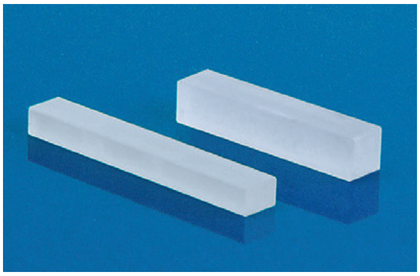
Nonlinear Crystals

LBO – LITHIUM TRIBORATE



LBO is well suited for various nonlinear optical applications:

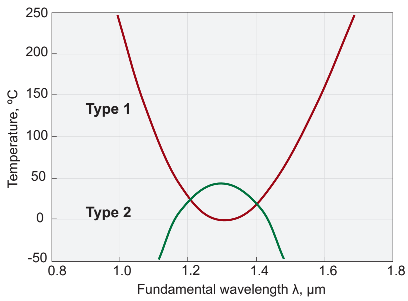
- frequency doubling and tripling of high peak power pulsed Nd doped, Ti:Sapphire and Dye lasers
- optical parametric oscillators (OPO) of both Type 1 and Type 2 phase-matching
- non-critical phase-matching for frequency conversion of CW and quasi-CW radiation.

STANDARD SPECIFICATIONS

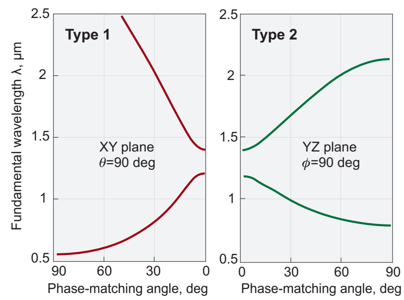
Flatness	λ/8 at 633 nm
Parallelism	< 20 arcsec
Surface quality	10 – 5 scratch & dig (MIL-PRF-13830B)
Perpendicularity	< 5 arcmin
Angle tolerance	< 30 arcmin
Aperture tolerance	± 0.1 mm
Clear aperture	90% of full aperture

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

OPTICAL COMPONENTS
NONLINEAR & LASER CRYSTALS
Nd:YAG LASERLINE COMPONENTS
FEMTOLINE COMPONENTS
OPTICAL SYSTEMS
OPTO-MECHANICAL COMPONENTS

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 us for further information or nonstandard specifications.

RELATED PRODUCTS

LBO crystals for SHG of Yb:KGW/KYW laser frequency conversion. *See page 4.42*

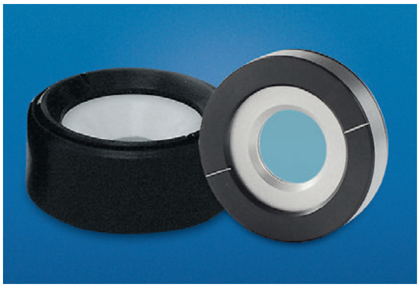
Crystal Oven TC2
See page 2.28

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

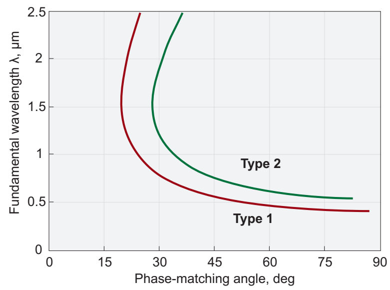
- Wide transparency region
- Broad phase-matching range
- Large nonlinear coefficient
- High damage threshold
- Wide thermal acceptance bandwidth
- High optical homogenity

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

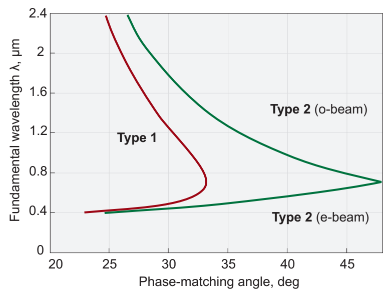
- harmonic generations (up to fifth) of Nd doped lasers
- frequency doubling and tripling of ultrashort pulse Ti:Sapphire and Dye lasers
- optical parametric oscillators (OPO) at both Type 1(ooe) and Type 2 (eoe) phase-matching
- frequency doubling of Argon ion and Copper vapour laser radiation
- electro-optic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

