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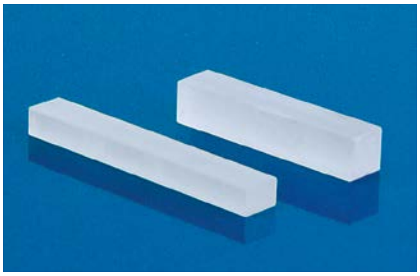
Nonlinear Crystals

LBO – LITHIUM TRIBORATE



LBO is well suited for various nonlinear optical applications:

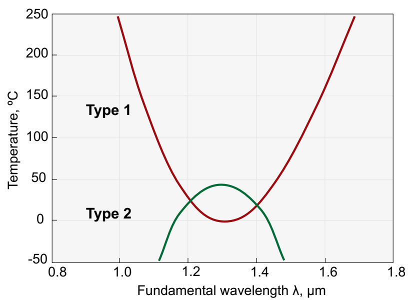
- frequency doubling and tripling of high peak power pulsed Nd doped, Ti:Sapphire and Dye lasers
- optical parametric oscillators (OPO) of both Type 1 and Type 2 phase-matching
- non-critical phase-matching for frequency conversion of CW and quasi-CW radiation.

STANDARD SPECIFICATIONS

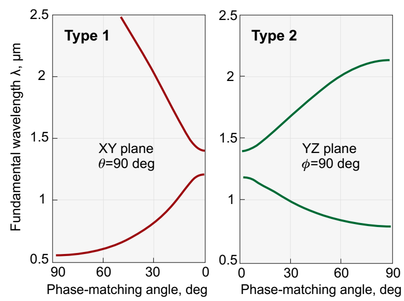
Flatness	λ/8 at 633 nm
Parallelism	< 20 arcsec
Surface quality	10 – 5 scratch & dig (MIL-PRF-13830B)
Perpendicularity	< 5 arcmin
Angle tolerance	< 30 arcmin
Aperture tolerance	± 0.1 mm
Clear aperture	90% of full aperture

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)	$n_x^2 = 2.4542 + 0.01125 / (\lambda^2 - 0.01135) - 0.01388\,\lambda^2$ $n_y^2 = 2.5390 + 0.01277 / (\lambda^2 - 0.01189) - 0.01849\,\lambda^2 + 4.3025 \times 10^{-5}\lambda^4 - 2.9131 \times 10^{-5}\lambda^6$ $n_z^2 = 2.5865 + 0.0131 / (\lambda^2 - 0.01223) - 0.01862\,\lambda^2 + 4.5778 \times 10^{-5}\lambda^4 - 3.2526 \times 10^{-5}\lambda^6$		
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) 248 mrad×cm (Type 1 NCPM SHG 1064 nm)		
Nonlinearity coefficients	$d_{31} = -(0.98 \pm 0.09)$ pm/V; $d_{32} = (1.05 \pm 0.09)$ 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 4.42*

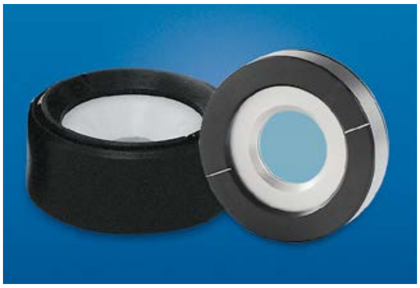
Crystal Oven TC2
See page 2.28

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 (see technical specifications, p. 2.28).

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

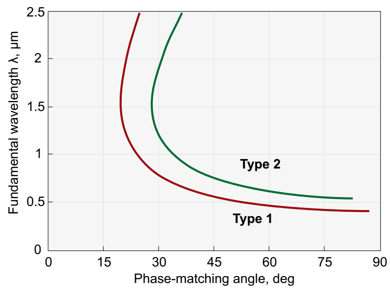
- Wide transparency region
- Broad phase-matching range
- Large nonlinear coefficient
- High damage threshold
- Wide thermal acceptance bandwidth
- High optical homogenity

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

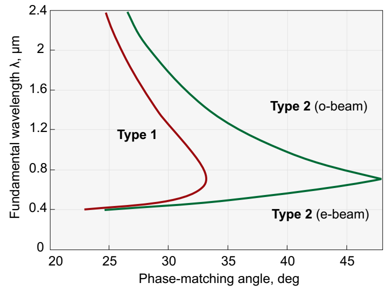
- harmonic generations (up to fifth) of Nd doped lasers
- frequency doubling and tripling of ultrashort pulse Ti:Sapphire and Dye lasers
- optical parametric oscillators (OPO) at both Type 1(ooe) and Type 2 (eoe) phase-matching
- frequency doubling of Argon ion and Copper vapour laser radiation
- electro-optic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

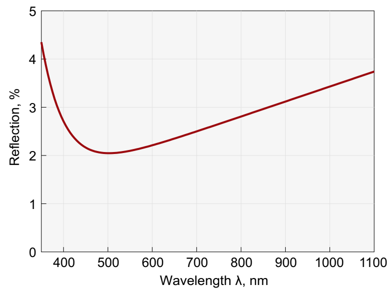
STANDARD CRYSTALS LIST

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

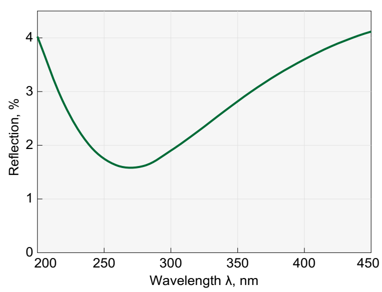
Wide selection of non-standard size and cut angle BBO crystals is available at **www.eksmaoptics.com**

PHYSICAL AND OPTICAL PROPERTIES

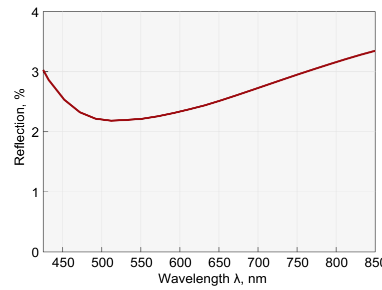
Chemical formula	BaB_2O_4	
Crystal structure	trigonal, 3m	
Optical symmetry	Negative Uniaxial ($n_o>n_e$)	
Space group	R3c	
Density	3.85 g/cm^3	
Mohs hardness	5	
Optical homogeneity	$\partial n = 10^{-6}$ cm^{-1}	
Transparency region at "0" transmittance level	189 – 3500 nm	
Linear absorption coefficient 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)	$n_o^2 = 2.7366122 + 0.0185720 / (\lambda^2 - 0.0178746) - 0.0143756\,\lambda^2$ $n_e^2 = 2.3698703 + 0.0128445 / (\lambda^2 - 0.0153064) - 0.0029129\,\lambda^2$	
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	$d_{ooe} = d_{31}\sin\theta - d_{22}\cos\theta\sin3\varphi$ $d_{eoe} = d_{oee} = d_{22}\cos^2\theta\cos3\varphi$	
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/cm^2 at 1064 nm, 10 ns ~ 50 GW/cm^2 at 1064 nm, 1 ps > 200 GW/cm^2 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 4.35

