# Nonlinear & Laser Crystals

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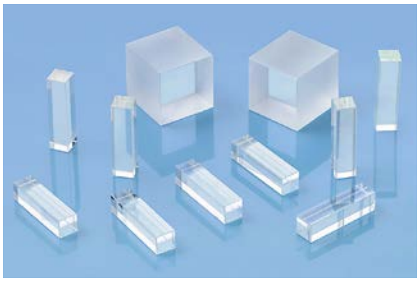
EKSMA OPTICS

# Nonlinear Crystals

## LBO – LITHIUM TRIBORATE



LBO is well suited for various nonlinear optical applications:

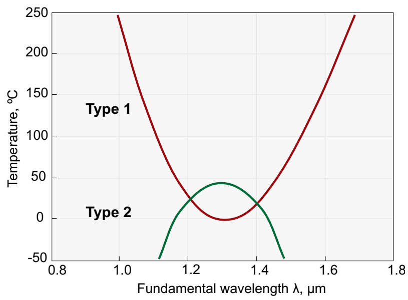
- frequency doubling and tripling of high peak power pulsed Nd doped, Ti:Sapphire and Dye lasers
- optical parametric oscillators (OPO) of both Type 1 and Type 2 phase-matching
- non-critical phase-matching for frequency conversion of CW and quasi-CW radiation.

### Standard specifications

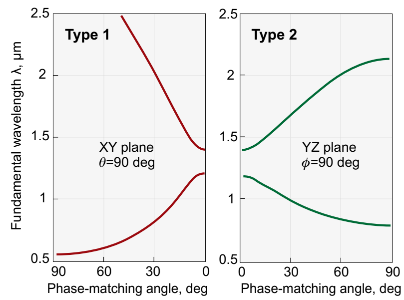
| | |
|---|---|
| Flatness | λ/8 at 633 nm |
| Parallelism | < 20 arcsec |
| Surface quality | 10 – 5 scratch & dig (MIL-PRF-13830B) |
| Perpendicularity | < 5 arcmin |
| Angle tolerance | < 30 arcmin |
| Aperture tolerance | ± 0.1 mm |
| Clear aperture | 90% of full aperture |

### Features

- Wide transparency region
- Broad Type 1 and Type 2
- Non-critical phase-matching (NCPM) range
- Small walk-off angle
- High damage threshold
- Wide acceptance angle
- High optical homogeneity




NCPM SHG temperature dependance of LBO




SHG tuning curves of LBO

### We offer:

- Crystals length up to 90 mm and aperture up to 60 × 60 mm
- AR, BBAR, P-coatings
- Different mounting and repolishing services

### Standard Crystals list

| Size, mm | θ, deg | φ, deg | Coating | Application | Catalogue number | Price, EUR |
|---|---|---|---|---|---|---|
| 3x3x10 | 90 | 11.6 | AR/AR @ 1064+532 nm | SHG @ 1064 nm | LBO-401 | 245 |
| 3x3x15 | 90 | 11.6 | AR/AR @ 1064+532 nm | SHG @ 1064 nm | LBO-402 | 325 |
| 4x4x10 | 90 | 11.6 | AR/AR @ 1064+532 nm | SHG @ 1064 nm | LBO-301 | 510 |
| 4x4x15 | 90 | 11.6 | AR/AR @ 1064+532 nm | SHG @ 1064 nm | LBO-302 | 630 |
| 4x4x20 | 90 | 11.6 | AR/AR @ 1064+532 nm | SHG @ 1064 nm | LBO-303 | 745 |
| 5x5x10 | 90 | 11.6 | AR/AR @ 1064+532 nm | SHG @ 1064 nm | LBO-501 | 655 |
| 5x5x15 | 90 | 11.6 | AR/AR @ 1064+532 nm | SHG @ 1064 nm | LBO-503 | 765 |
| 5x5x20 | 90 | 11.6 | AR/AR @ 1064+532 nm | SHG @ 1064 nm | LBO-502 | 940 |
| 3x3x15 | 90 | 0 | AR/AR @ 1064+532 nm | NCPM SHG @ 1064 nm, T = 149 °C | LBO-404 | 325 |
| 3x3x20 | 90 | 0 | AR/AR @ 1064+532 nm | NCPM SHG @ 1064 nm, T = 149 °C | LBO-405 | 405 |
| 3x3x30 | 90 | 0 | AR/AR @ 1064+532 nm | NCPM SHG @ 1064 nm, T = 149 °C | LBO-409 | 710 |
| 3x3x50 | 90 | 0 | AR/AR @ 1064+532 nm | NCPM SHG @ 1064 nm, T = 149 °C | LBO-410 | 1300 |
| 4x4x10 | 90 | 0 | AR/AR @ 1064+532 nm | NCPM SHG @ 1064 nm, T = 149 °C | LBO-304 | 510 |
| 4x4x15 | 90 | 0 | AR/AR @ 1064+532 nm | NCPM SHG @ 1064 nm, T = 149 °C | LBO-305 | 630 |
| 4x4x20 | 90 | 0 | AR/AR @ 1064+532 nm | NCPM SHG @ 1064 nm, T = 149 °C | LBO-306 | 745 |
| 3x3x10 | 42.2 | 90 | AR/AR @ 1064+532/355 nm | THG @ 1064 nm | LBO-406 | 245 |
| 3x3x15 | 42.2 | 90 | AR/AR @ 1064+532/355 nm | THG @ 1064 nm | LBO-407 | 325 |
| 4x4x10 | 42.2 | 90 | AR/AR @ 1064+532/355 nm | THG @ 1064 nm | LBO-307 | 510 |
| 4x4x15 | 42.2 | 90 | AR/AR @ 1064+532/355 nm | THG @ 1064 nm | LBO-308 | 630 |
| 5x5x10 | 42.2 | 90 | AR/AR @ 1064+532/355 nm | THG @ 1064 nm | LBO-507 | 655 |
| 5x5x15 | 42.2 | 90 | AR/AR @ 1064+532/355 nm | THG @ 1064 nm | LBO-508 | 765 |

## Physical and Optical properties

| | | | |
|---|---|---|---|
| Chemical formula | $LiB_3O_5$ | | |
| Crystal structure | orthorhombic, mm2 | | |
| Optical symmetry | Negative biaxial | | |
| Space group | $Pna2_1$ | | |
| Density | 2.47 g/cm$^3$ | | |
| Mohs hardness | 6 | | |
| Optical homogeneity | $\partial n = 10^{-6}$ cm$^{-1}$ | | |
| Transparency region at "0" transmittance level | 155 – 3200 nm | | |
| Linear absorption coefficient at 1064 nm | < 0.01 % cm$^{-1}$ | | |
| Refractive indices: | $n_x$ | $n_y$ | $n_z$ |
| at 1064 nm | 1.5656 | 1.5905 | 1.6055 |
| at 532 nm | 1.5785 | 1.6065 | 1.6212 |
| at 355 nm | 1.5971 | 1.6275 | 1.6430 |
| Sellmeier equations (λ, μm) | $n_x^2 = 2.4542 + 0.01125 / (\lambda^2 - 0.01135) - 0.01388\,\lambda^2$<br>$n_y^2 = 2.5390 + 0.01277 / (\lambda^2 - 0.01189) - 0.01849\,\lambda^2 + 4.3025 \times 10^{-5}\lambda^4 - 2.9131 \times 10^{-5}\lambda^6$<br>$n_z^2 = 2.5865 + 0.0131 / (\lambda^2 - 0.01223) - 0.01862\,\lambda^2 + 4.5778 \times 10^{-5}\lambda^4 - 3.2526 \times 10^{-5}\lambda^6$ | | |
| Phase matching range Type 1 SHG | 554 – 2600 nm | | |
| Phase matching range Type 2 SHG | 790 – 2150 nm | | |
| NCPM SHG temperature dependence: | | | |
| Type 1 range 950 – 1300 nm | $T1 = -1893.3\lambda^4 + 8886.6\lambda^3 - 13019.8\lambda^2 + 5401.5\lambda + 863.9$ | | |
| Type 1 range 1300 – 1800 nm | $T2 = 878.1\lambda^4 - 6954.5\lambda^3 + 20734.2\lambda^2 - 26378\lambda + 12020$ | | |
| Type 2 range 1100 – 1500 nm | $T3 = -21630.6\lambda^4 + 112251\lambda^3 - 220460\lambda^2 + 194153\lambda - 64614.5$ | | |
| NCPM SHG at 1064 nm Type 1 temperature | 149 °C | | |
| NCPM SHG at 1319 nm Type 2 temperature | 43 °C | | |
| Walk-off angle | 7 mrad (Type 1 SHG 1064 nm) | | |
| Thermal acceptance | 6.4 K×cm (Type 1 SHG 1064 nm) | | |
| Angular acceptance | 6.5 mrad×cm (Type 1 SHG 1064 nm)<br>248 mrad×cm (Type 1 NCPM SHG 1064 nm) | | |
| Nonlinearity coefficients | $d_{31} = (1.05 \pm 0.09)$ pm/V; $d_{32} = -(0.98 \pm 0.09)$ pm/V; $d_{33} = (0.05 \pm 0.006)$ pm/V | | |
| Effective nonlinearity: | | | |
| XY plane | $d_{ooe} = d_{32}\cos\varphi$ | | |
| YZ plane | $d_{oeo} = d_{eoo} = d_{31}\cos\theta$ | | |
| Expansion coefficients | $\alpha_x = 10.8 \times 10^{-5}$ K$^{-1}$; $\alpha_y = -8.8 \times 10^{-5}$ K$^{-1}$; $\alpha_z = 3.4 \times 10^{-5}$ K$^{-1}$ | | |
| Laser induced damage threshold (LIDT) | >5 J/cm$^2$ (>500 MW/cm$^2$), 1064 nm, 10 ns, 10 Hz | | |

Please contact EKSMA OPTICS for further information or nonstandard specifications.

## Related Products

LBO crystals for SHG of Yb:KGW/KYW laser frequency conversion. See page 2.17

Crystal Oven TC2
See page 2.28

149 °C temperature is required to achieve Non-Critical Phase Matching (NCPM) in LBO at type 1 SHG of 1064 nm application. **TC2 oven** is specially designed for this purpose.

Heatpoint Crystal Oven
See page 2.29

**Heatpoint** is a compact round oven designed for heating (30 – 80 °C) of humidity sensitive nonlinear crystals. It is used to prevent moisture condensation on crystal faces or for thermostabilization of the crystals.

# BBO – BETA BARIUM BORATE

## Features

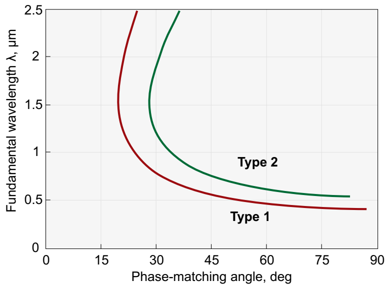
- Wide transparency region
- Broad phase-matching range
- Large nonlinear coefficient
- High damage threshold
- Wide thermal acceptance bandwidth
- High optical homogenity

As a result of its excellent properties BBO has a number of advantages for different applications:

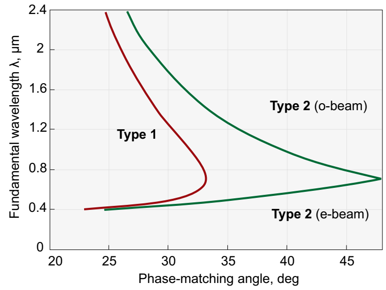
- harmonic generations (up to fifth) of Nd doped lasers
- frequency doubling and tripling of ultrashort pulse Ti:Sapphire and Dye lasers
- optical parametric oscillators (OPO) at both Type 1 (ooe) and Type 2 (eoe) phase-matching
- frequency doubling of Argon ion and Copper vapour laser radiation
- electro-optic crystal for Pockels cells
- ultrashot pulse duration measurements by autocorrelation.

## Standard specifications

| | |
|---|---|
| Flatness | λ/8 at 633 nm |
| Parallelism | < 20 arcsec |
| Surface quality | 10 – 5 scratch & dig (MIL-PRF-13830B) |
| Perpendicularity | < 5 arcmin |
| Angle tolerance | < 30 arcmin |
| Aperture tolerance | ± 0.1 mm |
| Clear aperture | 90% of full aperture |




SHG tuning curve of BBO




OPO tuning curves of BBO at 355 nm pump

## We offer:

- Crystal aperture up to 25×25 mm
- Crystal length up to 25 mm
- Thin crystals down to 5 μm thickness
- AR, BBAR, P-coating
- BBO with gold electrodes for e/o applications
- Different mounting and repolishing services

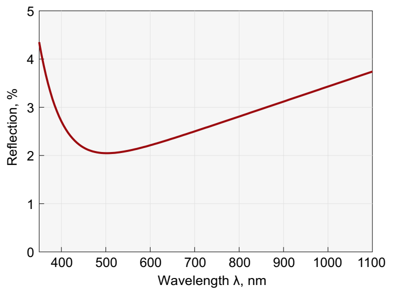
## Standard Crystals list

| Size, mm | θ, deg | φ, deg | Coating | Application | Catalogue number | Price, EUR |
|---|---|---|---|---|---|---|
| 6×6×0.1 | 29.2 | 90 | P/P @ 400-800 nm | SHG @ 800 nm, Type 1 | BBO-601H | 505 |
| 6×6×0.2 | 29.2 | 90 | P/P @ 400-800 nm | SHG @ 800 nm, Type 1 | BBO-602H | 505 |
| 6×6×0.5 | 29.2 | 90 | P/P @ 400-800 nm | SHG @ 800 nm, Type 1 | BBO-603H | 440 |
| 6×6×1 | 29.2 | 90 | P/P @ 400-800 nm | SHG @ 800 nm, Type 1 | BBO-604H | 390 |
| 6×6×2 | 29.2 | 90 | P/P @ 400-800 nm | SHG @ 800 nm, Type 1 | BBO-605H | 360 |
| 6×6×0.1 | 44.3 | 90 | P/P @ 400-800/266 nm | THG @ 800 nm, Type 1 | BBO-609H | 505 |
| 6×6×0.2 | 44.3 | 90 | P/P @ 400-800/266 nm | THG @ 800 nm, Type 1 | BBO-610H | 505 |
| 6×6×0.5 | 44.3 | 90 | P/P @ 400-800/266 nm | THG @ 800 nm, Type 1 | BBO-611H | 440 |
| 6×6×1 | 44.3 | 90 | P/P @ 400-800/266 nm | THG @ 800 nm, Type 1 | BBO-612H | 390 |
| 10×10×0.1 | 29.2 | 90 | P/P @ 400-800 nm | SHG @ 800 nm, Type 1 | BBO-1001H | 800 |
| 10×10×0.2 | 29.2 | 90 | P/P @ 400-800 nm | SHG @ 800 nm, Type 1 | BBO-1002H | 790 |
| 10×10×0.5 | 29.2 | 90 | P/P @ 400-800 nm | SHG @ 800 nm, Type 1 | BBO-1003H | 760 |
| 10×10×1 | 29.2 | 90 | P/P @ 400-800 nm | SHG @ 800 nm, Type 1 | BBO-1004H | 765 |
| 10×10×2 | 29.2 | 90 | P/P @ 400-800 nm | SHG @ 800 nm, Type 1 | BBO-1005H | 830 |
| 10×10×0.1 | 44.3 | 90 | P/P @ 400-800/266 nm | THG @ 800 nm, Type 1 | BBO-1009H | 800 |
| 10×10×0.2 | 44.3 | 90 | P/P @ 400-800/266 nm | THG @ 800 nm, Type 1 | BBO-1010H | 790 |
| 10×10×0.5 | 44.3 | 90 | P/P @ 400-800/266 nm | THG @ 800 nm, Type 1 | BBO-1011H | 760 |
| 10×10×1 | 44.3 | 90 | P/P @ 400-800/266 nm | THG @ 800 nm, Type 1 | BBO-1012H | 785 |