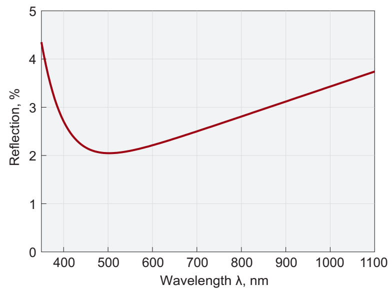
- Crystal aperture up to 25 × 25 mm
- Crystal length up to 25 mm
- Thin crystals down to 5 µm thickness
- AR, BBAR, P-coating
- BBO with gold electrodes for e/o applications
- Different mounting and repolishing services

STANDARD CRYSTALS LIST

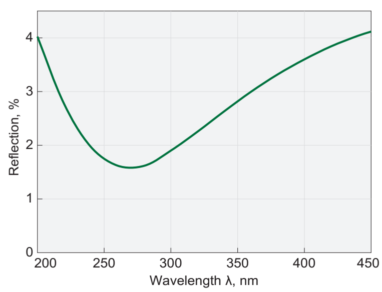
Size, mm	θ, deg	φ, deg	Coating	Application	Catalogue number	Price, EUR
6×6×0.1	29.2	90	P/P @ 400-800 nm	SHG @ 800 nm, Type 1	**BBO-601H**	505
6×6×0.2	29.2	90	P/P @ 400-800 nm	SHG @ 800 nm, Type 1	**BBO-602H**	505
6×6×0.5	29.2	90	P/P @ 400-800 nm	SHG @ 800 nm, Type 1	**BBO-603H**	440
6×6×1	29.2	90	P/P @ 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

PHYSICAL AND OPTICAL PROPERTIES

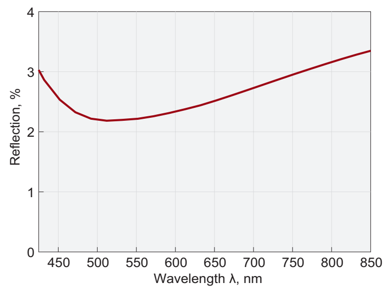
Chemical formula	BaB_2O_4	
Crystal structure	trigonal, 3m	
Optical symmetry	Negative Uniaxial ($n_o>n_e$)	
Space group	R3c	
Density	3.85 g/cm^3	
Mohs hardness	5	
Optical homogeneity	$\partial n = 10^{-6}$ cm^{-1}	
Transparency region at "0" transmittance level	189 – 3500 nm	
Linear absorption coefficient 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

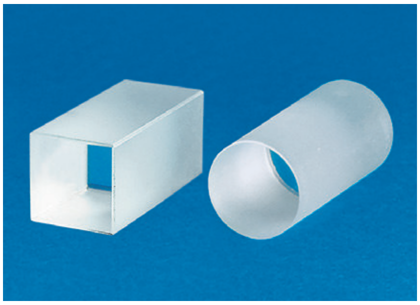
HOUSING ACCESSORIES

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

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		$k_{11} = 1.9\times10^{-2}$	$k_{11} = 1.9\times10^{-2}$ $k_{33} = 2.1\times10^{-2}$
Thermal expansion coefficients, K^{-1}		$a_{11} = 2.5\times10^{-5}$ $a_{33} = 4.4\times10^{-5}$	$a_{11} = 1.9\times10^{-5}$ $a_{33} = 4.4\times10^{-5}$
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)		$n_o = 1.4938$ $n_e = 1.4599$	$n_o = 1.4931$ $n_e = 1.4582$
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!