BBO crystals for SHG of Yb:KGW/KYW laser frequency conversion
See page 4.42

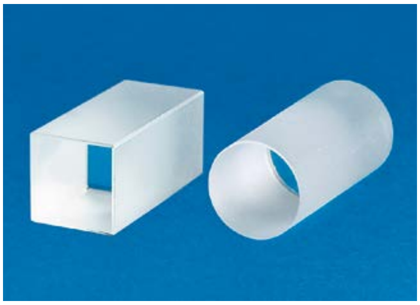
HOUSING ACCESSORIES

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

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

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

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.

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	485
15x15x13	53.5	0	AR/AR @ 1064+532 nm	SHG @ 1064 nm, Type 2	DKDP-402	485
12x12x20	59.3	0	AR/AR @ 1064+532 / 355 nm	THG @ 1064 nm, Type 2	DKDP-403	475
12x12x20	53.5	0	AR/AR @ 1064 / 1064+532 nm	SHG @ 1064 nm	DKDP-404	475
15x15x20	53.5	0	AR/AR @ 1064 / 1064+532 nm	SHG @ 1064 nm	DKDP-405	579
15x15x20	59.3	0	AR/AR @ 1064+532 / 355 nm	THG @ 1064 nm	DKDP-406	579
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/cm^3		2.332	2.355
Thermal conductivity, W/cm×K		k_{11}= 1.9×10^{-2}	k_{11}= 1.9×10^{-2} k_{33}= 2.1×10^{-2}
Thermal expansion coefficients, K^{-1}		a_{11}= 2.5×10^{-5} a_{33}= 4.4×10^{-5}	a_{11}= 1.9×10^{-5} a_{33}= 4.4×10^{-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 n_e = 1.4599	n_o = 1.4931 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 n_e	2.259276 2.132668	2.2409 2.1260
B	n_o n_e	13.00522 3.2279924	2.2470 0.7844
C	n_o n_e	400 400	126.9205 123.4032
D	n_o n_e	0.01008956 0.008637494	0.0097 0.0086
E	n_o n_e	0.012942625 0.012281043	0.0156 0.0120
Nonlinear coeff. d_{36}, pm/V (at 1.06 µm)		0.43	0.40
Effective nonlinear coefficient Type 1 Type 2		$d_{ooe} = d_{36} \times \sin\theta \times \sin2\varphi$ $d_{eoe} = d_{36} \times \sin\theta \times \cos2\varphi$	
Laser damage threshold, GW/cm^2 at 1.06 µm		10 ps – 100 1 ns – 10 15 ns – 14.4	250 ps – 6 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

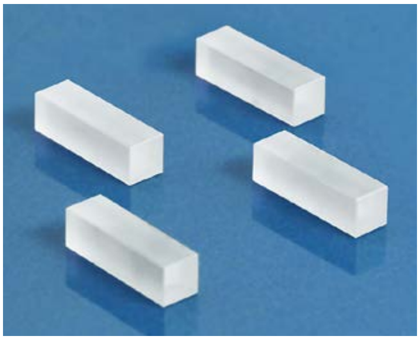
ADP, DADP, RDP, CDA and DCDA crystals are available upon request!

RELATED PRODUCTS

Nonlinear Crystal Oven CH8
See page 2.30

DKDP and KDP crystals are highly hygroscopic. CH8 and CH9 ovens help to protect hygroscopic crystals from moisture. The raised working temperature (40 – 60 °C) allows to extend crystal lifetime and to keep it thermostable. This helps to stabilise SHG efficiency.

KTP – POTASSIUM TITANYL PHOSPHATE



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

FEATURES

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

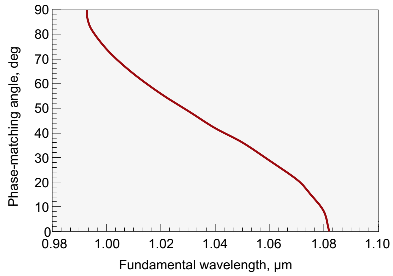


Fig. 1. *Type 2 SHG in x-y plane*

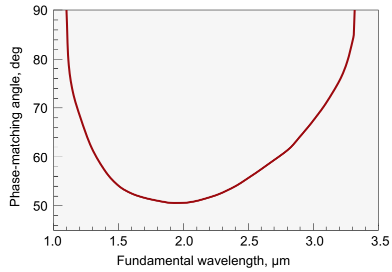


Fig. 2. *Type 2 SHG in x-z plane*

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.

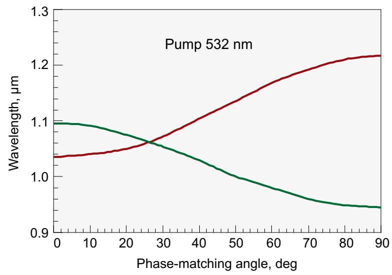


Fig. 3. *OPO tuning curve in x-y plane*

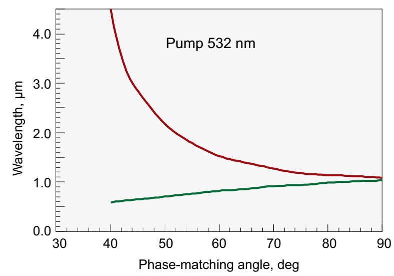


Fig. 4. *OPO tuning curve in x-z plane*

Fig. 1 represents Type 2 SHG tuning curve of KTP in x-y plane. In x-y plane the slope $\partial(\Delta k)/\partial\theta$ 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 $\partial(\Delta k)/\partial\lambda$ 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/cm³	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)$^{-1}$ $\partial n_y/\partial T = 1.3\times10^{-5}$ (K)$^{-1}$ $\partial n_z/\partial T = 1.6\times10^{-5}$ (K)$^{-1}$	
Wavelength dispersion of refractive indices	$n_x^2 = 3.0067 + 0.0395 / (\lambda^2 - 0.04251) - 0.01247\times\lambda^2$ $n_y^2 = 3.0319 + 0.04152 / (\lambda^2 - 0.04586) - 0.01337\times\lambda^2$ $n_z^2 = 3.3134 + 0.05694 / (\lambda^2 - 0.05941) - 0.016713\times\lambda^2$	