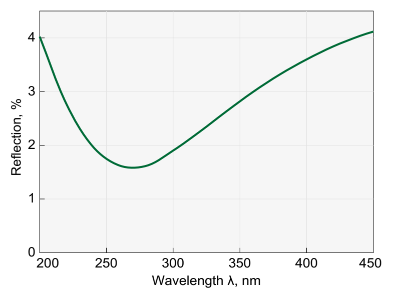
Wide selection of non-standard size and cut angle BBO crystals is available at **www.eksmaoptics.com**

## Physical and Optical properties

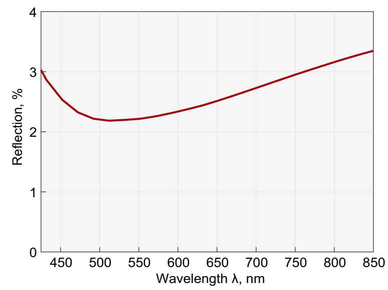
| | | |
|---|---|---|
| Chemical formula | $BaB_2O_4$ | |
| Crystal structure | trigonal, 3m | |
| Optical symmetry | Negative Uniaxial ($n_o > n_e$) | |
| Space group | R3c | |
| Density | 3.85 g/cm³ | |
| Mohs hardness | 5 | |
| Optical homogeneity | $\partial n = 10^{-6}$ cm$^{-1}$ | |
| Transparency region at "0" transmittance level | 189 – 3500 nm | |
| Linear absorption coefficient at 1064 nm | < 0.1% cm$^{-1}$ | |
| Refractive indices | $n_o$ | $n_e$ |
| at 1064 nm | 1.6551 | 1.5426 |
| at 532 nm | 1.6750 | 1.5555 |
| at 355 nm | 1.7055 | 1.5775 |
| at 266 nm | 1.7571 | 1.6139 |
| at 213 nm | 1.8465 | 1.6742 |
| Sellmeier equations (λ, μm) | $n_o^2 = 2.7366122 + 0.0185720 / (\lambda^2 - 0.0178746) - 0.0143756\,\lambda^2$<br>$n_e^2 = 2.3698703 + 0.0128445 / (\lambda^2 - 0.0153064) - 0.0029129\,\lambda^2$ | |
| Phase matching range Type 1 SHG | 410 – 3300 nm | |
| Phase matching range Type 2 SHG | 530 – 3300 nm | |
| Walk-off angle | 55.9 mrad (Type 1 SHG 1064 nm) | |
| Angular acceptance | 1.2 mrad × cm (Type 1 SHG 1064 nm) | |
| Thermal acceptance | 70 K × cm (Type 1 SHG 1064 nm) | |
| Nonlinearity coefficients | $d_{22} = \pm 2.2$ pm/V; $d_{15} = d_{31} = \pm 0.08$ pm/V | |
| Effective nonlinearity expressions | $d_{ooe} = d_{31} \sin\theta - d_{22} \cos\theta \sin 3\varphi$<br>$d_{eoe} = d_{oee} = d_{22} \cos^2\theta \cos 3\varphi$ | |
| Thermal expansion coefficient | $\alpha_{11} = 4 \times 10^{-6}$ K$^{-1}$; $\alpha_{33} = 36 \times 10^{-6}$ K$^{-1}$ | |
| Damage threshold for $TEM_{00}$ | > 0.5 GW/cm² at 1064 nm, 10 ns<br>~ 50 GW/cm² at 1064 nm, 1 ps<br>> 200 GW/cm² at 800 nm, 100 fs, 50 Hz | |



Typical P-coating for BBO SHG@800 nm application



Typical coating for BBO THG@800 nm or SHG@532 nm applications (output face P@266 nm)



Typical coating for BBO SHG@532 nm application (input face P@532 nm)

P-protective coating. It's a single or two layers antireflection coating made at specified wavelength range. Typical reflection values are R≈2% in the mid range, R<4% at the edges. P coating is recommended for ultra-short pulses applications and features low dispersion.

## Related Products

Thin BBO crystals for SHG and THG of Ti:Sapphire laser wavelength

See page 2.23

BBO crystals for SHG of Yb:KGW/KYW laser frequency conversion

See page 2.17

## Housing accessories

Ring Holders for Nonlinear Crystals

See page 2.26

Positioning Mount 840-0199 for Nonlinear Crystal Housing

Accepts crystals with aperture up to 12x12 mm and thichness up to 3 mm.

See page 2.27

# CESIUM LITHIUM BORATE – CLBO

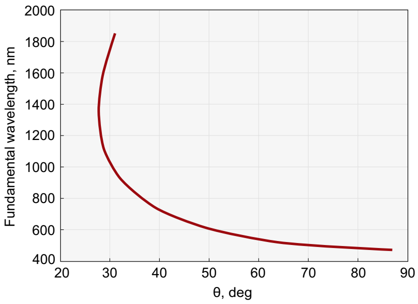
## Features

- Well suited for UV applications
- Small walk-off angle
- Large angle tolerance
- No saturation for high power generation

CLBO is a highly hygroscopic NLO crystal material. Therefore, standard CLBO crystals are supplied sealed in 1-inch (ø25.4 mm) housings with anti-reflection coated UV FS protective windows. Unmounted CLBO crystals are available upon custom request.

CLBO is a relatively new nonlinear crystal material, which has excellent properties in the UV that can be used for different applications:

- Harmonic generation (up to fifth) of Nd-doped lasers
- Frequency doubling and tripling of Alexandrite, Ti:Sapphire lasers




SHG Tuning curve of CLBO

## Standard Specifications

| | |
|---|---|
| Flatness | λ/8 @ 633 nm |
| Parallelism | 20 arcsec |
| Surface quality | 10 – 5 scratch & dig (MIL-O-13830A) |
| Perpendicularity | < 5 arcmin |
| Angle tolerance | < 30 arcmin |
| Aperture tolerance | ± 0.1 mm |
| Clear aperture | 90% of full aperture |

## Physical Properties

| | |
|---|---|
| Chemical formula | $CsLiB_6O_{10}$ |
| Transparency range | 180 – 2750 nm |
| Effective NLO coefficient | 1.01 pm/V @ 532 nm<br>1.16 pm/V @ 488 nm |
| NLO coefficients | $d_{eff}(I) = d_{36}\sin\theta m \sin(2\varphi)$<br>$d_{eff}(II) = d_{36}\sin(2\theta m)\cos(2\varphi)$ |
| Sellmeier equations,<br>CLBO at 20°C (0.1914 < λ < 2.09 μm) | $no^2 = 2.2104 + 0.01018 / (\lambda^2 - 0.01424) - 0.01258\lambda^2$<br>$ne^2 = 2.0588 + 0.00838 / (\lambda^2 - 0.01363) - 0.00607\lambda^2$ |
| Density | 2.461 g/cm³ |
| Mohs hardness | 5.5 |
| Melting point | 1118 K |
| Thermal conductivity | 1.25 W/mK |
| Refractive indices | $n_e$ = 1.4340, no = 1.4838 @ 1064 nm<br>$n_e$ = 1.4445, no = 1.4971 @ 532 nm |
| Therm-optic coefficients | $dn_o/dT = -1.9 \times 10^{-6}$/°C<br>$dn_e/dT = -0.5 \times 10^{-6}$/°C |

## Standard Crystals List

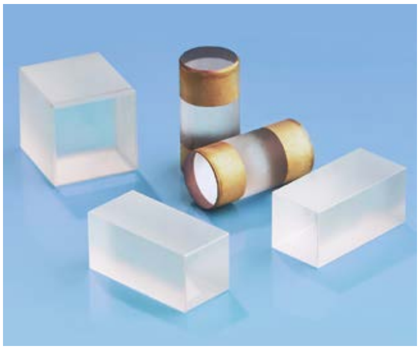
| Size, mm | θ, deg | φ, deg | Coating | Catalogue number | Price, EUR |
|---|---|---|---|---|---|
| 4 × 4 × 10 | 61.5 | 45 | AR/AR @ 532+266 nm | **CLBO-401S** | 2760 |
| 5 × 5 × 8 | 61.5 | 45 | AR/AR @ 532+266 nm | **CLBO-501S** | 3410 |

CLBO is a highly hygroscopic NLO crystal material. Standard CLBO crystals are supplied sealed in 1-inch (ø25.4 mm) housings with anti-reflection coated UV FS protective windows. Unmounted CLBO crystals are available upon custom request.

## Application

| Wavelength | Phase matching angle | Deff | Angle tolerence | Walk-off angle |
|---|---|---|---|---|
| 532 + 532 = 266 nm | 61.7° | 0.84 pm/V | 0.49 mrad - cm | 1.83° |

# KDP / DKDP – POTASSIUM DIDEUTERIUM PHOSPHATE



## Features

- Laser frequency conversion – harmonic generation for high pulse energy, low repetition (<100 Hz) rate lasers
- Electro-optical modulation
- Q-switching crystal for Pockels cells

## Electro-Optical/Q-switching application

- EKSMA OPTICS offers highly deuterated D>96% **electro-optic crystal – DKDP** for Q-switching application;
- Standard dimensions **of electro-optic DKDP crystals** for Q-switching are cylinders dia 9×20 mm and dia 12×24 mm however manufacturing of custom size and rectangular shape crystals is available;
- Gold evaporated or silver paste electrodes are available;
- **Dielectric thin film AR coatings** for specified laser wavelengths are available;
- Typical quarter wave voltage 3.4 kV at 1064 nm;
- Typical contrast ratio between crossed polarizers better than 1:2000;
- Damage threshold of AR coated DKDP surface >5 J/cm$^2$ at 1064 nm, 10 ns pulses.

## Standard specifications

| | |
|---|---|
| Flatness | λ/6 at 633 nm |
| Parallelism | < 20 arcsec |
| Surface quality | 20 – 10 scratch & dig (MIL-PRF-13830B) |
| Perpendicularity | < 5 arcmin |
| Angle tolerance | < 30 arcmin |
| Aperture tolerance | ± 0.1 mm |
| Clear aperture | 90% of full aperture |

## Frequency conversion applications

- **DKDP crystals** are used for second harmonic generation of high pulse energy low repetition rate (<100 Hz) Q-switched and mode-locked Nd:YAG lasers. Cut angle of crystal for operation at room temperature is 36.6° for Type 1 phase matching and 53.7° deg for Type 2 phase matching.
- **DKDP crystals** are used for third harmonic generation of high pulse energy Q-switched and mode-locked Nd:YAG lasers via sum frequency generation. Cut angle of crystal for operation at room temperature is 59.3° for Type 2 phase matching.
- Type 1 **DKDP crystals** with non-critical cut angle θ=90° are used for fourth harmonic generation (532 nm → 266 nm) of high pulse energy Q-switched and mode-locked Nd:YAG lasers. Crystal must be heated at ~50 °C temperature to match NCPM conditions.
- Type 1 **KDP crystals** with close to non-critical cut angle θ=76.5° are used for fourth harmonic generation (532 nm → 266 nm) of high pulse energy Q-switched and mode-locked Nd:YAG lasers. KDP has lower absorption at UV wavelengths comparing to DKDP.
- **KDP thin crystals** are used for second harmonic generation of Ti:Sapphire laser radiation or pulse duration measurement in single shot autocorrelators. KDP possesses ~2.4 times larger spectral acceptance and correspondingly smaller group velocity mismatch comparing to BBO crystal for SHG of 800 nm, what sometime is very critical parameter for femtosecond wide spectrum pulses.
- KDP crystals can be supplied by EKSMA OPTICS of aperture up to Ø80 mm. Actually KDP remains the only solution for harmonic generation of very high intensity femtosecond Ti:Sapphire lasers featuring sub-tera Watt or tera Watt peak power pulses in large >30 mm diameter beams.