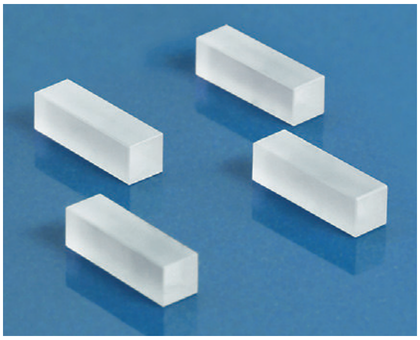
RELATED PRODUCTS

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

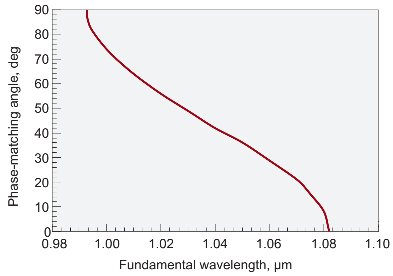


Fig. 1. *Type 2 SHG in x-y plane*

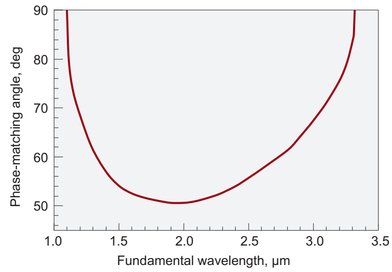


Fig. 2. *Type 2 SHG in x-z plane*

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.

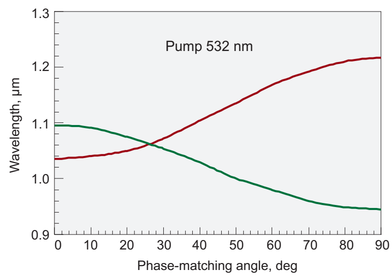


Fig. 3. *OPO tuning curve in x-y plane*

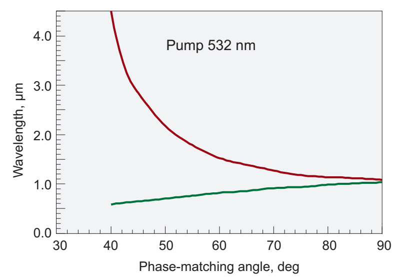


Fig. 4. *OPO tuning curve in x-z plane*

Fig. 1 represents Type 2 SHG tuning curve of KTP in x-y plane. In x-y plane the slope ∂(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

NONLINEAR CRYSTALS
LASER CRYSTALS
TERAHERTZ CRYSTALS
RAMAN CRYSTALS
POSITIONERS & HOLDERS
CRYSTAL OVENS

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	$\partial n_x/\partial T = 1.1\times10^{-5}\,(K)^{-1}$ $\partial n_y/\partial T = 1.3\times10^{-5}\,(K)^{-1}$ $\partial n_z/\partial T = 1.6\times10^{-5}\,(K)^{-1}$	
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/cm^2 *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

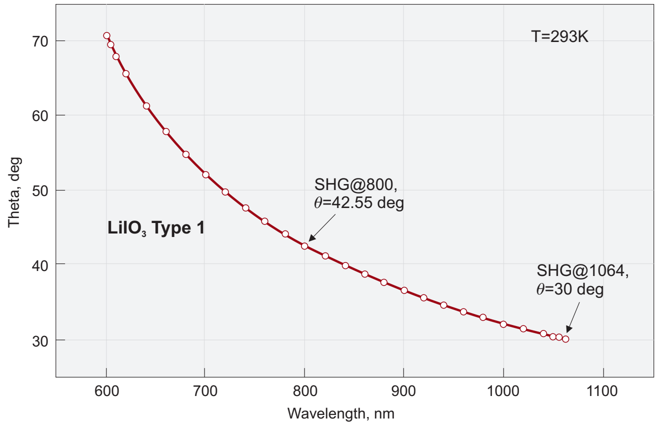
$LiIO_3$ – LITHIUM IODATE

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)

$$n_o^2 = 2.083648 + \frac{1.332068\,\lambda^2}{\lambda^2 - 0.035306} - 0.008525\,\lambda^2 \qquad n_e^2 = 1.673463 + \frac{1.245229\,\lambda^2}{\lambda^2 - 0.028224} - 0.003641\,\lambda^2$$