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 $\Delta\varphi = 10$ mrad × cm
Thermal acceptance	$\Delta T = 22$ K × cm
Spectral acceptance	$\Delta\nu = 0.56$ 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	$d_{oeo} = d_{eoo} = d_{24}\sin\theta$ $d_{31} = \pm 1.95$ pm/V $d_{32} = \pm 3.9$ pm/V $d_{33} = \pm 15.3$ pm/V $d_{24} = d_{32}$ $d_{15} = d_{31}$
Damage threshold	>500 MW/cm² *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

FEATURES

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

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

WE OFFER:

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

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

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	$n_x^2 = 1.90713 + 1.23522 \times \lambda^2 / (\lambda^2 - 0.196922^2) - 0.01025 \times \lambda^2$ $n_y^2 = 2.15912 + 1.00099 \times \lambda^2 / (\lambda^2 - 0.218442^2) - 0.01096 \times \lambda^2$ $n_z^2 = 2.14768 + 1.29559 \times \lambda^2 / (\lambda^2 - 0.227192^2) - 0.01436 \times \lambda^2$
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	$d_{oeo} = d_{eoo} = d_{24}\sin\theta$ d_{31}=2.3 pm/V, d_{32}=3.66 pm/V, d_{33}=15.5 pm/V 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 n_e = 2.156, n_o = 2.232 @ 1064 nm n_e = 2.203, n_o = 2.286 @ 632.8 nm
Sellmeier equations (λ, µm)	$n_o^2 = 4.9048 + 0.11768 / (\lambda^2 - 0.04750) - 0.027169\,\lambda^2$ $n_e^2 = 4.5820 + 0.099169 / (\lambda^2 - 0.04443) - 0.021950\,\lambda^2$
Thermal expansion coefficient @ 25 °C	//a, 2.0 × 10^{-6} / K //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 dn_e/dT = 39.073 × 10^{-6} / K at 1.4 µm

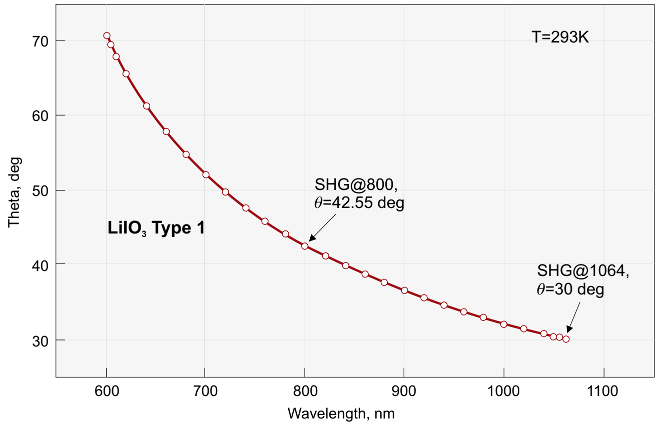
$LiIO_3$ – LITHIUM IODATE

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/cm^3	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/cm^2	> 100 for TEM_{00}, 1064 nm, 10 ns, 10 Hz

Wavelength dispersion of refractive indices (λ – in μm)

$$n_o^2 = 2.083648 + \frac{1.332068\,\lambda^2}{\lambda^2 - 0.035306} - 0.008525\,\lambda^2$$

$$n_e^2 = 1.673463 + \frac{1.245229\,\lambda^2}{\lambda^2 - 0.028224} - 0.003641\,\lambda^2$$

HOUSING ACCESSORIES

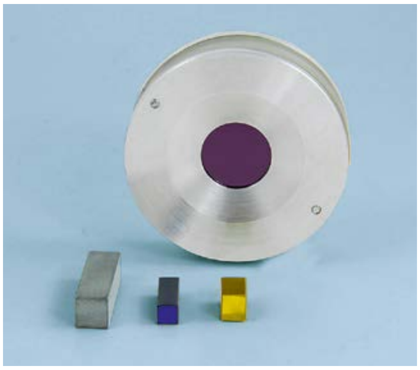
Ring Holders for Nonlinear Crystals

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



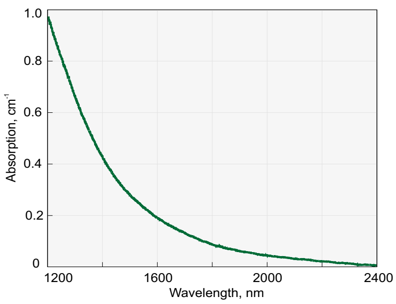
$ZnGeP_2$

$ZnGeP_2$ (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:

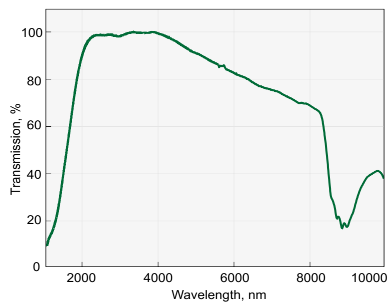
- up-conversion of CO_2 and CO laser radiation to near IR range via harmonics generation and mixing processes;
- efficient SHG of pulsed CO, CO_2 and chemical DF-laser;
- efficient down conversion of Holmium, Thulium and Erbium and laser wavelengths to mid infrared wavelength ranges by OPO process.

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.

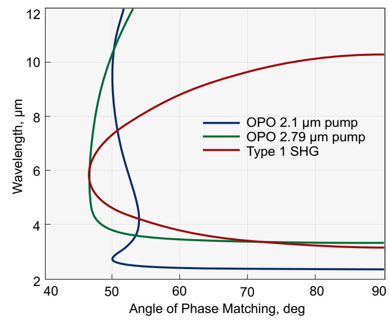
Typical absorption coefficient is <0.03 cm^{-1} at 2.5 – 8.2 µm range.