## Standard Crystals list

| Size, mm | θ, deg | φ, deg | Coating | Application | Catalogue number | Price, EUR |
|---|---|---|---|---|---|---|
| 15x15x13 | 36.5 | 45 | AR/AR @ 1064+532 nm | SHG @ 1064 nm, Type 1 | DKDP-401 | 890 |
| 15x15x13 | 53.5 | 0 | AR/AR @ 1064+532 nm | SHG @ 1064 nm, Type 2 | DKDP-402 | 890 |
| 12x12x20 | 59.3 | 0 | AR/AR @ 1064+532 / 355 nm | THG @ 1064 nm, Type 2 | DKDP-403 | 830 |
| 12x12x20 | 53.5 | 0 | AR/AR @ 1064 / 1064+532 nm | SHG @ 1064 nm | DKDP-404 | 830 |
| 15x15x20 | 53.5 | 0 | AR/AR @ 1064 / 1064+532 nm | SHG @ 1064 nm | DKDP-405 | 950 |
| 15x15x20 | 59.3 | 0 | AR/AR @ 1064+532 / 355 nm | THG @ 1064 nm | DKDP-406 | 950 |
| 12x12x5 | 76.5 | 45 | AR/AR @ 532/266 nm | SHG @ 532 nm | KDP-401 | 405 |
| 15x15x7 | 76.5 | 45 | AR/AR @ 532/266 nm | SHG @ 532 nm | KDP-402 | 480 |

Wide selection of non-standard size and cut angle DKDP crystals is available at **www.eksmaoptics.com**

## Physical and Optical properties

| Crystals | | KDP | DKDP |
|---|---|---|---|
| Chemical formula | | $KH_2PO_4$ | $KD_2PO_4$ |
| Symmetry | | 42 m | 42 m |
| Hygroscopicity | | high | high |
| Density, g/cm³ | | 2.332 | 2.355 |
| Thermal conductivity, W/cm×K | | $k_{11}= 1.9\times10^{-2}$ | $k_{11}= 1.9\times10^{-2}$<br>$k_{33}= 2.1\times10^{-2}$ |
| Thermal expansion coefficients, $K^{-1}$ | | $a_{11}= 2.5\times10^{-5}$<br>$a_{33}= 4.4\times10^{-5}$ | $a_{11}= 1.9\times10^{-5}$<br>$a_{33}= 4.4\times10^{-5}$ |
| Transmission range, µm | | 0.18–1.5 | 0.2–2.0 |
| Residual absorption, $cm^{-1}$ (at 1.06 µm) | | 0.04 | 0.005 |
| Measured refractive index (at 1.06 µm) | | $n_o = 1.4938$<br>$n_e = 1.4599$ | $n_o = 1.4931$<br>$n_e = 1.4582$ |
| Sellmeier coeff., λ – wavelength in µm | | $n^2 = A + \frac{B\lambda^2}{\lambda^2 - C} + \frac{D}{\lambda^2 - E}$ | |
| A | $n_o$<br>$n_e$ | 2.259276<br>2.132668 | 2.2409<br>2.1260 |
| B | $n_o$<br>$n_e$ | 13.00522<br>3.2279924 | 2.2470<br>0.7844 |
| C | $n_o$<br>$n_e$ | 400<br>400 | 126.9205<br>123.4032 |
| D | $n_o$<br>$n_e$ | 0.01008956<br>0.008637494 | 0.0097<br>0.0086 |
| E | $n_o$<br>$n_e$ | 0.012942625<br>0.012281043 | 0.0156<br>0.0120 |
| Nonlinear coeff. $d_{36}$, pm/V (at 1.06 µm) | | 0.43 | 0.40 |
| Effective nonlinear coefficient<br>Type 1<br>Type 2 | | $d_{ooe} = d_{36} \times \sin\theta \times \sin2\varphi$<br>$d_{eoe} = d_{36} \times \sin\theta \times \cos2\varphi$ | |
| Laser damage threshold, GW/cm² at 1.06 µm | | 10 ps – 100<br>1 ns – 10<br>15 ns – 14.4 | 250 ps – 6<br>10 ns – 0.5 |

## Phase matching angles and bandwidths for SHG of 1064 nm

| Crystal | KDP | | DKDP | |
|---|---|---|---|---|
| Type of phase matching | Type 1 ooe | Type 2 eoe | Type 1 ooe | Type 2 eoe |
| Cut angle θ, deg | 41.2 | 59.1 | 36.6 | 53.7 |
| Acceptances for crystal of 1 cm length (FWHM): | | | | |
| Δθ (angular), mrad | 1.1 | 2.2 | 1.2 | 2.3 |
| ΔT thermal, K | 10 | 11.8 | 32.5 | 29.4 |
| Δλ spectral, nm | 21 | 4.5 | 6.6 | 4.2 |
| Walk off, mrad | 28 | 25 | 25 | 25 |

**ADP, DADP, RDP, CDA and DCDA crystals are available upon request!**

# KTP – POTASSIUM TITANYL PHOSPHATE

## Features

- Excellent nonlinear, electro-optical and acousto-optical properties
- High nonlinear coefficient
- Wide transparency range
- Broad angular acceptance
- Broad thermal acceptance

## We offer:

- Crystal size up to 10×10×20 mm
- Singleband and dualband AR and BBAR coatings
- Standard and customised mounts and housings
- Free technical consulting.

KTP is a standard crystal mostly used in extracavity configuration when a single pass through the crystal is required.

KTP crystals are optimised for SHG intracavity configuration in low peak power CW lasers. Due to the large number of passes through the crystal, low insertion losses and high homogeneity are essential for conversion efficiency. The special highest quality material selected by SHG efficiency mapping of each crystal, fine surface polishing and dual band AR coatings with very low losses allow EKSMA OPTICS to produce KTP crystals suitable for intracavity SHG application.

## Standard specifications

| | |
|---|---|
| Flatness | λ/8 at 633 nm |
| Parallelism | < 20 arcsec |
| Surface quality | 10 – 5 scratch & dig (MIL-PRF-13830B) |
| Perpendicularity | < 5 arcmin |
| Angle tolerance | < 30 arcmin |
| Aperture tolerance | ± 0.1 mm |
| Clear aperture | 90% of full aperture |

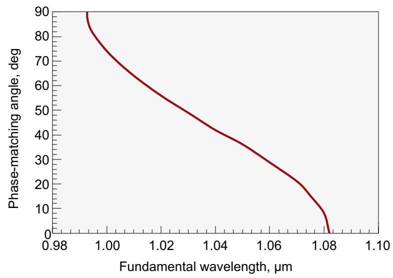



***Fig. 1.*** Type 2 SHG in x-y plane

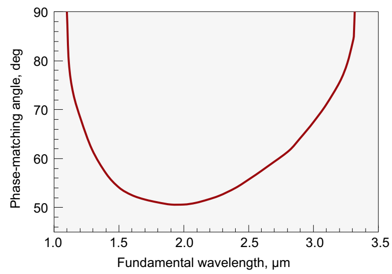



***Fig. 2.*** Type 2 SHG in x-z plane

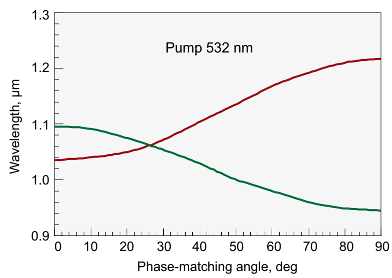



***Fig. 3.*** OPO tuning curve in x-y plane

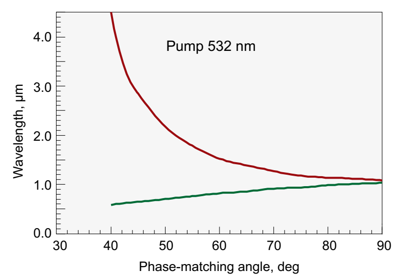



***Fig. 4.*** OPO tuning curve in x-z plane

Fig. 1 represents Type 2 SHG tuning curve of KTP in x-y plane. In x-y plane the slope ∂(Δk)/∂θ is small. This corresponds to quasi-angular noncritical phase-matching, which ensures the double advantage of a large acceptance angle and a small walk off. Otherwise in x-z plane the slope ∂(Δk)/∂λ is almost zero for wavelengths in the range 1.5–2.5 µm and this corresponds to quasi-wavelength noncritical phase-matching, which ensures a large spectral acceptance (see Fig. 2). Wavelength noncritical phase-matching is highly desirable for frequency conversion of short pulses.

As a lasing material for OPG, OPA or OPO, KTP can most usefully be pumped by Nd lasers and their second harmonic or any other source with intermediate wavelength, such as a dye laser (near 600 nm). Fig. 3 and Fig. 4 show the phase-matching angles for OPO/OPA pumped at 532 nm in x-y and x-z plane respectively.

## Standard Crystals list

| Size, mm | θ, deg | φ, deg | Coating | Application | Catalogue number | Price, EUR |
|---|---|---|---|---|---|---|
| 3x3x5 | 90 | 23.5 | AR/AR @ 1064+532 nm | SHG @ 1064 nm | **KTP-401** | 76 |
| 3x3x10 | 90 | 23.5 | AR/AR @ 1064+532 nm | SHG @ 1064 nm | **KTP-402** | 109 |
| 4x4x6 | 90 | 23.5 | AR/AR @ 1064+532 nm | SHG @ 1064 nm | **KTP-403** | 118 |
| 7x7x9 | 90 | 23.5 | AR/AR @ 1064+532 nm | SHG @ 1064 nm | **KTP-404** | 529 |

## Physical properties

| | |
|---|---|
| Crystal structure | orthorhombic |
| Point group | mm2 |
| Space group | $Pna2_1$ |
| Lattice constants, Å | a = 6.404, b = 10.616, c = 12.814, z = 8 |
| Density, $g/cm^3$ | 3.01 |
| Melting point, °C | 1172 |
| Transition temperature, °C | 936 |
| Mohs hardness | 5 |
| Thermal expansion coefficients, $°C^{-1}$ | $a_x = 11\times10^{-6}$, $a_y = 9\times10^{-6}$, $a_z = 0.6\times10^{-6}$ |
| Thermal conductivity, W/cm°C | 13 |
| Not hygroscopic | |

## Optical properties

| | | |
|---|---|---|
| Transparency | 350–4400 nm | |
| Refractive indices | at 1064 nm | at 532 nm |
| | $n_x = 1.7404$ | $n_x = 1.7797$ |
| | $n_y = 1.7479$ | $n_y = 1.7897$ |
| | $n_z = 1.8296$ | $n_z = 1.8877$ |
| Thermooptic coefficients in 0.4 – 1.0 µm range | $\partial n_x/\partial T = 1.1\times10^{-5}\,(K)^{-1}$<br>$\partial n_y/\partial T = 1.3\times10^{-5}\,(K)^{-1}$<br>$\partial n_z/\partial T = 1.6\times10^{-5}\,(K)^{-1}$ | |
| Wavelength dispersion of refractive indices | $n_x^2 = 3.0067 + 0.0395/(\lambda^2 - 0.04251) - 0.01247\times\lambda^2$<br>$n_y^2 = 3.0319 + 0.04152/(\lambda^2 - 0.04586) - 0.01337\times\lambda^2$<br>$n_z^2 = 3.3134 + 0.05694/(\lambda^2 - 0.05941) - 0.016713\times\lambda^2$ | |

## Nonlinear properties

| | |
|---|---|
| Phase matching range for: | |
| Type 2 SHG in x-y plane | 0.99÷1.08 µm |
| Type 2 SHG in x-z plane | 1.1÷3.4 µm |
| For Type 2, SHG @ 1064 nm, cut angle θ=90°, φ=23.5° | |
| Walk-off | 4 mrad |
| Angular acceptances | $\Delta\theta = 55$ mrad × cm<br>$\Delta\varphi = 10$ mrad × cm |
| Thermal acceptance | $\Delta T = 22$ K × cm |
| Spectral acceptance | $\Delta v = 0.56$ nm × cm |
| Up to 80% extracavity SHG efficiency | |
| Effective nonlinearity | |
| x-y plane | $d_{eoe} = d_{oee} = d_{15}\sin^2\varphi + d_{24}\cos^2\varphi$ |
| x-z plane | $d_{oeo} = d_{eoo} = d_{24}\sin\theta$<br>$d_{31} = \pm 1.95$ pm/V   $d_{32} = \pm 3.9$ pm/V<br>$d_{33} = \pm 15.3$ pm/V   $d_{24} = d_{32}$   $d_{15} = d_{31}$ |
| Damage threshold | >500 $MW/cm^2$<br>*for pulses λ=1064 nm, τ=10 ns, 10 Hz, $TEM_{00}$* |

## Related Products

Crystal Oven TC2

See page 2.28

Ring Holders for Nonlinear Crystals

See page 2.26

Heatpoint Crystal Oven

See page 2.29


Positioning Mount 840-0199 for Nonlinear Crystal Housing

See page 2.27

# KTA – POTASSIUM TITANYLE ARSENATE


Potassium titanyle arsenate ($KTiOAsO_4$), or KTA, is a nonlinear optical crystal for Optical Parametric Oscillation (OPO) application. It has good nonlinear optical and electro-optical properties, e.g. significantly reduced absorption in band range of 2.0 – 5.0 µm, broad angular and temperature bandwidth, low dielectric constants.

## Specifications

| | |
|---|---|
| Flatness | λ/8 at 633 nm |
| Parallelism | < 20 arcsec |
| Surface quality | 10 – 5 scratch & dig (MIL-PRF-13830B) |
| Perpendicularity | < 15 arcmin |
| Angle tolerance | < ± 0.2° |
| Aperture tolerance | ± 0.1 mm |
| Clear aperture | > 90% central area |
| Transmitting wavefront distortion | less than λ/8 @ 633 nm |

## Features

- Significantly reduced absorption in band range of 2.0 – 5.0 µm
- Broad angular bandwidth
- Broad temperature bandwidth
- Low dielectric constants

## Primary applications

- OPO for mid IR generation – up to 4 µm
- Sum and Difference Frequency Generation in mid IR range
- Electro-optical modulation and Q-switching

## We offer:

- KTA crystals size up to 15×15×30 mm
- AR and BBAR coatings for VIS-IR and mid IR ranges

## Standard Crystals list

| Size, mm | θ, deg | φ, deg | Coating | Application | Catalogue number | Price, EUR |
|---|---|---|---|---|---|---|
| 5×5×20 | 45 | 0 | AR/AR @ 1064+(1500-4500) nm | Nanosecond OPO @ 1064 nm | KTA-503 | 1985 |
| 5×5×10 | 45 | 0 | AR/AR @ 1064+(1500-4500) nm | Picosecond OPG/A @ 1064 nm | KTA-504 | 1060 |
| 6×6×1 | 47 | 0 | AR/AR @ 1.2-2.4/2.6-5.0 µm | DFG @ 1.2-2.4 µm | KTA-601H | 675 |
| 6×6×3 | 46 | 0 | AR/AR @ 1030+(1700-5000) nm | OPO @ 1030 nm | KTA-602H | 590 |

## Physical properties

| | |
|---|---|
| Crystal structure | orthorhombic |
| Point group | mm2 |
| Space group | Pna21 |
| Lattice constants, Å | a = 13.125, b = 6.5716, c = 10.786 |
| Density, g/cm³ | 3.45 |
| Melting point, °C | 1130 |
| Mohs hardness | 5 |
| Thermal conductivity, W/m×K | $k_1$=1.8, $k_2$=1.9, $k_3$=2.1 |
| Not hygroscopic | |

## Nonlinear & Optical properties

| | |
|---|---|
| Transparency | 350 – 5300 nm |
| Wavelength dispersion of refractive indices | $n_x^2 = 1.90713 + 1.23522 \times \lambda^2 / (\lambda^2 - 0.196922^2) - 0.01025 \times \lambda^2$<br>$n_y^2 = 2.15912 + 1.00099 \times \lambda^2 / (\lambda^2 - 0.218442^2) - 0.01096 \times \lambda^2$<br>$n_z^2 = 2.14768 + 1.29559 \times \lambda^2 / (\lambda^2 - 0.227192^2) - 0.01436 \times \lambda^2$ |
| Electro optical constants | $r_{33}$ = 37.5 pm/V, $r_{23}$ = 15.4 pm/V, $r_{13}$ = 11.5 pm/V |
| Effective nonlinearity | |
| x-y plane | $d_{eoe} = d_{oee} = d_{15}\sin^2\varphi + d_{24}\cos^2\varphi$ |
| x-z plane | $d_{oeo} = d_{eoo} = d_{24}\sin\theta$<br>$d_{31}$=2.3 pm/V, $d_{32}$=3.66 pm/V, $d_{33}$=15.5 pm/V<br>$d_{24}$ = 3.64 pm/V, $d_{15}$ = 2.3 pm/V |
| Damage threshold | >500 MW/cm² for pulses λ=1064 nm, τ=10 ns, 10 Hz, $TEM_{00}$ |

