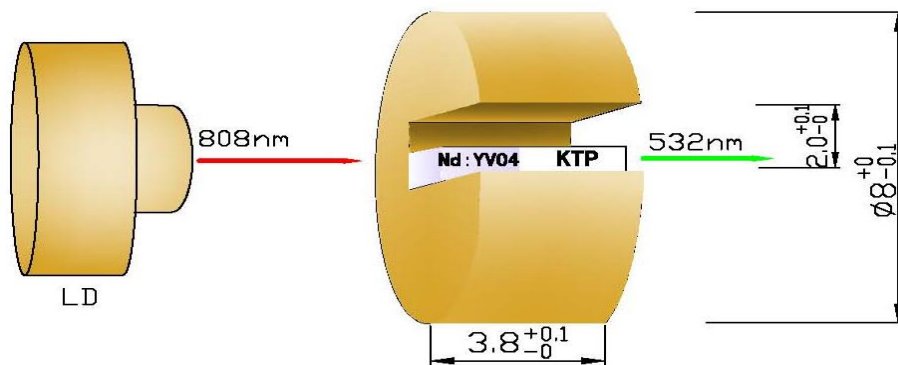
Introduction

Glued Crystals(Nd:YVO₄+KTP) are consisted of laser crystal Nd:YVO₄ and non-linear optical crystal KTP. They are combined together by UV glue and can generate as high as 10mW 532nm green laser with 200mw diode pumping. They have the advantages of high conversion efficiency, compact design, low cost, etc..

CASTECH is able to steadily supply Glued Crystals(Nd:YVO₄+KTP) with large amount (more than 30000pcs/month). The main dimension options are: 1.3x1.3x2.5mm and 1.0x1.0x2.5mm. We can also supply free copper holder(Dia.8mm) upon request. For the other size of copper holder please inquire our sales people.

Size	1.3x1.3x2.5mm or 1.0x1.0x2.5mm
Coating	Input: HR-(1064/532)nm,HT-808nm, R>99.8%@1064nm&532nm,T>95%@808nm Output: HR-1064nm, HT-532nm, R>99.8%@1064nm, T>95%@532nm
Pumping	808(+/-)nm
Output	532nm
Clear Aperture	>80%
Working temperature	20~ 30°C





We have 2 kinds of Glued Crystals (Nd:YVO₄+KTP) according to the output 532nm power:

- A. 180mW LD pumped, output 532nm power>3mW.
- B. 180mW LD pumped, output 532nm power>5mW.

For pumping power>200mW and output 532nm power larger than 10mW we recommend our another product: Optical-contact composites (Nd:YVO₄+KTP), P65.

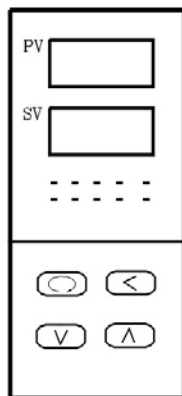
Oven & Temperature Controller

Introduction

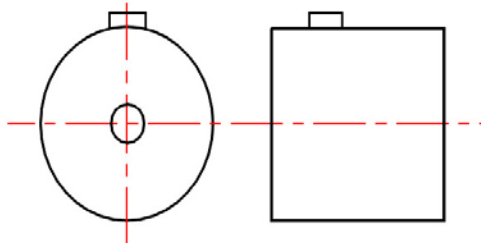
CASTECH provides oven and temperature controller for heating the crystal and controlling its temperature to a certain value.

Specifications

Temperature Controller	Oven
<ul style="list-style-type: none"> • Purpose ASIC processor • PID control • Auto tuning • RS-232 interface (optional) • Programmable (optional) • Stability: $\pm 0.1^{\circ}\text{C}$ • Size: $50 \times 100 \times 135\text{mm}^3$ • Normal Package Standard • Voltage: 85~135VAC 	<ul style="list-style-type: none"> • Design: Radioactive heat compensation • Plane temperature distribution • Fast tuning • Size: $\phi 50\text{mm} \times 55\text{mm}$ • Cavity size: $\phi 10\text{mm} \times 55\text{mm}$ • Sensor: Pt100 thermocouple • Working temperature: $\leq 180^{\circ}\text{C}$



Temperature Controller



Oven

Applications:

Heating nonlinear crystals is usually employed in NCPM, OPO, OPA, etc.

Note: Special applications are available upon request.