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



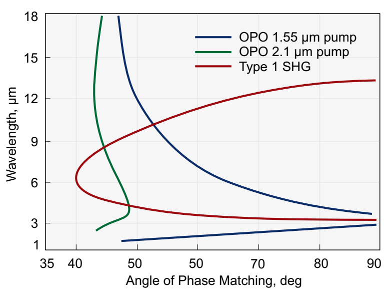
Type 1 OPO and SHG tuning curves in $ZnGeP_2$

TYPE 1 $ZnGeP_2$ CRYSTALS FOR OPO AT 3.5-5 µm RANGE PUMPED AT ~2.1 µm

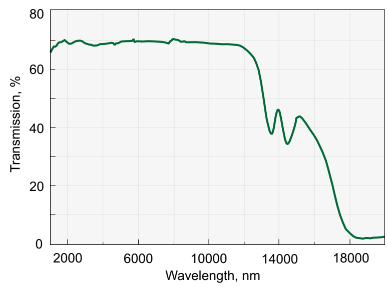
Size, mm	θ, deg	φ, deg	Coating	Application	Catalogue number
7×5×15	54	0	AR @ 2.1 µm + BBAR @ 3.5-5 µm	OPO@2.1 → 3.5-5 µm	**ZGP-401**
7×5×20	54	0	AR @ 2.1 µm + BBAR @ 3.5-5 µm	OPO@2.1 → 3.5-5 µm	**ZGP-402**
7×5×25	54	0	AR @ 2.1 µm + BBAR @ 3.5-5 µm	OPO@2.1 → 3.5-5 µm	**ZGP-403**

$AgGaSe_2$

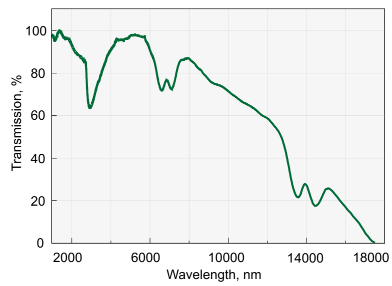
$AgGaSe_2$ has band edges at 0.73 and 18 µm. Its useful transmission range of 0.9–16 µm and wide phase matching capability provide excellent potential for OPO applications when pumped by a variety of currently available lasers. Tuning from 2.5–12 µm has been obtained when pumping by Ho:YLF laser at 2.05 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 $AgGaSe_2$



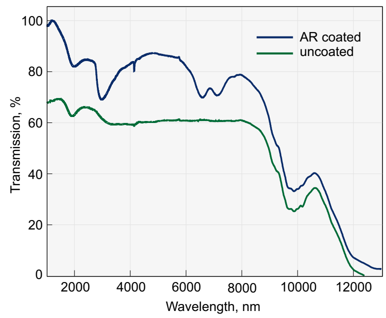
Transmission spectra of 18 mm long uncoated $AgGaSe_2$ crystal



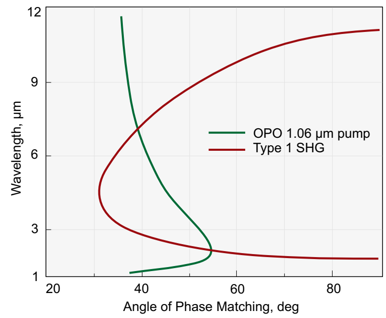
Transmission spectra of 25 mm long AR coated $AgGaSe_2$ crystal

$AgGaS_2$

$AgGaS_2$ 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 $AgGaS_2$

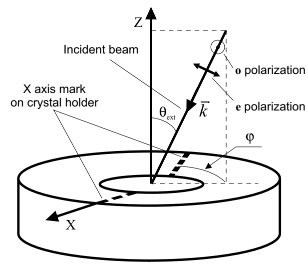
LIST OF STANDARD $AgGaS_2$ CRYSTALS

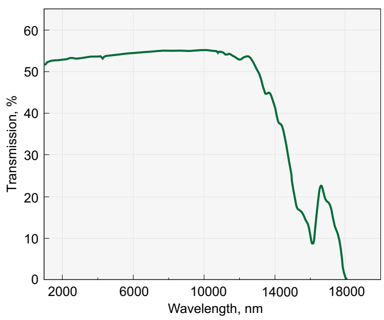
Size, mm	θ, deg	φ, deg	Coating	Application	Catalogue number	Price, EUR
5×5×1	39	45	BBAR/BBAR @ 1.1-2.6 / 2.6-11 µm	DFG @ 1.2-2.4 µm -> 2.4-11 µm	AGS-401H	835
6×6×2	50	0	BBAR/BBAR @ 1.1-2.6 / 2.6-11 µm	DFG @ 1.2-2.4 µm -> 2.4-11 µm	AGS-402H	1345
5×5×0.4	34	45	BBAR/BBAR @ 3-6 / 1.5-3 µm	SHG @ 3-6 µm, Type 1	AGS-403H	995
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	995
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	2340
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	2140

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

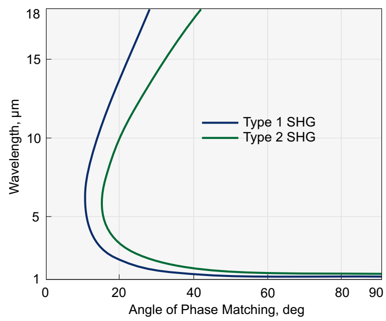
GaSe

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 c	5.465 10.771	5.9901 10.8823	5.757 10.305	3.742 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 n_e	3.2324 3.2786	2.7005 2.6759	2.4508 2.3966	2.9082 2.5676
5.3 µm	n_o n_e	3.1141 3.1524	2.6140 2.5823	2.3954 2.3421	2.8340 2.4599
10.6 µm	n_o n_e	3.0725 3.1119	2.5915 2.5585	2.3466 2.2924	2.8158 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 τ 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 τ_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 4.35; 4.42*

Ring Holders for Nonlinear Crystals
See page 2.26

Positioning Mount 840-0199 for Nonlinear Crystal Housing
See page 2.27

Laser Crystals

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	6.9×10^{-6} °C^{-1}
∂n/∂t	7.3×10^{-6} °C^{-1}
Young's modulus	3.17×10^4 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.*

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

RELATED PRODUCTS

Laser Safety Eyewear
See page 1.17

Visualizator 990-0840
See page 1.17

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

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

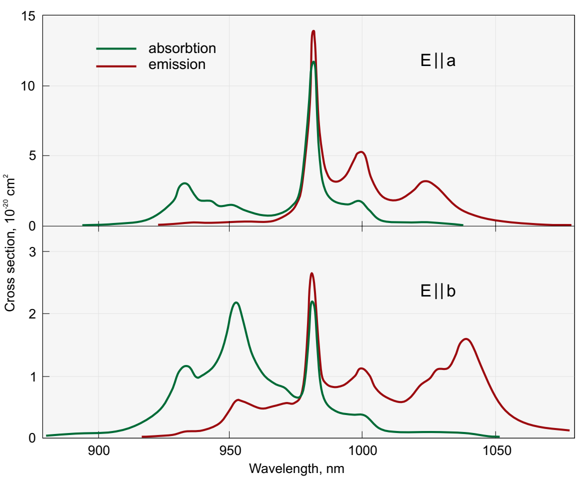
- Various shapes (slabs, rods, cubes)
- Different dopant levels
- Diversified coatings