# $LiNbO_3$ – LITHIUM NIOBATE

Lithium Niobate ($LiNbO_3$) nonlinear optical crystals are well suited for a wide range of applications:

- Electro-optical modulation
- Q-switching
- Laser frequency conversion of wavelengths >1 µm

## Specifications

| | |
|---|---|
| Flatness | λ/8 at 633 nm |
| Parallelism | < 20 arcsec |
| Surface quality | 10 – 5 scratch & dig (MIL-PRF-13830B) |
| Perpendicularity | < 5 arcmin |
| Angle tolerance | < 30 arcmin |
| Clear aperture | 90% of full aperture |

## Standard Crystals list

| Size, mm | Orientation | Coating | Catalogue number | Price, EUR |
|---|---|---|---|---|
| 6×6×25 | z-cut | AR/AR @ 1064 nm | **LNO-602** | 550 |
| 9××9×25 | z-cut | AR/AR @ 1064 nm | **LNO-901** | 620 |

## Physical and Optical properties

| | |
|---|---|
| Chemical formula | $LiNbO_3$ |
| Crystal structure | trigonal |
| Space group | R3C |
| Density | 4.64 g/cm$^3$ |
| Mohs hardness | 5 |
| Optical homogenity | ~ 5 × $10^{-5}$ / cm |
| Transparency range | 420 – 5200 nm |
| Absorption coefficient | ~ 0.1 % / cm @ 1064 nm |
| Refractive indices at 1064 nm | $n_e$ = 2.146, $n_o$ = 2.220 @ 1300 nm<br>$n_e$ = 2.156, $n_o$ = 2.232 @ 1064 nm<br>$n_e$ = 2.203, $n_o$ = 2.286 @ 632.8 nm |
| Sellmeier equations (λ, µm) | $n_o^2 = 4.9048 + 0.11768 / (\lambda^2 - 0.04750) - 0.027169\ \lambda^2$<br>$n_e^2 = 4.5820 + 0.099169 / (\lambda^2 - 0.04443) - 0.021950\ \lambda^2$ |
| Thermal expansion coefficient @ 25 °C | //a, 2.0 × $10^{-6}$ / K<br>//c, 16.7 × $10^{-6}$ / K |
| Thermal conductivity | ~ 5 W/m/K @ 25 °C |
| Thermal optical coefficient | $dn_o/dT$ = -0.874 × $10^{-6}$ / K at 1.4 µm<br>$dn_e/dT$ = 39.073 × $10^{-6}$ / K at 1.4 µm |

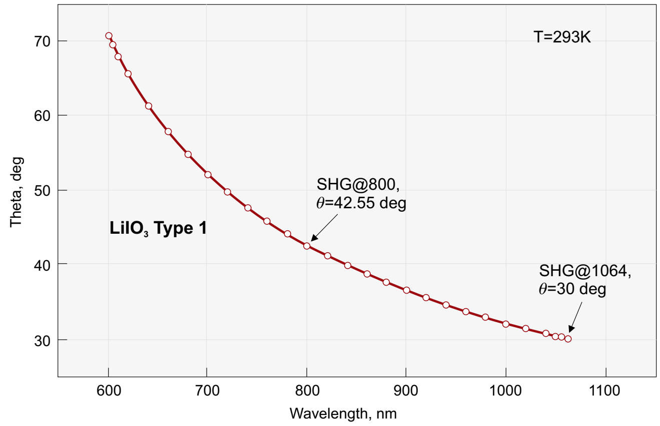
# $LiIO_3$ – LITHIUM IODATE

## Features

- High nonlinear optical coefficients
- Wide transparency range
- Low damage threshold – not recommended for high power applications

## Applications

- Harmonic generators
- Thin $LiIO_3$ for autocorrelation measurements




$LiIO_3$ Second harmonic generation phasematching

## Specifications

| | |
|---|---|
| Flatness | λ/6 at 633 nm |
| Parallelism | < 30 arcsec |
| Surface quality | 20 – 10 scratch & dig (MIL-PRF-13830B) |
| Perpendicularity | < 5 arcmin |
| Angle tolerance (Δθ & Δφ) | < 30 arcmin |
| Clear aperture | 90% of full aperture |

## Physical and Optical properties

| | |
|---|---|
| Crystal structure | hexagonal |
| Point group | 6 |
| Density, g/cm³ | 4.487 |
| Mohs hardness | 3.5–4.0 |
| Transparency range, nm | 280–4000 |
| Absorption at 1064 nm, $cm^{-1}$ | < 0.05 |
| Refractive indices at 1064 nm | $n_o$ = 1.8571, $n_e$ = 1.7165 |
| at 800 nm | $n_o$ = 1.8676, $n_e$ = 1.7245 |
| at 532 nm | $n_o$ = 1.8982, $n_e$ = 1.7480 |
| Phase matching range for Type 1 SHG, nm | 570–4000 |
| Acceptances for Type 1 SHG at 1064 nm | |
| Angular, mrad×cm | 0.77 |
| Spectral, $cm^{-1}$×cm | 12.74 |
| Walk-off for Type 1 SHG at 1064 nm, mrad | 74.30 |
| Nonlinear optical coefficient $d_{31}$, pm/V | 4.4 (at 1064 nm) |
| Effective nonlinearity | $d_{ooe} = d_{15}\sin\theta$ |
| Damage threshold, MW/cm² | > 100 for $TEM_{00}$, 1064 nm, 10 ns, 10 Hz |
| Wavelength dispersion of refractive indices (λ – in µm) | $n_e^2 = 1.673463 + \frac{1.245229\lambda^2}{\lambda^2 - 0.028224} - 0.003641\lambda^2$ <br> $n_o^2 = 2.083648 + \frac{1.332068\lambda^2}{\lambda^2 - 0.035306} - 0.008525\lambda^2$ |

## Housing accessories

Ring Holders for Nonlinear Crystals

See page 2.26

Positioning Mount 840-0199 for Nonlinear Crystal Housing

See page 2.27

# $ZnGeP_2$ / $AgGaSe_2$ / $AgGaS_2$ / GaSe – INFRARED NONLINEAR CRYSTALS

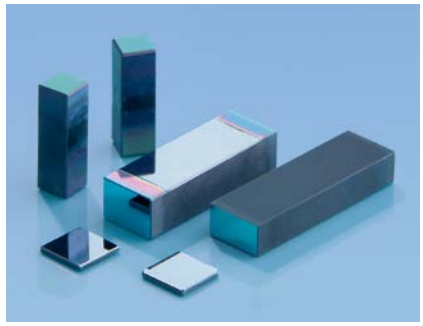
## $ZnGeP_2$

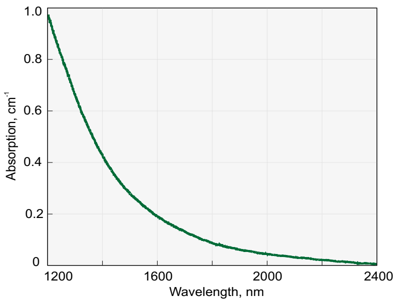
$ZnGeP_2$ (ZGP) crystal has transmission band edges at 0.74 and 12 µm. However it's useful transmission range is from 1.9 to 8.6 µm and from 9.6 to 10.2 µm. ZGP crystal has the largest nonlinear optical coefficient and relatively high laser damage threshold. The crystal is successfully used in diverse applications:

- up-conversion of $CO_2$ and CO laser radiation to near IR range via harmonics generation and mixing processes;
- efficient SHG of pulsed CO, $CO_2$ and chemical DF-laser;
- efficient down conversion of Holmium, Thulium and Erbium and laser wavelengths to mid infrared wavelength ranges by OPO process.

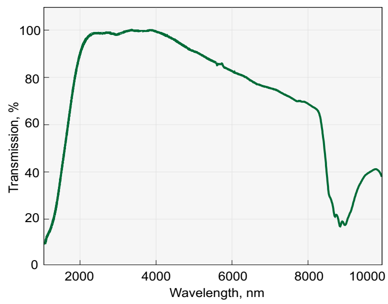
Crystals with high damage threshold BBAR coatings and the lowest absorption coefficient $\alpha < 0.05$ cm$^{-1}$ at pump wavelengths 2.05 – 2.1 µm „o"- polarisation are available for OPO applications.

Typical absorption coefficient is <0.03 cm$^{-1}$ at 2.5 – 8.2 µm range.

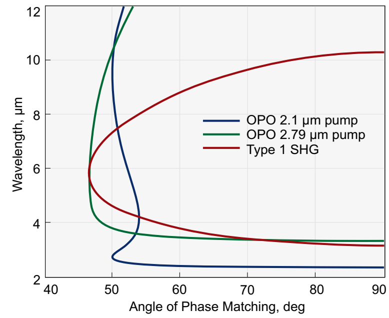





Absorption spectra of $ZnGeP_2$ crystal near 2 µm




Transmission spectra of 15 mm long AR coated $ZnGeP_2$ crystal for OPO @ 2.1 µm



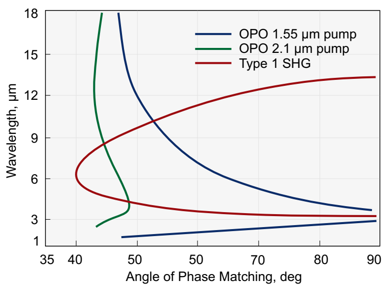

Type 1 OPO and SHG tuning curves in $ZnGeP_2$

### Type 1 $ZnGeP_2$ crystalS for OPO at 3.5-5 µm range pumped at ~2.1 µm

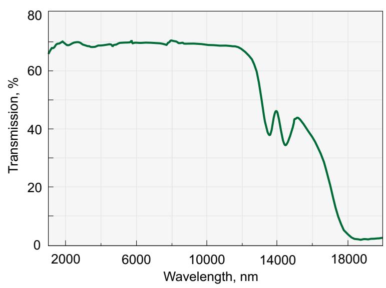
| Size, mm | θ, deg | φ, deg | Coating | Application | Catalogue number |
|---|---|---|---|---|---|
| 7×5×15 | 54 | 0 | AR @ 2.1 µm + BBAR @ 3.5-5 µm | OPO@2.1 → 3.5-5 µm | **ZGP-401** |
| 7×5×20 | 54 | 0 | AR @ 2.1 µm + BBAR @ 3.5-5 µm | OPO@2.1 → 3.5-5 µm | **ZGP-402** |
| 7×5×25 | 54 | 0 | AR @ 2.1 µm + BBAR @ 3.5-5 µm | OPO@2.1 → 3.5-5 µm | **ZGP-403** |

## $AgGaSe_2$

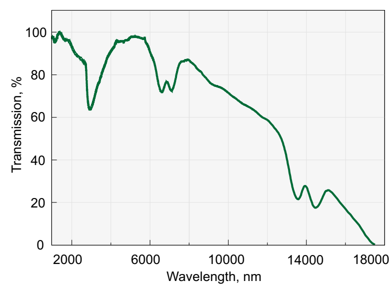
$AgGaSe_2$ has band edges at 0.73 and 18 µm. Its useful transmission range of 0.9–16 µm and wide phase matching capability provide excellent potential for OPO applications when pumped by a variety of currently available lasers. Tuning from 2.5–12 µm has been obtained when pumping by Ho:YLF laser at 2.05 µm; as well as NCPM operation from 1.9–5.5 µm when pumping at 1.4–1.55 µm. Efficient SHG of pulsed $CO_2$ laser has been demonstrated.




Type 1 OPO and SHG tuning curves in $AgGaSe_2$



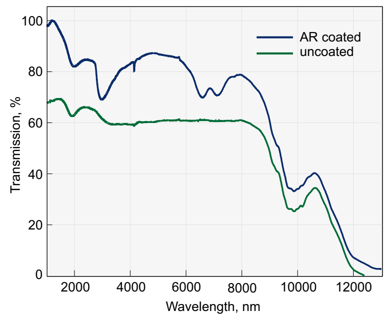

Transmission spectra of 18 mm long uncoated $AgGaSe_2$ crystal



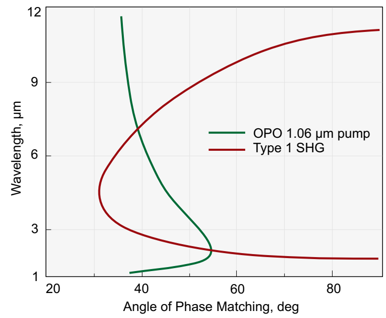

Transmission spectra of 25 mm long AR coated $AgGaSe_2$ crystal

## $AgGaS_2$

$AgGaS_2$ is transparent from 0.53 to 12 µm. Although nonlinear optical coefficient is the lowest among the above mentioned infrared crystals, its high short wavelength transparency edging at 550 nm is used in OPOs pumped by Nd:YAG laser; in numerous difference frequency mixing experiments using diode, Ti:Sapphire, Nd:YAG and IR dye lasers covering 3–12 µm range; direct infrared countermeasure systems, and SHG of $CO_2$ laser.




Transmission spectra of 14 mm long AR coated and uncoated $AgGaS_2$ crystal used for OPO pumped by Nd:YAG laser




Type 1 OPO and SHG tuning curves in $AgGaS_2$

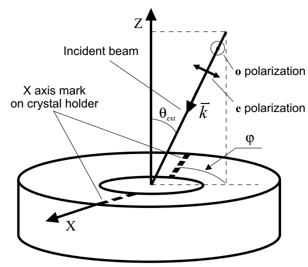
## List of Standard $AgGaS_2$ Crystals

| Size, mm | θ, deg | φ, deg | Coating | Application | Catalogue number | Price, EUR |
|---|---|---|---|---|---|---|
| 5×5×1 | 39 | 45 | BBAR/BBAR @ 1.1-2.6 / 2.6-11 µm | DFG @ 1.2-2.4 µm -> 2.4-11 µm | **AGS-401H** | 1770 |
| 6×6×2 | 50 | 0 | BBAR/BBAR @ 1.1-2.6 / 2.6-11 µm | DFG @ 1.2-2.4 µm -> 2.4-11 µm | **AGS-402H** | 2375 |
| 5×5×0.4 | 34 | 45 | BBAR/BBAR @ 3-6 / 1.5-3 µm | SHG @ 3-6 µm, Type 1 | **AGS-403H** | 2040 |
| 5×5×0.4 | 39 | 45 | BBAR/BBAR @ 1.1-2.6 / 2.6-11 µm | DFG @ 1.2-2.4 µm -> 2.4-11 µm | **AGS-404H** | 2040 |
| 8×8×0.4 | 39 | 45 | BBAR/BBAR @ 1.1-2.6 / 2.6-11 µm | DFG @ 1.2-2.4 µm, Type 1 | **AGS-801H** | 4080 |
| 8×8×1 | 39 | 45 | BBAR/BBAR @ 1.1-2.6 / 2.6-11 µm | DFG @ 1.2-2.4 µm, Type 1 | **AGS-802H** | 3670 |

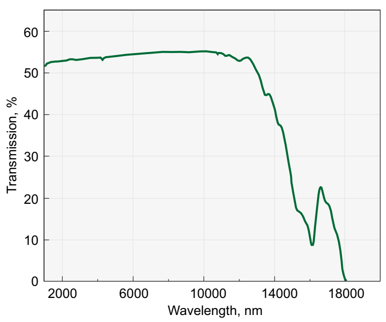
Crystals are mounted into open ring holders (see page 2.26).