HOUSING ACCESSORIES

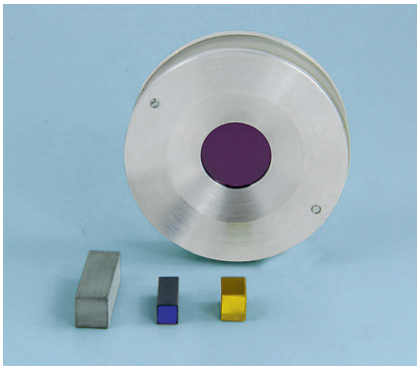
Ring Holders for Nonlinear Crystals

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



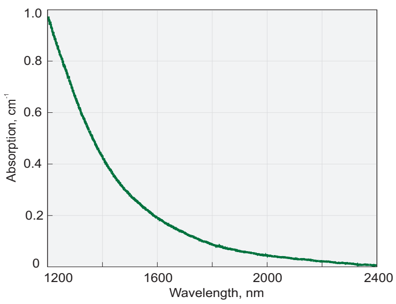
$ZnGeP_2$

$ZnGeP_2$ (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:

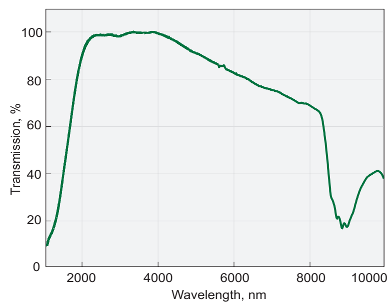
- up-conversion of CO_2 and CO laser radiation to near IR range via harmonics generation and mixing processes;
- efficient SHG of pulsed CO, CO_2 and chemical DF-laser;
- efficient down conversion of Holmium, Thulium and Erbium and laser wavelengths to mid infrared wavelength ranges by OPO process.

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.

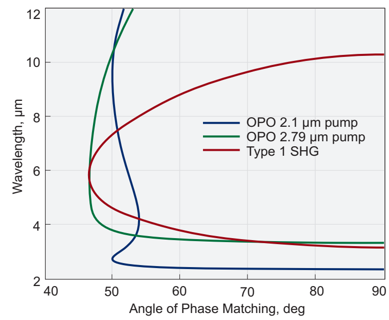
Typical absorption coefficient is <0.03 cm^{-1} at 2.5 – 8.2 µm range.



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



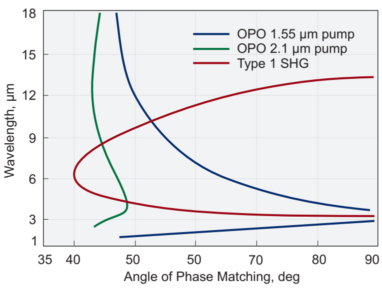
Type 1 OPO and SHG tuning curves in $ZnGeP_2$

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

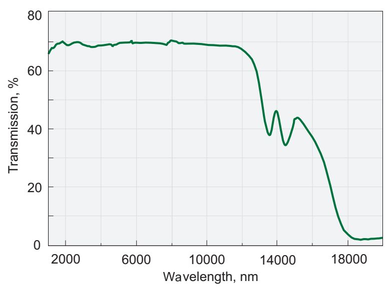
Size, mm	θ, deg	φ, deg	Coating	Application	Catalogue number
7×5×15	54	0	AR @ 2.1 µm + BBAR @ 3.5-5 µm	OPO@2.1 → 3.5-5 µm	**ZGP-401**
7×5×20	54	0	AR @ 2.1 µm + BBAR @ 3.5-5 µm	OPO@2.1 → 3.5-5 µm	**ZGP-402**
7×5×25	54	0	AR @ 2.1 µm + BBAR @ 3.5-5 µm	OPO@2.1 → 3.5-5 µm	**ZGP-403**