FEATURES

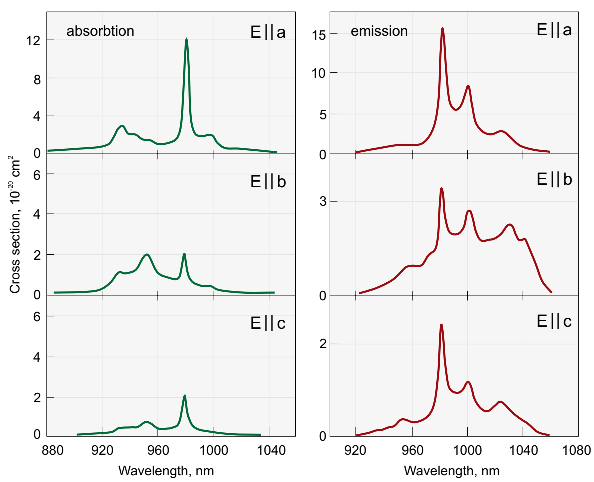
- High absorption coefficient @ 981 nm
- High stimulated emission cross section
- Low laser threshold
- Extremely low quantum defect $\lambda_{pump}/\lambda_{se}$
- Broad polarized output at 1023–1060 nm
- High slope efficiency with diode pumping (~ 60%)
- High Yb doping concentration

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	$\partial n_p/\partial T$= -15.7×10^{-6} K^{-1} $\partial n_m/\partial T$= -11.8×10^{-6} K^{-1} $\partial n_g/\partial T$= -17.3×10^{-6} K^{-1}	*For 20% Yb:KYW* $\partial n_p/\partial T$= -13.08×10^{-6} K^{-1} $\partial n_m/\partial T$= -7.61×10^{-6} K^{-1} $\partial n_g/\partial T$= -11.83×10^{-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)	2.6×10^{-20} cm²	3×10^{-20} cm²
Absorption peak and bandwidth	α_a=26 cm^{-1}, λ=981 nm, Δλ=3.7 nm	α_a=40 cm^{-1}, λ=981 nm, Δλ=3.5 nm
Absorption cross section	1.2×10^{-19} cm²	1.33×10^{-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

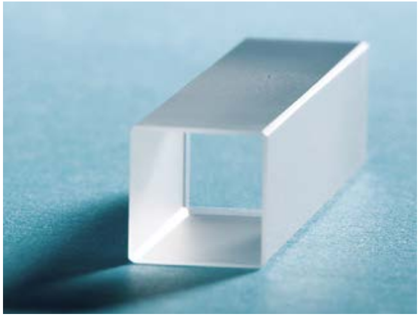


Absorption and emission spectra of Yb(5%):KYW



Absorption and emission spectrae 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.

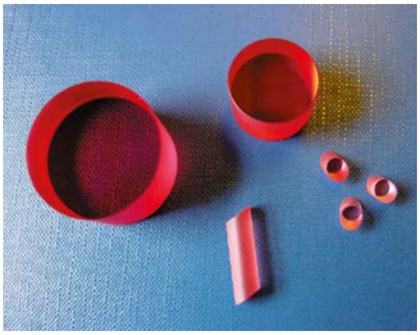
STANDARD SPECIFICATIONS

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

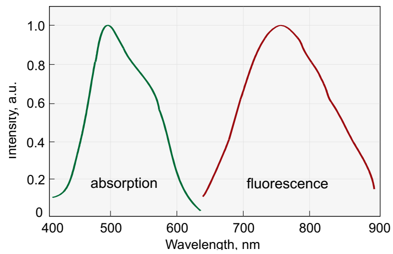
Chemical formula	$KGd(WO_4)$:Nd
Lattice constants	a = 8.095 Å, b = 10 Å, c = 7.588 Å
Optical orientation	n_g = b, n_pc = 20 deg
Angle between optical axis	86.5 angular grad
Density	7.27 g/cm^3
Mohs hardness	5
Thermal conductivity	2.8 W/(m×grad) [100] 2.2 W/(m×grad) [010] 3.5 W/(m×grad) [001]
Thermal expansion	4×10^{-6} grad^{-1} [100] 3.6×10^{-6} grad^{-1} [010] 8.5×10^{-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 n_p = 1.937 @ 1.067 µm 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	4.3×10^{-19} cm^{-2}
Emission temperature drift	8.5×10^{-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/cm^3
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	975
10×10	0.2	Ø25.4	ZnTe-200H	775
10×10	0.5	Ø25.4	ZnTe-500H	660
10×10	1.0	Ø25.4	ZnTe-1000H	540
10×10	2.0	Ø25.4	ZnTe-2000H	825

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

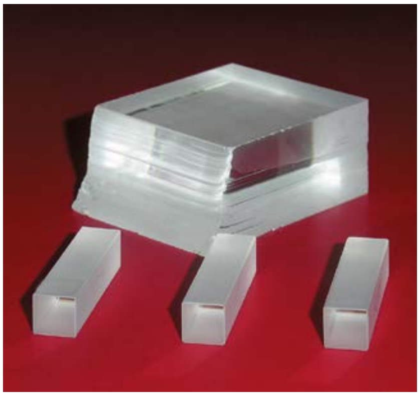
GaSe, Z-CUT

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	-20×10^{-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) 768 cm^{-1} (p[gg]p)
Raman gain, pump 1064 nm	3.3 cm/GW (901 cm^{-1}) 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	0.4×10^{-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	Price, EUR
7 × 7 × 30	Uncoated	**KGW-701**	600
5 × 7.5 × 30	BBAR/BBAR @ 400 – 700 nm	**KGW-702**	785

Barium & Strontium tungstate-molybdate – CRYSTALS FOR RAMAN SHIFT

- **$Ba(MoO_4)_X(WO_4)_{1-X}$**, 0<x<0.01
- **$Sr(MoO_4)_X(WO_4)_{1-X}$**, 0<x<0.01
- **$Sr(MoO_4)_X(WO_4)_{1-X}$**, 0.99<x<1

New Barium and Strontium tungstate-molybdate single crystals feature higher Raman gain as compared to KGW or $CaCO_3$ and relatively higher thermal conductivity as compared to a $Ba(NO_2)_3$.