## GaSe

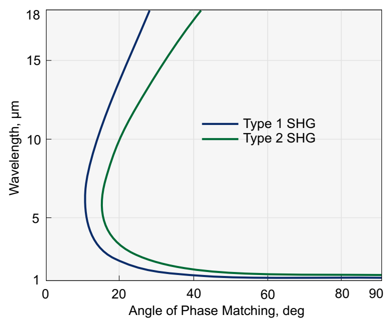
GaSe has band edges at 0.65 and 18 µm. GaSe has been successfully used for efficient SHG of $CO_2$ laser, for SHG of pulsed CO, $CO_2$ and chemical DF-laser (λ = 2.36 µm) radiation; up conversion of CO and $CO_2$ laser radiation into the visible range; infrared pulses generation via difference frequency mixing of Neodymium and infrared dye laser or (F-)-centre laser pulses; OPG light generation within 3.5–18 µm; efficient TeraHertz generation in 100–1600 µm range. It is impossible to cut crystals for certain phase matching angles because of material structure (cleave along (001) plane) limiting areas of applications.








Transmission spectra of 17 mm long uncoated GaSe crystal




Type 1 and Type 2 SHG tuning curves in GaSe

## GaSe, Z-Cut

| Clear aperture, mm | Thickness, µm | Holder, mm | Catalogue number | Price, EUR |
|---|---|---|---|---|
| Ø7 | 10 | Ø25.4 | **GaSe-10H1** | 1950 |
| Ø7 | 30 | Ø25.4 | **GaSe-30H1** | 1625 |
| Ø7 | 100 | Ø25.4 | **GaSe-100H1** | 1475 |
| Ø7 | 500 | Ø25.4 | **GaSe-500H1** | 1460 |
| Ø7 | 1000 | Ø25.4 | **GaSe-1000H1** | 1635 |
| Ø7 | 2000 | Ø25.4 | **GaSe-2000H1** | 1810 |

Please note that from now all standard GaSe crystals are provided mounted into Ø25.4 mm ring holders.
Crystals could be mounted into Ø40 mm holders under your request.

## Related Products

Ring Holders for Nonlinear Crystals

See page 2.26

Optical nonlinear crystals $ZnGeP_2$, $AgGaSe_2$, $AgGaS_2$, GaSe have gained tremendous interest for middle and deep infrared applications due to their unique features. The crystals have large effective optical nonlinearity, wide spectral and angular acceptances, broad transparency range, non-critical requirements for temperature stabilization and vibration control, are well mechanically processed (except GaSe).

## Physical Properties

| Crystal | | $ZnGeP_2$ | $AgGaSe_2$ | $AgGaS_2$ | GaSe |
|---|---|---|---|---|---|
| Crystal Symmetry | | Tetragonal | Tetragonal | Tetragonal | Hexagonal |
| Point Group | | 42m | 42m | 42m | 62m |
| Lattice Constants, Å | a<br>c | 5.465<br>10.771 | 5.9901<br>10.8823 | 5.757<br>10.305 | 3.742<br>15.918 |
| Density, g/cm3 | | 4.175 | 5.71 | 4.56 | 5.03 |

## Optical Properties

| Crystal | | $ZnGeP_2$ | $AgGaSe_2$ | $AgGaS_2$ | GaSe |
|---|---|---|---|---|---|
| Optical transmission, µm | | 0.74–12 | 0.73–18 | 0.53–12 | 0.65–18 |
| Indices of Refraction at | | | | | |
| 1.06 µm | $n_o$<br>$n_e$ | 3.2324<br>3.2786 | 2.7005<br>2.6759 | 2.4508<br>2.3966 | 2.9082<br>2.5676 |
| 5.3 µm | $n_o$<br>$n_e$ | 3.1141<br>3.1524 | 2.6140<br>2.5823 | 2.3954<br>2.3421 | 2.8340<br>2.4599 |
| 10.6 µm | $n_o$<br>$n_e$ | 3.0725<br>3.1119 | 2.5915<br>2.5585 | 2.3466<br>2.2924 | 2.8158<br>2.4392 |
| Absorption Coefficient, $cm^{-1}$ at | | | | | |
| 1.06 µm | | 3.0 | <0.02 | <0.09 | 0.25 |
| 2.5 µm | | 0.03 | <0.01 | 0.01 | 0.05 |
| 5.0 µm | | 0.02 | <0.01 | 0.01 | 0.05 |
| 7.5 µm | | 0.02 | — | 0.02 | 0.05 |
| 10.0 µm | | 0.4 | – | <0.6 | 0.05 |
| 11.0 µm | | 0.8 | – | 0.6 | 0.05 |

## Nonlinear Optical Properties

| Crystal | $ZnGeP_2$ | $AgGaSe_2$ | $AgGaS_2$ | GaSe |
|---|---|---|---|---|
| Laser damage threshold, $MW/cm^2$ | 60 | 25 | 10 | 28 |
| at pulse duration, ns | 100 | 50 | 20 | 150 |
| at wavelength, µm | 2.05 | 10.6 | 1.06 | 9.3 |
| Nonlinearity, pm/V | 111 | 43 | 31 | 63 |
| Phase matching angle for Type 1 SHG at 10.6 µm, deg | 76 | 55 | 67 | 14 |
| Walk-off angle at 5.3 µm, deg | 0.57 | 0.67 | 0.85 | 3.4 |

## Thermal Properties

| Crystal | | $ZnGeP_2$ | $AgGaSe_2$ | $AgGaS_2$ | GaSe |
|---|---|---|---|---|---|
| Melting point, °C | | 1298 | 851 | 998 | 1233 |
| Thermal Expansion Coefficient, $10^{-6}$/°K | ⊥ | 17.5 (a) | 23.4 (c) | 12.5 | 9.0 |
| | ⊥ | 9.1 (b) | 18.0 (d) | | |
| | \|\| | 1.59 (a) | -6.4 (c) | -13.2 | 8.25 |
| | \|\| | 8.08 (b) | -16.0 (d) | | |

a) at 293–573 K, b) at 573–873 K, c) at 298–423 K, d) at 423–873 K

## Sellmeier equations for calculation of indices of refraction

| Crystal | | A | B | C | D | E | F | Expression |
|---|---|---|---|---|---|---|---|---|
| $ZnGeP_2$ | $n_o$ | 8.0409 | 1.68625 | 0.40824 | 1.2880 | 611.05 | – | $n^2 = A + B\lambda^2 / (\lambda^2 - C) + D\lambda^2 / (\lambda^2 - E)$ |
| | $n_e$ | 8.0929 | 1.8649 | 0.41468 | 0.84052 | 452.05 | – | |
| $AgGaSe_2$ | $n_o$ | 6.8507 | 0.4297 | 0.15840 | 0.00125 | – | – | $n^2 = A + B / (\lambda^2 - C) - D\lambda^2$ |
| | $n_e$ | 6.6792 | 0.4598 | 0.21220 | 0.00126 | – | – | |
| $AgGaS_2$ | $n_o$ | 3.3970 | 2.3982 | 0.09311 | 2.1640 | 950.0 | – | $n^2 = A + B / (1 - C / \lambda^2) + D / (1 - E / \lambda^2)$ |
| | $n_e$ | 3.5873 | 1.9533 | 0.11066 | 2.3391 | 1030.7 | – | |
| GaSe | $n_o$ | 7.443 | 0.405 | 0.0186 | 0.0061 | 3.1485 | 2194 | $n^2 = A + B/\lambda^2 + C/\lambda^4 + D/\lambda^6 + E/(1 - F/\lambda^2)$ |
| | $n_e$ | 5.76 | 0.3879 | -0.2288 | 0.1223 | 1.855 | 1780 | |

# BBO / LBO / KDP / $LiIO_3$ / $AgGaS_2$ / GaSe – ULTRATHIN NONLINEAR CRYSTALS



Thin crystals are used in different applications with femtosecond pulses:

- Harmonic generation (SHG, SFG)
- Optical parametric generation and amplification (OPG, OPA)
- Difference frequency generation (DFG)
- Pulse width measurements by auto and cross correlation
- THz frequency generation (in GaSe crystal)

The propagation of a ultrashort optical pulses through the crystal results in a delay of the pulses because of Group Velocities Mismatch (GVM), a duration broadening because of Group Delay Dispersion (GDD) and a frequency chirp. Unfortunately those effects forces to limit nonlinear crystal thickness in frequency generation schemes.

For two collinearly propagating pulses with different group velocities their quasistatic interaction length ($L_{qs}$) is defined as distance over which they separate by a path equal to the one of the pulses duration (or to the desired pulse duration):

$$L_{qs} = \tau / GVM \,;$$

where GVM is the group velocity mismatch and $\tau$ is the duration of the pulse. GVM calculations are presented for the most popular Type 1 phase matching applications for different crystals in *Table 2.*

Optimal BBO, LBO, KDP and $LiIO_3$ crystal thicknesses which are limited by GVM for Type 1 SHG of 800 nm at different fundamental pulse duration are presented in the *Table 3*. Also effective coefficients and phase matching angles at room temperature (20 °C) are calculated. If longer crystal will be used this will cause second harmonic pulse broadening to the duration longer than fundamental pulse duration (or desired pulse duration).

Group delay dispersion (GDD) has an important impact on the propagation of pulses, because a pulse always has certain spectral width, so that dispersion will cause its frequency components to propagate with different velocities. In case of crystals where we have normal dispersion when refractive index decreases with increasing wavelength this leads to a lower group velocity of higher-frequency components, and thus to a positive chirp.

The frequency dependence of the group velocity also has an influence on the pulse duration. If the pulse is initially unchirped, dispersion in a crystal will always increase its duration. This is called dispersive pulse broadening. For an originally unchirped Gaussian pulse with the duration $\tau_0$, the pulse duration is increased according to:

$$t = \tau_0 \sqrt{1 + \left( \frac{4 \ln 2 \cdot D \cdot L}{\tau_0^{\,2}} \right)^2}$$

L – thickness of the crystal in mm. D – second order group delay dispersion or dispersion parameter. *Table 1* gives D parameter for Type 1 phase matching SHG @ 800 nm for 800 nm pulse with „o" polarization and 400 nm pulse with „e" polarization in different crystals.

*Table 1.* **D parameter for Type 1 SHG @ 800 nm orientation crystals for 800 nm (o-pol) and 400 nm (e-pol) pulses**

| Crystal | D at 800 nm | D at 400 nm |
|---|---|---|
| BBO | 75 $fsec^2/mm$ | 196 $fsec^2/mm$ |
| LBO | 47 $fsec^2/mm$ | 128 $fsec^2/mm$ |
| KDP | 27 $fsec^2/mm$ | 107 $fsec^2/mm$ |
| $LiIO_3$ | 196 $fsec^2/mm$ | 589 $fsec^2/mm$ |

We may calculate that spectrum limited initial 30 fsec Gaussian pulse at 400 nm will be broadened to 35 fsec pulse after passing 1 mm thickness BBO crystal.

*Table 2.* **Group velocity mismatch between shortest and longest wave pulse for Type 1 phase matching**

| Crystal | SFM 800+266 nm | SFM 800+400 nm | SHG 800 nm | SHG 1030 nm | SHG 1064 nm | DFG 1.26-2.18 → 3 µm | DFG 1.48-1.74 → 10 µm |
|---|---|---|---|---|---|---|---|
| BBO | 2074 fs/mm | 737 fs/mm | 194 fs/mm | 94 fs/mm | 85 fs/mm | – | – |
| LBO | – | 448 fs/mm | 123 fs/mm | 51 fs/mm | 44 fs/mm | – | – |
| KDP | – | 370 fs/mm | 77 fs/mm | 1 fs/mm | -7 fs/mm | – | – |
| LiIO3 | – | – | 559 fs/mm | 285 fs/mm | 262 fs/mm | – | – |
| $AgGaS_2$ | – | – | – | – | – | 170 fs/mm | -10 fs/mm |

*Table 3.* **Quasistatic interaction length for Type 1 SHG of 800 nm**

| Crystal | 200 fs | 100 fs | 50 fs | 20 fs | 10 fs | Cut angles θ, φ | Coefficient deff |
|---|---|---|---|---|---|---|---|
| BBO | 1.0 mm | 0.5 mm | 0.26 mm | 0.1 mm | 0.05 mm | 29.2°, 90° | 2.00 pm/V |
| LBO | 1.6 mm | 0.8 mm | 0.4 mm | 0.16 mm | 0.08 mm | 90°, 31.7° | 0.75 pm/V |
| KDP | 2.6 mm | 1.3 mm | 0.6 mm | 0.26 mm | 0.13 mm | 44.9°, 45° | 0.30 pm/V |
| $LiIO_3$ | 0.4 mm | 0.18 mm | 0.01 mm | 0.04 mm | 0.018 mm | 42.5°, 0° | 3.59 pm/V |

## FREE STANDING CRYSTALS

The crystals of thickness down to 100 µm can be supplied as free standing crystals not attached to the support. However the ring mounts are highly recommended for safe handling of these thin crystals. The tolerance is ±50 µm for crystals of thickness down to 300 µm and ±20 µm for crystals of thickness down to 100 µm.