$AgGaSe_2$

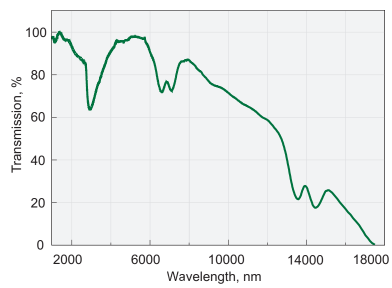
$AgGaSe_2$ has band edges at 0.73 and 18 µm. Its useful transmission range of 0.9–16 µm and wide phase matching capability provide excellent potential for OPO applications when pumped by a variety of currently available lasers. Tuning from 2.5–12 µm has been obtained when pumping by Ho:YLF laser at 2.05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



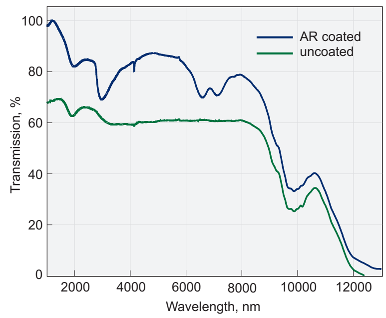
Transmission spectra of 18 mm long uncoated $AgGaSe_2$ crystal



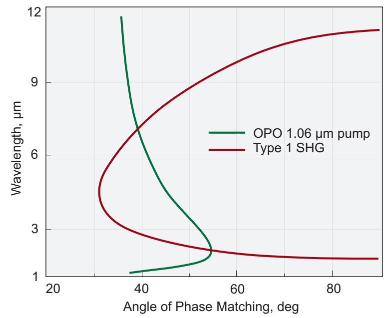
Transmission spectra of 25 mm long AR coated $AgGaSe_2$ crystal

$AgGaS_2$

$AgGaS_2$ 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 $AgGaS_2$

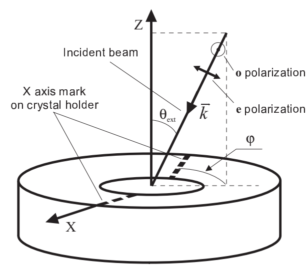
LIST OF STANDARD $AgGaS_2$ CRYSTALS

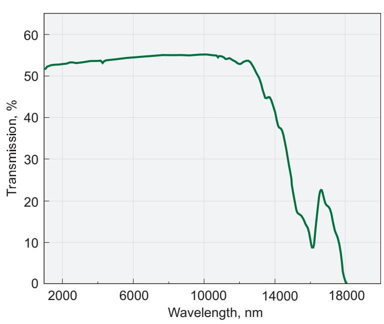
Size, mm	θ, deg	φ, deg	Coating	Application	Catalogue number	Price, EUR
5×5×1	39	45	BBAR/BBAR @ 1.1-2.6 / 2.6-11 µm	DFG @ 1.2-2.4 µm -> 2.4-11 µm	**AGS-401H**	835
6×6×2	50	0	BBAR/BBAR @ 1.1-2.6 / 2.6-11 µm	DFG @ 1.2-2.4 µm -> 2.4-11 µm	**AGS-402H**	1345
5×5×0.4	34	45	BBAR/BBAR @ 3-6 / 1.5-3 µm	SHG @ 3-6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

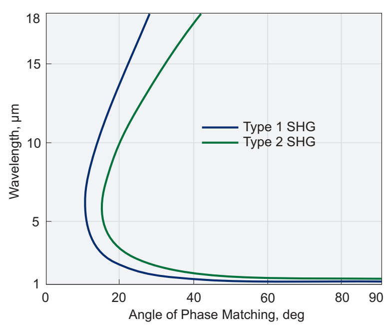
GaSe

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