Barium and Strontium tungstate-molybdate single crystals are grown and provided with cut along a-direction. Active elements do not require precise positioning since stimulated Raman scattering (SRS) threshold slightly depends on the crystal orientation relative to pump polarization (within a few percent) and minimum threshold is reached at E||c. In this case, the polarization of the pump and stokes pulses are parallel to the optical axis (c-axis).

The crystals are water-insoluble and durable. Available sizes and shapes of active elements are rectangular up to 10 × 10 × 100 mm or with cylindrical cross-section up to Ø10 × 100 mm.

APPLICATIONS

- Raman converters – new crystals extend the capabilities of the Raman devices in addition to commercially available $Ba(NO_2)_3$, $CaCO_3$, KGW crystals, since new crystals have different values of the Stokes shift and allow to obtain a laser radiation at the other wavelengths
- Raman lasers including self-Raman generation
- Laser pulse compressors based on stimulated Raman scattering effect

RAMAN WAVELENGTHS GENERATION IN BARIUM TUNGSTATE, STRONTIUM TUNGSTATE AND STRONTIUM MOLYBDATE SINGLE CRYSTALS

Crystal	Barium tungstate		Strontium tungstate		Strontium molybdate	
Chemical formula	$Ba(MoO_4)_X(WO_4)_{1-X}$ 0 < x < 0.01		$Sr(MoO_4)_X(WO_4)_{1-X}$ 0 < x < 0.01		$Sr(MoO_4)_X(WO_4)_{1-X}$ 0.99 < x < 1	
Oscillation coeficient	925 cm^{-1}		921.5 cm^{-1}		888 cm^{-1}	
Pump	1064 nm	532 nm	1064 nm	532 nm	1064 nm	532 nm
1 Stoke	1180	560	1180	559	1175	558
2 Stoke	1325	590	1324	590	1312	588
3 Stoke	1510	624	1507	624	1485	620
4 Stoke	1755	662	1751	662	1710	656
1 Antistoke	969	507	969	507	972	508

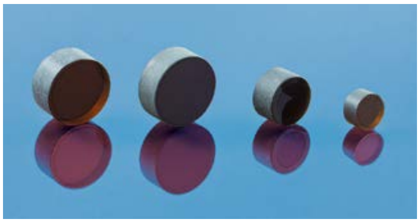
PHYSICAL AND OPTICAL PROPERTIES

Crystal	Barium tungstate	Strontium tungstate	Strontium molybdate
Chemical formula	$Ba(MoO_4)_X(WO_4)_{1-X}$ 0 < x < 0.01	$Sr(MoO_4)_X(WO_4)_{1-X}$ 0 < x < 0.01	$Sr(MoO_4)_X(WO_4)_{1-X}$ 0.99 < x < 1
Crystal structure	Tetragonal, space group $I4_1/a$	Tetragonal, space group $I4_1/a$	Tetragonal, space group $I4_1/a$
Density	6.35 g/cm^3	6.26 g/cm^3	4.65 g/cm^3
Thermal conductivity	2.3 W/m·K	3 W/m·K	4 W/m·K
Transparency range	0.45 – 5.4 µm	0.25 – 5.4 µm	0.25 – 5.4 µm
Refractive index	n_o =1.806, n_e = 1.804 at 1064 nm n_o =1.848, n_e = 1.846 at 532 nm	n_o =1.84, n_e = 1.85 at 1064 nm n_o =1.87, n_e = 1.88 at 532 nm	n_o =1.878, n_e = 1.88 at 1064 nm n_o =1.919, n_e = 1.924 at 532 nm
Stokes shift	925 cm^{-1}	921.5 cm^{-1}	888 cm^{-1}
Steady-state Raman gain at 1064 nm	8.5 cm/GW	5 cm/GW	5.5 cm/GW
Can be supplied Nd doped: Nd^{3+} concentration in the crystal	0 – 0.15 at. % (on Ba site)	0 – 1.5 at. % (on Sr site)	0 – 1.5 at. % (on Sr site)
Surface optical damage threshold (1064 nm, 4.2 ns)	2 GW/cm^2	1.9 GW/cm^2	0.8 GW/cm^2
Mohs hardness	4	4	4

$BaWO_4$ CRYSTALS FOR RAMAN GENERATION, POLISHED, A-CUT

Dimensions, mm	Coating	Catalogue number	Price, EUR
5 × 5 × 20	Uncoated	**BaWO-501**	1300
5 × 5 × 30	Uncoated	**BaWO-502**	1700
5 × 5 × 50	Uncoated	**BaWO-503**	2060

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 (3.5×10^{-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.

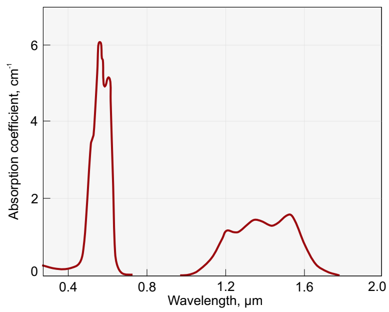


Fig. 1. Absorption spectra of the Co:Spinel crystal

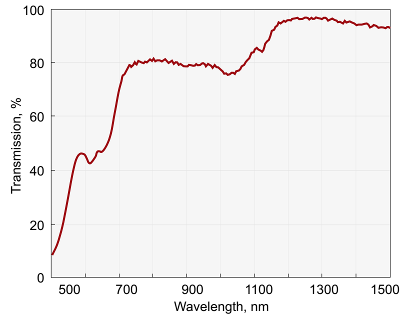


Fig. 2. Transmission of AR coated at 1064 nm Cr:YAG Q-switch with initial transmission of 80% at 1064 nm

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	3.5×10^{-19} (at 1.54 µm)	5×10^{-18} (at 1.06 µm)
Excited state absorption cross-section, cm^2	–	7×10^{-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

Positioners & Holders

RING HOLDERS FOR NONLINEAR CRYSTALS – 830-0001

830-0001-10

830-0001-06

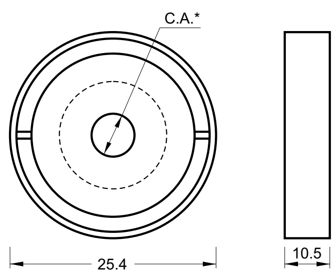
FEATURES

- 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.