GaSe crystal is supplied glued in to dia Ø40 mm ring holder only.

| Crystal | Minimal aperture | Maximal aperture | Minimal thickness |
|---|---|---|---|
| BBO | 2×2 mm | 25×25 mm | 0.1 mm |
| LBO | 2×2 mm | 60×60 mm | 0.1 mm |
| KDP | 2×2 mm | Ø75 mm | 0.1 mm* |
| $LiIO_3$ | 2×2 mm | 50×50 mm | 0.1 mm* |
| $AgGaS_2$ | 5×5 mm | 20×20 mm | 0.1 mm |
| GaSe | Ø5 mm | Ø19 mm | 0.01 mm |

* the thickness should be about 0.5 mm for max aperture KDP and $LiIO_3$

## OPTICALLY CONTACTED CRYSTALS

BBO crystals of thickness less than 100 µm can be supplied optically contacted on UV Fused Silica substrates sizes 10×10×2 mm or 12×12×2 mm. Other sizes of substrates are also available on request. The tolerances of BBO crystal thickness is +10/-5 µm.

| Crystal | Minimal aperture | Maximal aperture | Minimal thickness |
|---|---|---|---|
| BBO | 5×5 mm | 18×18 mm | 10±5 µm |

EKSMA OPTICS provides various AR, BBAR and protective coatings for all free standing crystals and optically contacted crystals. Ring mounts made from anodized aluminium and teflon are available for safe and convenient handling of ultrathin crystals.

## Standard specifications of crystals

| Crystals | BBO, LBO | KDP, $LiIO_3$, $AgGaS_2$ | GaSe |
|---|---|---|---|
| Flatness | λ/6 at 633 nm | λ/4 at 633 nm | cleaved perpendicularly to optical axis. Polish is not available |
| Parallelism | < 10 arcsec | < 30 arcsec | |
| Angle tolerance | < 15 arcmin | < 30 arcmin | |
| Surface quality | 10 – 5 scratch/dig | 20 – 10 scratch/dig | |

## Related Products

Other Ultrahin BBO crystals available. See pages 2.17; 2.23

Ring Holders for Nonlinear Crystals

See page 2.26

Positioning Mount 840-0199 for Nonlinear Crystal Housing

See page 2.27

## Nd:YAG – NEODYMIUM DOPED YTTRIUM ALUMINIUM GARNET

Nd:YAG crystal is the most popular lasing media for solid-state lasers. EKSMA OPTICS offers standard specifications high optical quality Nd:YAG rods with high damage threshold AR @ 1064 nm coatings.

### Properties of 1.0% Nd:YAG at 25 °C

| | |
|---|---|
| Formula | $Y_{2.97}Nd_{0.03}Al_5O_{12}$ |
| Crystal structure | Cubic |
| Density | 4.55 g/cm$^3$ |
| Melting point | 1970 °C |
| Mohs hardness | 8.5 |
| Transition | $^4F_{3/2} \rightarrow {}^4I_{11/2}$ @ 1064 nm |
| Fluorescence lifetime | 230 µs for 1064 nm |
| Thermal conductivity | 0.14 Wcm$^{-1}$K$^{-1}$ |
| Specific heat | 0.59 Jg$^{-1}$K$^{-1}$ |
| Thermal expansion | $6.9 \times 10^{-6}$ °C$^{-1}$ |
| ∂n/∂t | $7.3 \times 10^{-6}$ °C$^{-1}$ |
| Young's modulus | $3.17 \times 10^4$ Kg/mm$^{-2}$ |
| Poisson ratio | 0.25 |
| Thermal shock resistance | 790 Wm$^{-1}$ |
| Refractive index | 1.818 @ 1064 nm |

### Standard Rods Sizes

| Diameter, mm | Length, mm | Doping, % | Wedge of the ends, deg | Catalogue number | Price, EUR |
|---|---|---|---|---|---|
| 3 | 53 | 0.9 | 0/0 | E-Y-3-0.9-A/A | 215 |
| 3 | 65 | 0.8 | 0/0 | E-Y-3-0.8-A/A | 265 |
| 3 | 65 | 1.1 | 0/0 | E-Y-3-1.1-A/A | 325 |
| 4 | 65 | 0.8 | 3/3 parallel | E-Y-4-0.8-A/A | 530 |
| 4 | 65 | 1.1 | 3/3 parallel | E-Y-4-1.1-A/A | 530 |
| 6.35 | 85* | 1.1 | 3/3 parallel | E-Y-6.35-1.1-A/A | 890 |
| 8 | 85* | 1.1 | 3/3 parallel | E-Y-8-1.1-A/A | 1340 |
| 10 | 85* | 1.1 | 3/3 parallel | E-Y-10-1.1-A/A | 2200 |
| 12 | 100* | 0.8 | 3/3 parallel | E-Y-12-0.8-A/A | 4740 |
| 12 | 100* | 1.1 | 3/3 parallel | E-Y-12-1.1-A/A | 4740 |

* rods with barrel grooving, except 10 mm at both ends of the rod without grooving.

### Related Products

Laser Safety Eyewear

See page 1.17

Visualizator 990-0840

See page 1.17

### Specifications of Standard Nd:YAG Laser Rods

| | |
|---|---|
| Nd Doping Level | 0.8% or 1.1% |
| Orientation | <111> crystalline direction |
| Surface Quality | 10 – 5 scratch & dig (MIL-PRF-13830B) |
| Surface Flatness | λ/10 at 633 nm |
| Parallelism | < 10 arcsec |
| Perpendicularity | < 5 arcmin for plano/plano ends |
| Diameter Tolerance | +0 / -0.05 mm |
| Length Tolerance | +1 / -0.5 mm |
| Clear Aperture | > 90 % of full aperture |
| Chamfers | 0.1 mm at 45 deg |
| Coating | both sides coated AR @ 1064 nm, R < 0.2%, AOI = 0 deg |
| Barrel grooving | all dia 6.35, 8, 10, 12 mm rods with barrel grooving |

# Yb:KGW / Yb:KYW – Yb-DOPED POTASSIUM GADOLINIUM TUNGSTATE

## Features

- High absorption coefficient @ 981 nm
- High stimulated emission cross section
- Low laser threshold
- Extremely low quantum defect $\lambda_{pump}/\lambda_{se}$
- Broad polarized output at 1023–1060 nm
- High slope efficiency with diode pumping (~ 60%)
- High Yb doping concentration

## Applications

- Yb:KGW and Yb:KYW thin (100–150 µm) crystals are used as lasing materials to generate ultrashort (hundreds of fsec) high power (>22 W) pulses. Standard pumping @ 981 nm, output: 1023–1060 nm
- Yb:KGW and Yb:KYW can be used as ultrashort pulses amplifiers
- Yb:KGW and Yb:KYW are some of the best materials for high power thin disk lasers

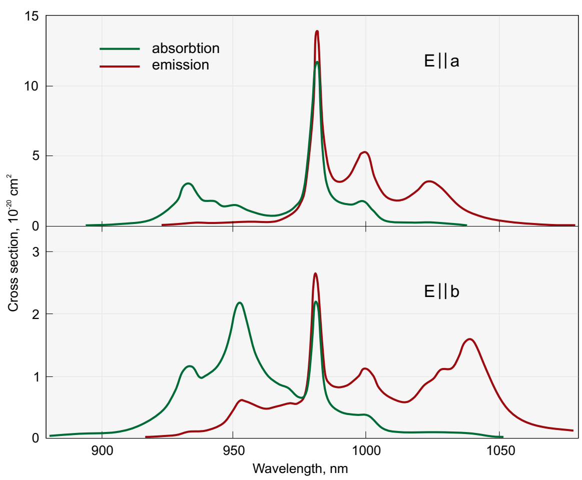
Yb-Doped Potassium Gadolinium Tungstate (**$Yb:KGd(WO_4)_2$**) and Yb-doped Potassium Itrium Tungstate (**$Yb:KY(WO_4)_2$**) single crystals are the laser crystals for diode or laser pumped solid-state laser applications.

## Custom manufacturing capabilities

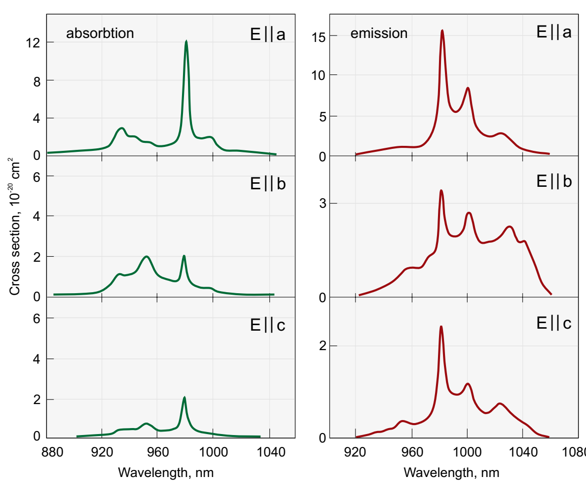
- Various shapes (slabs, rods, cubes)
- Different dopant levels
- Diversified coatings

## Properties of Yb:KGW and Yb:KYW

| Name | Yb:KGW | Yb:KYW |
|---|---|---|
| $Yb^{3+}$ concentration | 0.5–5% | 0.5–100% |
| Crystal structure | monoclinic | monoclinic |
| Point group | C2/c | C2/c |
| Lattice parameters | a=8.095 Å, b=10.43 Å, c=7.588 Å, β=94.43° | a=8.05 Å, b=10.35 Å, c=7.54 Å, β=94° |
| Thermal expansion | $\alpha_a=4\times10^{-6}$/°C, $\alpha_b=3.6\times10^{-6}$/°C, $\alpha_c=8.5\times10$ | — |
| Thermal conductivity | $K_a$=2.6 W/mK, $K_b$=3.8 W/mK, $K_c$=3.4 W/mK | — |
| Density | 7.27 g/cm³ | 6.61 g/cm³ |
| Mohs' hardness | 4–5 | 4–5 |
| Melting temperature | 1075 °C | — |
| Transmission range | 0.35–5.5 µm | 0.35–5.5 µm |
| Refractive indices (λ=1.06 µm) | $n_g$=2.037, $n_p$=1.986, $n_m$=2.033 | — |
| Thermo-optic coefficients @ 1064 nm | $\partial n_p/\partial T=-15.7\times10^{-6}\ K^{-1}$<br>$\partial n_m/\partial T=-11.8\times10^{-6}\ K^{-1}$<br>$\partial n_g/\partial T=-17.3\times10^{-6}\ K^{-1}$ | *For 20% Yb:KYW*<br>$\partial n_p/\partial T=-13.08\times10^{-6}\ K^{-1}$<br>$\partial n_m/\partial T=-7.61\times10^{-6}\ K^{-1}$<br>$\partial n_g/\partial T=-11.83\times10^{-6}\ K^{-1}$ |
| Laser wavelength | 1023–1060 nm | 1025–1058 nm |
| Fluorescence lifetime | 0.3 ms | 0.3 ms |
| Stimulated emission cross section (**E**‖a) | $2.6\times10^{-20}$ cm² | $3\times10^{-20}$ cm² |
| Absorption peak and bandwidth | $\alpha_a$=26 cm$^{-1}$, λ=981 nm, Δλ=3.7 nm | $\alpha_a$=40 cm$^{-1}$, λ=981 nm, Δλ=3.5 nm |
| Absorption cross section | $1.2\times10^{-19}$ cm² | $1.33\times10^{-19}$ cm² |
| Lasing threshold | 35 mW | 70 mW |
| Stark levels energy (in cm$^{-1}$) of the $^2F_{5/2}$ manifolds of $Yb^{3+}$ @ 77K | 10682, 10471, 10188 | 10695, 10476, 10187 |
| Stark levels energy (in cm$^{-1}$) of the $^2F_{7/2}$ manifolds of $Yb^{3+}$ @ 77K | 535, 385, 163, 0 | 568, 407, 169, 0 |

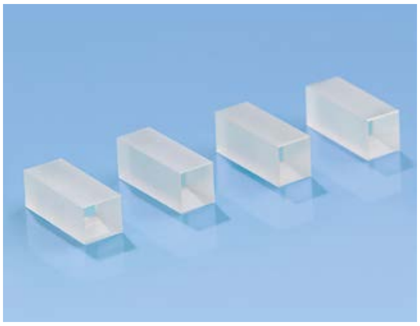



Absorption and emission spectra of Yb(5%):KYW




Absorption and emission spectra of Yb(5%):KGW

# Nd:KGW – Nd-DOPED POTASSIUM GADOLINIUM TUNGSTATE



Nd:KGW crystals are low lasing threshold, highly efficient laser material exceptionally suitable for laser rangefinding applications.

The efficiency of Nd:KGW lasers is 3–5 times higher than the one of Nd:YAG lasers. Nd:KGW laser medium is one of the best choices ensuring effective laser generation at low pump energies (0.5 – 1 J). These crystals supplied by EKSMA OPTICS feature high optical quality and great value of bulk resistans for laser radiation.

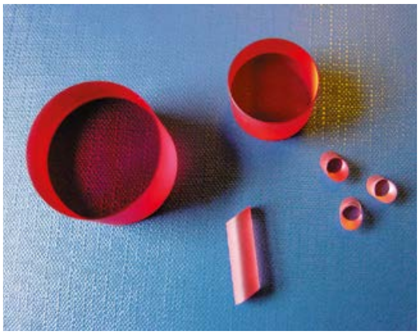
## Standard specifications

| | |
|---|---|
| Orientation | [010] ± 30 min |
| Dopant concentration | 2 – 10 at % |
| Diameter tolerance | +0.0 / -0.1 mm |
| Length tolerance | +1.0 / -0.0 mm |
| Chamfer | 45(±10) deg × 0.2(±0.1) mm |
| Flatness | λ/10 @ 633 nm |
| Parallelism | better than 30 arcsec |
| Perpendicularity | better than 15 arcmin |
| Surface Quality | 10 – 5 scratch & dig (MIL-PRF-13830B) |
| Absorption losses | < 0.005 $cm^{-1}$ |

## Physical and Laser properties

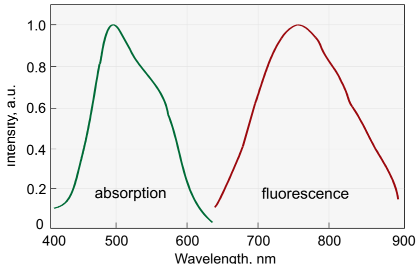
| | |
|---|---|
| Chemical formula | $KGd(WO_4)$:Nd |
| Lattice constants | a = 8.095 Å, b = 10 Å, c = 7.588 Å |
| Optical orientation | $n_g$ = b, $n_p$c = 20 deg |
| Angle between optical axis | 86.5 angular grad |
| Density | 7.27 $g/cm^3$ |
| Mohs hardness | 5 |
| Thermal conductivity | 2.8 W/(m×grad) [100]<br>2.2 W/(m×grad) [010]<br>3.5 W/(m×grad) [001] |
| Thermal expansion | $4\times10^{-6}$ $grad^{-1}$ [100]<br>$3.6\times10^{-6}$ $grad^{-1}$ [010]<br>$8.5\times10^{-6}$ $grad^{-1}$ [001] |
| Phase transition | 1005 °C |
| Melting point | 1075 °C |
| Transmission range | 0.35–5.5 µm |
| Refractive index | $n_g$ = 2.033 @ 1.067 µm<br>$n_p$ = 1.937 @ 1.067 µm<br>$n_m$ = 1.986 @ 1.067 µm |
| Transition | $^4F_{3/2} \rightarrow {}^4I_{11/2}$ |
| Laser wavelength | 1.0672 µm |
| Fluorescence lifetime | 120 µs |
| Fluorescent width | 24 $cm^{-1}$ |
| Emission cross-section | $4.3\times10^{-19}$ $cm^{-2}$ |
| Emission temperature drift | $8.5\times10^{-4}$ nm, $K^{-1}$ |

# Ti:Sapphire – TITANIUM DOPED SAPPHIRE



$Al_2O_3:Ti^{3+}$ – titanium-doped sapphire crystals combine outstanding physical and optical properties with broadest lasing range.

$Al_2O_3:Ti^{3+}$ indefinitely long stability and useful lifetime added to the lasing over entire band of 660 – 1050 nm challenge "dirty" dyes in variety of applications. Medical laser systems, lidars, laser spectroscopy, direct femtosecond pulse generation by Kerr-type mode-locking – there are few of existing and potential applications.




The absorption band of Ti:Sapphire centered at 490 nm makes it suitable for variety of laser pump sources – argon ion, frequency doubled Nd:YAG and YLF, copper vapour lasers. Because of 3.2 μs fluorescence lifetime Ti:Sapphire crystals can be effectively pumped by short pulse flashlamps in powerful laser systems.

| $Ti_2O_3$ wt % | a, $cm^{-1}$ @ 490 nm | a, $cm^{-1}$ @ 514 nm | a, $cm^{-1}$ @ 532 nm |
|---|---|---|---|
| 0.03 | 0.7* | 0.6 | 0.5 |
| 0.05 | 1.1 | 0.9 | 0.8 |
| 0.07 | 1.5 | 1.3 | 1.2 |
| 0.10 | 2.2 | 1.9 | 1.7 |
| 0.12 | 2.6 | 2.2 | 2.0 |
| 0.15 | 3.3 | 2.8 | 2.5 |
| 0.20 | 4.3 | 3.7 | 3.4 |
| 0.25 | 5.4 | 4.6 | 4.1 |

* Presented values are given with ±0.05 $cm^{-1}$ accuracy.

## Standard specifications

| | |
|---|---|
| Orientation | optical axis C normal to rod axis |
| $Ti_2O_3$ concentration | 0.03–0.25 wt % |
| Figure Of Merit | > 150 (> 300 available on special requests) |
| Size | up to 15 mm dia and up to 30 mm length |
| End configurations | flat/flat or Brewster/Brewster ends |
| Flatness | λ/10 @ 633 nm |
| Parallelism | 10 arcsec |
| Surface Quality | 10 – 5 scratch & dig (MIL-PRF-13830B) |
| Wavefront distortion | λ/4 inch |

## Physical and Laser properties

| | |
|---|---|
| Chemical formula | $Ti^{3+}:Al_2O_3$ |
| Crystal structure | Hexagonal |
| Lattice constants | a=4.748, c=12.957 |
| Density | 3.98 g/cm³ |
| Mohs hardness | 9 |
| Thermal conductivity | 0.11 cal/(°C×sec×cm) |
| Specific heat | 0.10 cal/g |
| Melting point | 2050 °C |
| Laser action | 4-Level Vibronic |
| Fluorescence lifetime | 3.2 μsec (T=300K) |
| Tuning range | 660–1050 nm |
| Absorbtion range | 400–600 nm |
| Emission peak | 795 nm |
| Absorption peak | 488 nm |
| Refractive index | 1.76 @ 800 nm |

# Terahertz Crystals



## GaSe / ZnTe – SEMICONDUCTOR TERAHERTZ CRYSTALS

### ZnTe

ZnTe (Zinc Telluride) crystals with <110> orientation are used for THz generation by optical rectification process. Optical rectification is a difference frequency generation in media with large second order susceptibility. For femtosecond laser pulses which have large bandwidth the frequency components interact with each other and their difference produce bandwidth from 0 to several THz.

Detection of the THz pulse occurs via free-space electro-optic detection in another <110> oriented ZnTe crystal. The THz pulse and the visible pulse are propagated collinearly through the ZnTe crystal. The THz pulse induces a birefringence in ZnTe crystal which is read out by a linearly polarized visible pulse. When both the visible pulse and the THz pulse are in the crystal at the same time, the visible polarization will be rotated by the THz pulse. Using a λ/4 waveplate and a beamsplitting polarizer together with a set of balanced photodiodes, it is possible to map THz pulse amplitude by monitoring the visible pulse polarization rotation after the ZnTe crystal at a variety of delay times with respect to the THz pulse. The ability to read out the full electric field, both amplitude and delay, is one of the attractive features of time-domain THz spectroscopy.

ZnTe are also used for IR optical components substrates and vacuum deposition.

NOTE: ZnTe crystal contains micro bubbles and they are visible in projection of illuminated crystal. However this does not affect the THz generation. We do not accept complains on presence of bubbles in crystal.


### ZnTe, <110> Cut

| Size, mm | Thickness, mm | Holder, mm | Catalogue number | Price, EUR |
|---|---|---|---|---|
| 10×10 | 0.1 | Ø25.4 | ZnTe-100H | 2145 |
| 10×10 | 0.2 | Ø25.4 | ZnTe-200H | 1880 |
| 10×10 | 0.5 | Ø25.4 | ZnTe-500H | 1420 |
| 10×10 | 1.0 | Ø25.4 | ZnTe-1000H | 1570 |
| 10×10 | 2.0 | Ø25.4 | ZnTe-2000H | 1790 |
| 10×10 | 3.0 | Ø25.4 | ZnTe-3000H | 2510 |

### GaSe

GaSe (Gallium Selenide) crystals used for THz generation shows a large bandwidth of up to 41 THz. GaSe is a negative uniaxial layered semiconductor with a hexagonal structure of 62 m point group and a direct bandgap of 2.2 eV at 300 K. GaSe crystal features high damage threshold, large nonlinear optical coefficient (54 pm/V), suitable transparent range, and low absorption coefficient, which make it an alternative solution for broadband mid infrared electromagnetic waves generation. Due to broadband THz generation and detection using a sub-20 fs laser source, GaSe emitter-detector system performance is considered to achieve comparable or even better results than using thin ZnTe crystals.

In order to achieve frequency selective THz wave generation and detection system, GaSe crystals of appropriate thickness should be used.

NOTE: because of material structure it is possible to cleave GaSe crystal along (001) plane only. Another disadvantage is softness and fragility of GaSe.


GaSe crystal mounted in Ø25.4 mm holder

### GaSe, Z-Cut

| Clear aperture, mm | Thickness, µm | Holder, mm | Catalogue number | Price, EUR |
|---|---|---|---|---|
| Ø7 | 10 | Ø25.4 | GaSe-10H1 | 1950 |
| Ø7 | 30 | Ø25.4 | GaSe-30H1 | 1625 |
| Ø7 | 100 | Ø25.4 | GaSe-100H1 | 1475 |
| Ø7 | 500 | Ø25.4 | GaSe-500H1 | 1460 |
| Ø7 | 1000 | Ø25.4 | GaSe-1000H1 | 1635 |
| Ø7 | 2000 | Ø25.4 | GaSe-2000H1 | 1810 |

Please note that from now all standard GaSe crystals are provided mounted into Ø25.4 mm ring holders. Crystals could be mounted into Ø40 mm holders under your request.

# Raman Crystals

## KGW / $Ba(NO_3)_2$ – CRYSTALS FOR STIMULATED RAMAN SCATTERING

EKSMA OPTICS offers crystalline materials – **Barium Nitrate – $Ba(NO_3)_2$** and **undoped potassium gadolinium tungstate $KGd(WO_4)_2$** or KGW which have attracted much interest for stimulated Raman scattering (SRS). These materials can be used for frequency conversion in lasers for extending the tuning range. SRS in crystals is compatible with current all-solid-state technology and provides a very simple, compact means of frequency conversion.

$Ba(NO_3)_2$ has a highest Raman gain coefficient. The gain coefficient affects the threshold for Raman laser. However, the thermal lensing is particularly strong in this material. This is indicated by the large value ∂n/∂T and low thermal conductivity. Thermal effects are significantly smaller in KGW. This along with the high damage threshold make the crystal an excellent candidate for power scaling.

Comparing $Ba(NO_3)_2$ and KGW for Raman application $Ba(NO_3)_2$ is more optimal in case of ns and longer pulses, KGW – in case of shorter pulses.

### $Ba(NO_3)_2$ Physical and Optical properties

| | |
|---|---|
| Crystal symmetry | cubic, $P2_13$ |
| Transmission range | 0.35 – 1.8 µm |
| Density | 3.25 g/cm³ |
| Hardness Mohs | 2.5 – 3 |
| Refractive indices @ 1064 nm | n = 1.555 |
| Raman shift | 1048 $cm^{-1}$ |
| Raman gain, pump 1064 nm | 11 cm/GW |
| Thermal conductivity, W/mK | 1.17 |
| ∂n/∂T | $-20\times10^{-6}$ $K^{-1}$ |
| Optical Damage Threshold | ~ 0.4 GW/cm² |

### KGW Physical and Optical properties

| | |
|---|---|
| Crystal symmetry | monoclinic, C2/c |
| Transmission range | 0.35–5.5 µm |
| Density | 7.27 g/cm³ |
| Hardness Mohs | 4 – 5 |
| Refractive indices @ 1064 nm | $n_g = 2.061$; $n_m = 2.010$; $n_p = 1.982$ |
| Raman shift | 901 $cm^{-1}$ (p[mm]p)<br>768 $cm^{-1}$ (p[gg]p) |
| Raman gain, pump 1064 nm | 3.3 cm/GW (901 $cm^{-1}$)<br>4.4 cm/GW (768 $cm^{-1}$) |
| Thermal conductivity, W/mK | $K_a$=2.6; $K_b$=3.8; $K_c$=3.4 |
| ∂n/∂T | $0.4\times10^{-6}$ $K^{-1}$ |
| Optical Damage Threshold | > 10 GW/cm² |

### Raman wavelengths

in KGW (oscillation coefficient 901.5 $cm^{-1}$) and $Ba(NO_3)_2$ (oscillation coefficient 1048.6 $cm^{-1}$) crystals

| Stokes | KGW pumped @ 532 nm | KGW pumped @ 1064 nm | $Ba(NO_3)_2$ pumped @ 532 nm | $Ba(NO_3)_2$ pumped @ 1064 nm | Typical efficiency, % |
|---|---|---|---|---|---|
| 1 Stoke | 558 | 1177 | 563 | 1197 | 35–70 |
| 2 Stoke | 588 | 1316 | 598 | 1369 | 20–40 |
| 3 Stoke | 621 | 1494 | 638 | 1599 | 10–15 |
| 4 Stoke | 658 | 1726 | 684 | 1924 | <10 |
| 1 Antistoke | 507 | 970 | 503 | 957 | 10–30 |

### Standard specifications

| | $Ba(NO_3)_2$ | KGW |
|---|---|---|
| Surface quality, scratch & dig (MIL-PRF-13830B) | 40-20 | 10-5 |
| Flatness @ 633 nm | λ/4 | λ/8 |
| Maximal element dimensions, mm | 10×10×100 | 10×10×80 |

### Standard KGW Crystals. Updoped, b-cut

| Dimensions, mm | Coating | Catalogue number |
|---|---|---|
| 7 × 7 × 30 | Uncoated | **KGW-701** |
| 5 × 7.5 × 30 | BBAR/BBAR @ 400 – 700 nm | **KGW-702** |

## Co:Spinel / $Cr^{4+}$:YAG – PASSIVE Q-SWITCHING CRYSTALS

$Cr^{4+}$:YAG crystals

**Fe:ZnSe, Cr:ZnSe, Co:ZnS solid-state saturable absorbers also are available upon request**

Co:Spinel ($Co^{2+}$:$MgAl_2O_4$) is a relatively new material for passive Q-switching in lasers emitting from 1.2 to 1.6 µm, in particular, for eye-safe 1.54 µm Er:glass laser, but also works at 1.44 µm and 1.34 µm wavelengths. High absorption cross section ($3.5\times10^{-19}$ $cm^2$) permits Q-switching of Er:glass laser without intracavity focusing both with flash-lamp and diode-laser pumping. Negligible excited-state absorption results in high contrast of Q-switch, i.e. the ratio of initial (small signal) to saturated absorption is higher than 10 (Fig. 1).

$Cr^{4+}$:YAG is one of the best passive Q-switch for high power lasers emitting at ~1 µm wavelength. Standard diameter apertures – 5, 8, 9.5 mm and various initial transmission (or optical density) are available upon request. Also $Cr^{4+}$:YAG laser rods for ultra-short pulse solid-state lasers are available.