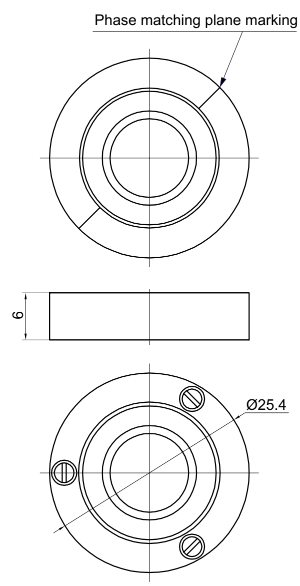
Please indicate the exact crystal size when ordering.

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

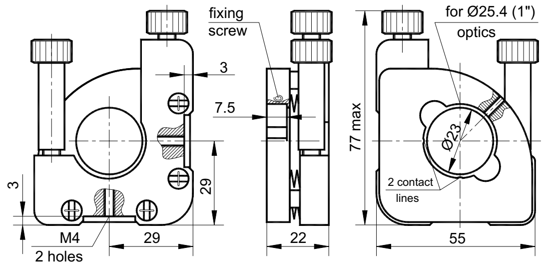
Positioning Mount 840-0199 for Nonlinear Crystal Housing

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

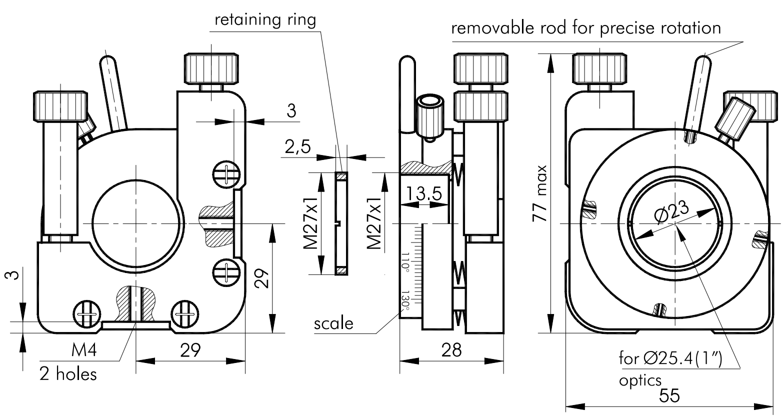
- Accepts Ø25.4 mm and up to 10.5 mm thickness ring housings
- Kinematic design
- Wedge and ball drive mechanism
- Tilt/tip range: ±2°
- Sensitivity: 3 arcsec
- Fine adjustment screws with 0.25 mm pitch
- Hardened seats under adjustment screws
- Rotation range: 360°
- Scale gradation: 2°
- Compact and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

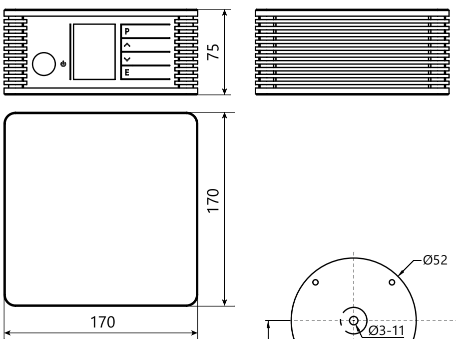
Many of widely used nonlinear crystals are susceptible to ambient humidity, for example KD*P, BBO, LBO. Protective coatings applied to the surface can reduce degradation to some extent only. To improve the protection of surfaces of the crystals from the degradation it is desirable to keep the crystals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

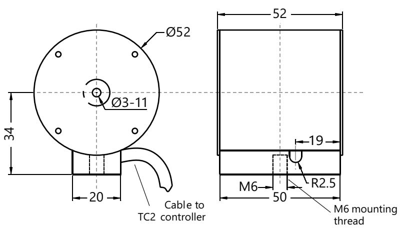
TEMPERATURE CONTROLLER TC2 WITH OVEN CO1

TC2 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 C01-30 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.



Temperature controller TC2 outline drawing



Crystal oven CO1 outline drawing

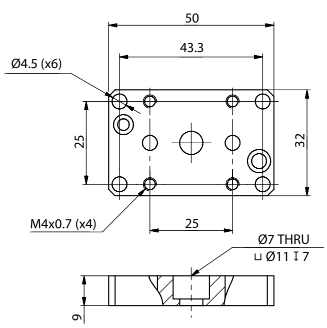
SPECIFICATIONS

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	
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	Ø52×52 mm	Ø52×72 mm

Specifications are subject to changes without advance notice.

RELATED PRODUCTS

Adapter MS-4 for CO1 mounting on tilt stage



ORDERING INFORMATION

Catalogue number **		Description, features
TC2		Temperature controller, RT-200 °C, Fuzzy logic can control two CO1 ovens, long-term stability ±0.05 °K
For crystal length up to 30 mm	For crystal length up to 50 mm	
CO1-30-y/y	CO1-50-y/y	Standard crystal sizes *
CO1-30-y/z	CO1-50-y/z	Custom crystal sizes
CO1-30S-y/y	CO1-50S-y/y	Sealed, standard crystal sizes *
MS-4		Optional adapter for CO1 oven mounting on a tilt stage. Tilt stage should be ordered separately

** Sizes 3×3, 4×4, 5×5, 6×6,12×12 are standard.* *** y/y, y/z – crystal size.*

ROUND OVEN Heatpoint FOR NONLINEAR CRYSTALS

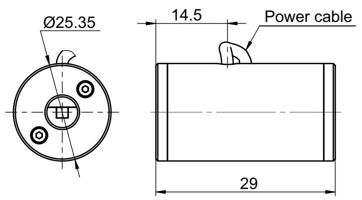
Heatpoint Crystal oven

Heatpoint is a compact round oven designed for heating of humidity sensitive nonlinear crystals. It is used to prevent moisture condensation on the crystal faces or for thermo-stabilization of the crystals.

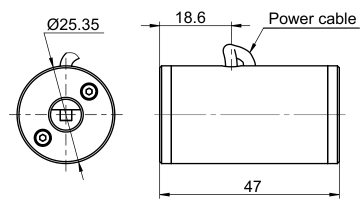
The oven features precise long term stability and compact design. Heatpoint is designed to be used with common one-inch optics positioning mounts or with our special positioning mount PM1. A small thermocontroller is attached to the oven on a wiring.

Required temperature of the oven is preset in the factory and it can be chosen by the customer in the range between 30 °C and 80 °C. Preset temperature can be adjusted in ±5 °C range.

Heatpoint oven has special crystal adapter and fits crystals of size up to 6×6×30 mm. The adapter is made exactly for particular crystal size and it cannot be used for a crystal of a different size.



HP1 dimensions



HP2 dimensions

SPECIFICATIONS

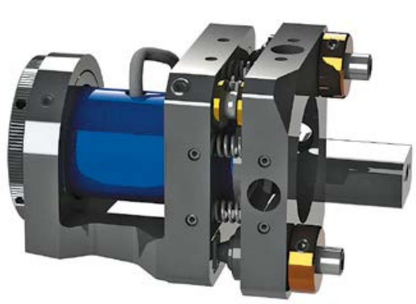
Model	HP1	HP2
Maximum crystals dimensions	6 × 6 × 15 mm	6 × 6 × 30 mm
Preset temperature	30 – 80 °C	
Temperature tuning range near preset	± 5 °C	
Long-term stability	± 0.15 at 30-50 °C ± 0.2 at 50-80 °C	
Powering requirements	12 – 16 V	
Power consumption (PMAX)	5.5 W	
Sensor type	PTC thermo resistor	
Output connector	2.5 mm mono plug	
Thermocontroller size	18 × 12 × 42.5 mm	
Distance (wiring length) from oven to thermocontroller	180 mm	
Oven dimension, dia × L	Ø25.4 × 29 mm	Ø25.4 × 47 mm

MOUNT SPECIFICATIONS

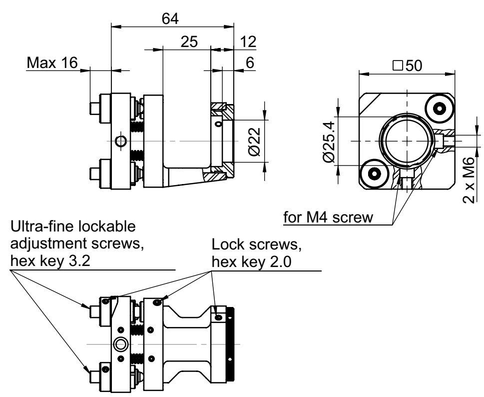
Model	PM1
Adjusting angles, tilt and tip	± 3.5°
Rotation along Z-axis	180°

ORDERING INFORMATION

Catalogue number	Description
HP1	Heatpoint oven (Ø25.4 × 29 mm) with attached thermocontroller
HP2	Heatpoint oven (Ø25.4 × 47 mm) with attached thermocontroller
PM1	Positioning mount for Heatpoint ovens

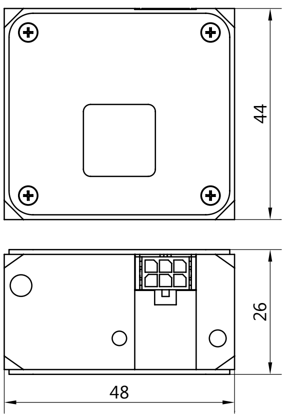


Heatpoint Crystal oven with PM1 holder



OVEN CH8 FOR NONLINEAR CRYSTALS

CH8 is compact oven with built-in thermocontroller for nonlinears crystals to keep them at stabilized temperature in range 30…80 °C. It is ideal for larger aperture crystals like KD*P. The crystals with up to 15 × 15 mm dimensions can be mounted. Each oven is made exactly for specific crystal aperture size, so it cannot be used for different size crystals. CH8 crystal oven can be used with temperature preset at the factory or customer has the possibility to adjust temperature in the range 30 – 80 °C via CAN interface. Our CAN-USB converter is required in this case and it is sold separately.



***CH8** dimensions*

SPECIFICATIONS

Model	CH8-20	CH8-30	CH8-50
Temperature range	30 – 80 °C		
Maximum crystals dimensions	15×15×20 mm	15×15×30 mm	15×15×50 mm
Temperature stability	better than ± 0.05 °C		
Power consumption	<6 W	<6 W	<9 W
Control interface	CAN		
Crystal center position above pad	16 mm		
Dimensions, W×H×D	48×44×26 mm	48×44×36 mm	48×44×56 mm

Specifications are subject to changes without advance notice.

ORDERING INFORMATION

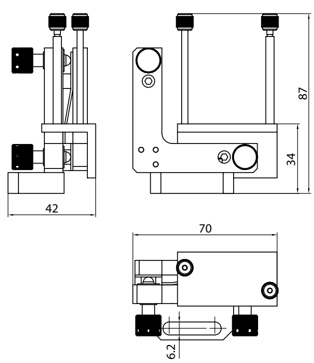
Catalogue number **	Description, features
CH8-20 – crystal length up to 20 mm	
CH8-20-y/y	Standard crystal sizes *
CH8-20-y/z	Non-standard crystal size
CH8-30 – crystal length up to 30 mm	
CH8-30-y/y	Standard crystal sizes *
CH8-30-y/z	Non-standard crystal size
CH8-50 – crystal length up to 50 mm	
CH8-50-y/y	Standard crystal sizes *
CH8-50-y/z	Non-standard crystal size
MOUNTING ACCESSORIES	
MS-1	Two axis tilt adjustment 5 degrees range, suitable for all types of CH8 crystal ovens
MS-2	Two axis tilt stage, adjustment in 5 degree range, fits two pc. of CH8 ovens
POWER SUPPLY	
PS-12	Power supply for CH8 crystal oven, 100 – 240 VAC mains, +12 VDC output
OPTIONAL EQUIPMENT	
CAN-USB	CAN-USB converter for adjustment of temperature at 30 – 80 °C range

** Sizes 3×3, 4×4, ...,15×15 are standard.*
*** y/y, y/z – crystal size.*

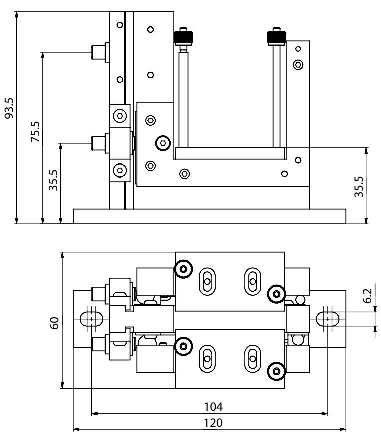
RELATED PRODUCTS

Mounts for fine tuning of CH8 crystal ovens angle. The tuning range is ± 2.5°.

*Mount **MS-1***



*Mount **MS-1** outline drawing*



*Mount **MS-2** outline drawing*