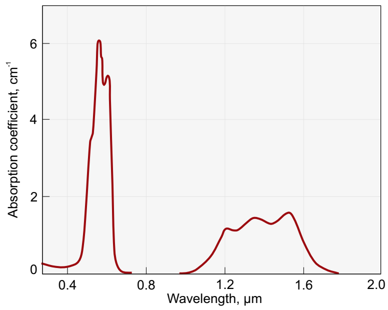



*Fig. 1.* Absorption spectra of the Co:Spinel crystal

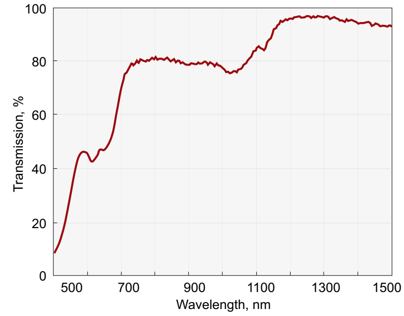



*Fig. 2.* Transmission of AR coated at 1064 nm Cr:YAG Q-switch with initial transmission of 80% at 1064 nm

## Specifications

| | Co:Spinel | $Cr^{4+}$:YAG |
|---|---|---|
| Working wavelength range, µm | 1.2 – 1.6 | 0.8 – 1.2 |
| Ground state absorption cross section, $cm^2$ | $3.5\times10^{-19}$ (at 1.54 µm) | $5\times10^{-18}$ (at 1.06 µm) |
| Excited state absorption cross-section, $cm^2$ | – | $7\times10^{-19}$ (at 1.06 µm) |
| Initial transmittance, % | 30 – 99 | 20 – 99 |
| Transmission tolerances | ±2 % | ±2 % |
| Wavefront distortion | <λ/10 @ 632.8 nm | <λ/8 @ 632.8 nm |
| Diameter tolerances | +0.0 / -0.2 mm | +0.0 / -0.2 mm |
| Parallelism error | < 20 arcsec | ≤ 30 arcsec |
| Perpendicularity | < 5 arcmin | ≤ 15 arcsec |
| Surface quality | 10 – 5 scratch & dig (per MIL-O-13830A) | 20 – 10 scratch & dig (per MIL-O-13830A) |
| Chamfer | <0.1 mm @ 45° | <0.1 mm @ 45° |
| AR Coating reflectivity | <0.2 % @ 1540 nm | <0.2 % @ 1064 nm |

## Standard $Cr^{4+}$:YAG Crystals

| Initial Transmission, % | Diameter, mm | Catalogue number | Price, EUR |
|---|---|---|---|
| 20 | 7 | **CrYAG-07-20** | 130 |
| 30 | 7 | **CrYAG-07-30** | 130 |
| 35 | 7 | **CrYAG-07-35** | 130 |
| 40 | 7 | **CrYAG-07-40** | 130 |
| 45 | 7 | **CrYAG-07-45** | 130 |
| 50 | 7 | **CrYAG-07-50** | 130 |
| 65 | 7 | **CrYAG-07-65** | 130 |
| 70 | 7 | **CrYAG-07-70** | 130 |
| 80 | 7 | **CrYAG-07-80** | 130 |
| 85 | 7 | **CrYAG-07-85** | 130 |

## Standard Co:Spinel Crystals

| Initial Transmission, % | Diameter, mm | Catalogue number | Price, EUR |
|---|---|---|---|
| 30 | 5 | **CoMALO-05-30** | 725 |
| 40 | 5 | **CoMALO-05-40** | 725 |
| 50 | 5 | **CoMALO-05-50** | 725 |
| 60 | 5 | **CoMALO-05-60** | 725 |
| 70 | 5 | **CoMALO-05-70** | 725 |
| 80 | 5 | **CoMALO-05-80** | 725 |
| 90 | 5 | **CoMALO-05-90** | 725 |

EKSMA OPTICS

# Positioners & Holders

## RING HOLDERS FOR NONLINEAR CRYSTALS – 830-0001

*830-0001-10*

*830-0001-06*

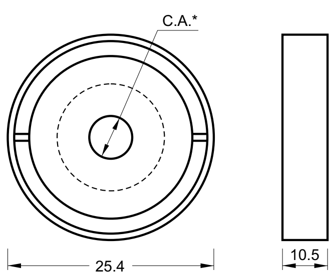
### Features

- Black anodized aluminium body
- Teflon or white anodized aluminium adapter for particular crystal size
- Easy assembling and disassembling

Ring mounts made from black anodized aluminum and Teflon or white anodized aluminium adapter are available for safe and convenient handling of nonlinear crystals. The crystals are glued into white anodized aluminium adapter (830-0001-06). No glue is used for fixation of the crystal into open ring holder with teflon adapter. The standard sizes are Ø25.4 or Ø30 mm and thickness – 6, 10.5, 13.5 or 17.5 mm depending on crystal size.

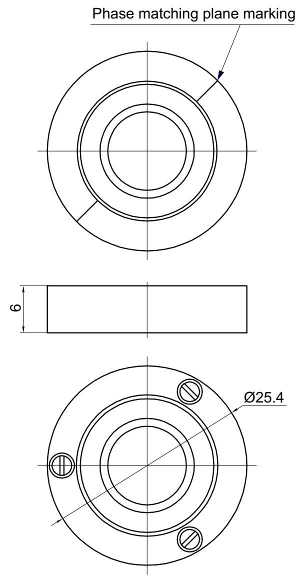
Please indicate the exact crystal size when ordering.

| Diameter, mm | Thickness, mm | Max. acceptable crystal size, mm | Catalogue number | Price, EUR |
|---|---|---|---|---|
| 25.4 | 6 | 12×12×0.5 | 830-0001-06 | 50 |
| 25.4 | 10.5 | 12×12×3 | 830-0001-10 | 50 |
| 25.4 | 13.5 | 12×12×6 | 830-0001-13 | 50 |
| 25.4 | 17.5 | 12×12×15 | 830-0001-17 | 90 |
| 30 | 10.5 | 15×15×3 | 830-0002-10 | 50 |
| 30 | 13.5 | 15×15×6 | 830-0002-13 | 50 |
| 30 | 17.5 | 15×15×15 | 830-0002-17 | 90 |




* C.A. - depends on crystal aperture

*830-0001-10*




*830-0001-06*

### Housing accessories

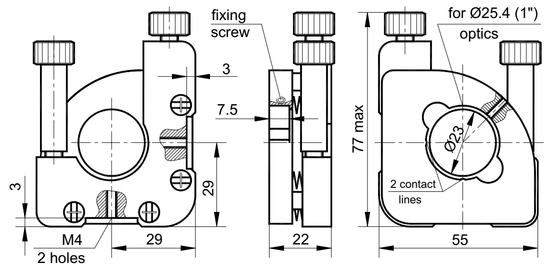
Positioning Mount 840-0199 for Nonlinear Crystal Housing

See page 2.27

## KINEMATIC POSITIONING MOUNT – 840-0193

### Features

- For Ø25.4 mm (1 inch) ring holders
- Kinematic design
- Tilt/tip range ±2°
- Sensitivity 3 arcsec
- Both tilt and tip controlled from aside the optical path
- Fine adjustment screws with 0.25 mm pitch
- Hardened seats under adjustment screws




| Catalogue number | Weight, kg | Price, EUR |
|---|---|---|
| 840-0193 | 0.12 | 87 |

## POSITIONING MOUNT FOR NONLINEAR CRYSTAL HOUSING – 840-0199

***840-0199*** Positioning Mount with ***830-0001*** Ring Holder

### Features

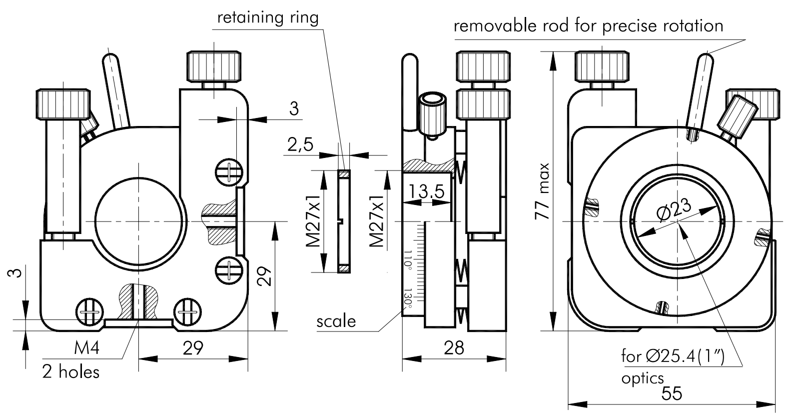
- Accepts Ø25.4 mm and up to 10.5 mm thickness ring housings
- Kinematic design
- Wedge and ball drive mechanism
- Tilt/tip range: ±2°
- Sensitivity: 3 arcsec
- Fine adjustment screws with 0.25 mm pitch
- Hardened seats under adjustment screws
- Rotation range: 360°
- Scale gradation: 2°
- Compact and robust design
- Material: black anodized aluminum

This kinematic mount accepts crystal housings of Ø25.4 mm and thickness up to 10.5 mm.

Large knobs on the adjusting screws relieve the strain on operator fingers during adjustment. Both screws protrude from the top allowing convenient adjustment outside the laser beam path and providing easy access for adjustments in densely packed optical set-ups.

An extra M4 tapped hole on the side of the base allows you to operate the mount as a side-drive adjustment control mount. The mount is made of black anodized aluminium to help minimize reflections.

A retaining ring M27×1, two Teflon rings and a tightening key to fix the crystal ring housing is included.


| Catalogue number | Weight, kg | Price, EUR |
|---|---|---|
| 840-0199 | 0.12 | 165 |

# Crystal Ovens

Many of widely used nonlinear crystals are susceptible to ambient humidity, for example KD*P, BBO, LBO. Protective coatings applied to the surface can reduce degradation to some extent only. To improve the protection of surfaces of the crystals from the degradation it is desirable to keep the crystals at higher than ambient temperature, which helps avoid condensation on the crystal surfaces.

In addition, if the crystal is used for harmonics generation, the phase-matching angle depends on crystal temperature. For example, the output power of second harmonics generator based on KD*P crystal can decrease by 50 % if the crystal temperature changes just by one degree, hence for good laser stability precise crystal temperature stabilization is necessary.

## TEMPERATURE CONTROLLER TC2 WITH OVEN CO1 – TC2 / CO1

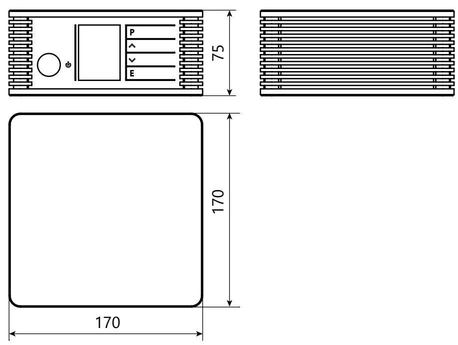
TC2 and CO1 is high temperature set (up to 200 °C) consisting of thermocontroller TC2 and crystal oven CO1. TC2 has two independent outputs and can control two CO1-30 ovens simultaneously. Controller is equipped by LAN and USB computer control interfaces.

The nonlinear crystal is mounted into adapter before insertion into oven CO1. Such design facilitates handling and replacement of the crystal. The nonlinear crystal can be sealed with fused silica windows in order to provide extra protection. The standard adapters are 30 and 50 mm length with apertures of 3×3, 4×4, 5×5, 6×6 mm and up to 12×12 mm size. Oven is delivered with one, customer's specific size of adapter. Adapters for different sizes can be ordered separately.


### Specifications

| Model | TC2 + CO1-30 | TC2 + CO1-50 |
|---|---|---|
| Quantity of ovens possible to connect to one controller TC2 | 2 | |
| Temperature tuning range | RT – 200 °C | |
| Maximum crystals dimensions | 12×12×30 mm | 12×12×50 mm |
| Sealing (optional) | FS windows (operation wavelength must be specified before ordering) | |
| Temperature tuning step | 0.05 °C | |
| Accuracy | ± 0.5 °C | |
| Long-term stability | ± 0.05 °C | |
| Control interfaces | LAN, USB | |
| Mains | 90–264 V, 47–66 Hz | |
| Power consumption | < 50 W | |
| Dimensions, DiaxD | Ø52x52 mm | Ø52x72 mm |
| Price, EUR | 2130 | 2275 |

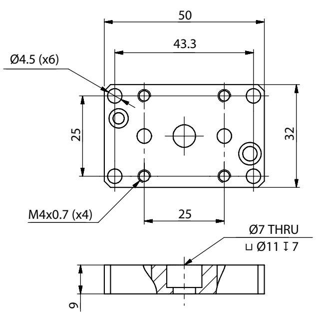
Specifications are subject to changes without advance notice.

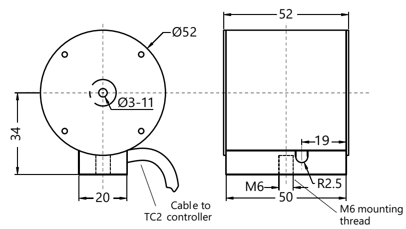



Temperature controller ***TC2*** outline drawing

### Related products

Adapter MS-4 for CO1 mounting on tilt stage




Crystal oven ***CO1-30*** outline drawing



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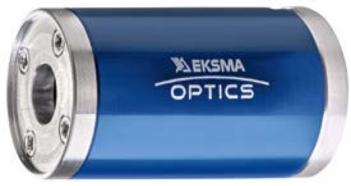
## COMPACT OVEN FOR NONLINEAR CRYSTALS – Heatpoint

Heatpoint is a compact round oven designed for heating and thermo-stabilization of humidity sensitive nonlinear crystals. Temperature of the oven can be adjusted in 25 – 70 °C range using a small thermocontroller attached on a wire. Heatpoint ovens exhibit precise long-term stability and are ideal for keeping nonlinear crystals at their optimal operational temperature, preventing moisture condensation on crystal's faces.

Because of their compact design, Heatpoint ovens can be easily installed into tight spaces. These ovens can be mounted in any standard one-inch optics positioning mount.

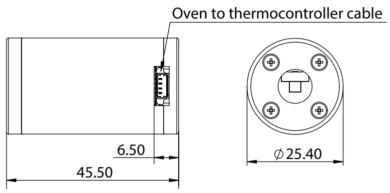
Heatpoints are available in two sizes: HP15 accepts crystals up to 15 mm in length, while slightly longer HP30 fits crystals up to 30 mm in length. The exact aperture of the crystal must be specified when ordering, as a special adapter is made for the installation.

Each oven is made exactly for specific crystal aperture size, so it cannot be used for different size crystals.

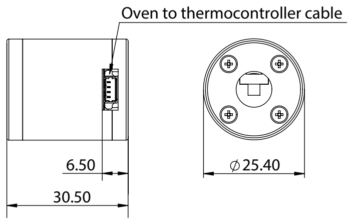



***Heatpoint HP30***


***Heatpoint HP15***




***HP30*** dimensions



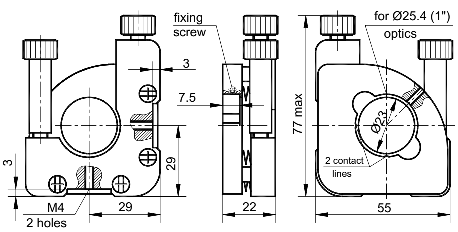

***HP15*** dimensions


***Heatpoint HP30*** with thermocontroller

## Specifications

| Model | HP15 | HP30 |
|---|---|---|
| Crystal length (max) | 15 mm | 30 mm |
| Crystal aperture (max) | 6 × 6 mm | |
| Temperature tuning range | 25 – 70 °C | |
| Temperature tuning step | 0.1 °C | |
| Long-term stability | ± 0.1 °C | |
| Temperature ramp rate | 3 °C/min | |
| Powering requirements | 12 V DC | |
| Power consumption (PMAX) | 6 W | |
| Power connector | 2.1/5.5 mm | |
| Power adaptor (included) | 90 – 264 V AC, 47 – 66 Hz, 12 V DC | |
| Dimensions (oven) | Ø 25.4 × 30.5 mm | Ø 25.4 × 45.5 mm |
| Dimensions (thermocontroller) | 60 × 14 × 7.5 mm | |
| Distance (wiring length) from oven to thermocontroller | 250 mm | |
| Price, EUR | 350 | 350 |

## Related products




Positioning mount ***840-0193***