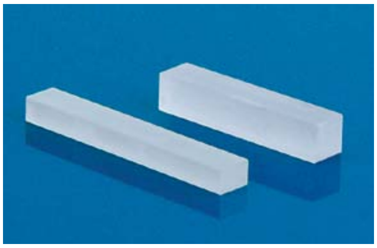
EKSMA OPTICS

Nonlinear Crystals

LBO — LITHIUM TRIBORATE



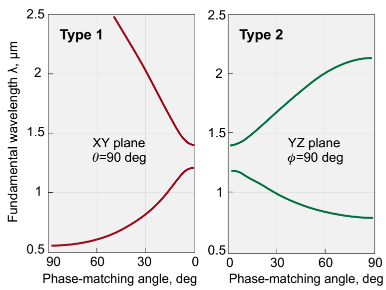
- wide transparency region
- broad Type 1 and Type 2 non-critical phase-matching (NCPM) range
- small walk-off angle
- high damage threshold
- wide acceptance angle
- high optical homogeneity

LBO is well suited for various nonlinear optical applications:

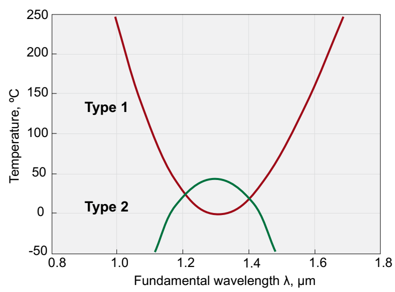
- frequency doubling and tripling of high peak power pulsed Nd doped, Ti:Sapphire and Dye lasers
- optical parametric oscillators (OPO) of both Type 1 and Type 2 phase-matching
- non-critical phase-matching for frequency conversion of CW and quasi-CW radiation.

EKSMA OPTICS OFFERS

- crystals length up to 50 mm and aperture up to 40 × 40 mm
- thin crystals down to 10 µm thickness
- AR, BBAR, P-coating
- different mounting and repolishing services
- accurate quality control
- attractive prices and fast delivery
- one month customer's satisfaction term.



SHG tuning curves of LBO



NCPM SHG temperature dependance of LBO

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)	$n_x^2 = 2.4542 + 0.0113 / (\lambda^2 - 0.0114) - 0.0139\,\lambda^2$		
	$n_y^2 = 2.5390 + 0.0128 / (\lambda^2 - 0.0119) - 0.0185\,\lambda^2$		
	$n_z^2 = 2.5865 + 0.0131 / (\lambda^2 - 0.0122) - 0.0186\,\lambda^2$		
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	4 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} = (1.09±0.09) pm/V
	d_{32} = (1.17±0.14) pm/V
Effective nonlinearity:	
XY plane	$d_{ooe} = d_{32} \cos\varphi$
YZ plane	$d_{oeo} = d_{eoo} = d_{31} \cos\theta$

Please contact EKSMA OPTICS
for special OEM and large volume pricing.

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

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

Please contact EKSMA OPTICS
for further information
or nonstandard specifications.

STANDARD CRYSTALS LIST

Code	Size, mm	θ, deg	φ, deg	Coating	Application
LBO-401	3x3x10	90	11.6	AR/AR @ 1064+532 nm	SHG @ 1064 nm
LBO-402	3x3x15	90	11.6	AR/AR @ 1064+532 nm	SHG @ 1064 nm
LBO-403	5x5x15	90	11.6	AR/AR @ 1064+532 nm	SHG @ 1064 nm
LBO-404	3x3x15	90	0	AR/AR @ 1064+532 nm	NCPM SHG @ 1064 nm, T = 149 °C
LBO-405	3x3x20	90	0	AR/AR @ 1064+532 nm	NCPM SHG @ 1064 nm, T = 149 °C
LBO-406	3x3x10	42.2	90	AR/AR @ 1064+532/355 nm	THG @ 1064 nm
LBO-407	3x3x15	42.2	90	AR/AR @ 1064+532/355 nm	THG @ 1064 nm
LBO-408	5x5x15	42.2	90	AR/AR @ 1064+532/355 nm	THG @ 1064 nm

RELATED PRODUCTS

LBO crystals for SHG of Yb:KGW/KYW laser frequency conversion. *See page 5.32*

Crystal Oven TC1
See page 2.27

149 °C temperature is required to achieve Non-Critical Phase Matching (NCPM) in LBO at type 1 SHG of 1064 nm application. **TC1 oven** is specially designed for this purpose (see technical specifications, p. 2.27).

Nonlinear Crystal Oven CH7
See page 2.30

CH7 oven is designed to keep the crystal at the elevated temperature (40–60 °C) for thermostabilisation of nonlinear crystal. The elevation of working temperature also extends hygroscopic crystals lifetime. LBO crystal is slightly hygroscopic and polished faces could become foggy after some time of exposition of crystal at ambient enviroment.

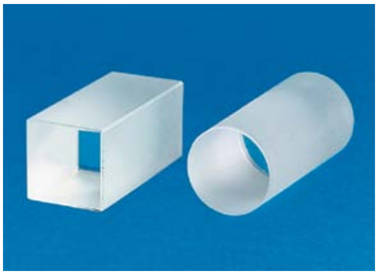
HOUSING ACCESSORIES

Ring Holders for Nonlinear Crystals
See page 2.24

Positioning Mount 840-0056
See page 2.25

Kinematic Positioning Mount 840-0193
See page 2.25

KDP • DKDP POTASSIUM DIDEUTERIUM PHOSPHATE



APPLICATIONS

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

ELECTRO-OPTICAL/Q-SWITCHING APPLICATION

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

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.

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

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

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

STANDARD CRYSTALS LIST

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

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

Please contact EKSMA OPTICS for special OEM and large volume pricing.

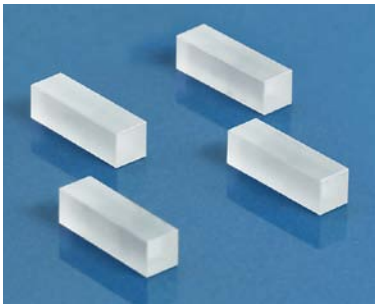
RELATED PRODUCTS

Nonlinear Crystal Oven CH3
See page 2.28

Nonlinear Crystal Oven CH4
See page 2.29

DKDP and KDP crystals are highly hygroscopic. CH3 and CH4 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



EKSMA OPTICS OFFERS

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

EKSMA OPTICS GUARANTEES

- Accurate quality control
- One month customer's satisfaction term
- Conformity of crystal specifications to highest standards
- Attractive prices
- Fast delivery.

KTP ($KTiOPO_4$) is a nonlinear optical crystal, which possesses excellent nonlinear, electrooptical and acousto-optical properties. A combination of high nonlinear coefficient, wide transparency range, and broad angular as well as thermal acceptances makes KTP very attractive for different nonlinear optical and wavequide applications.

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.

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.

Please contact EKSMA OPTICS for special OEM and large volume pricing.

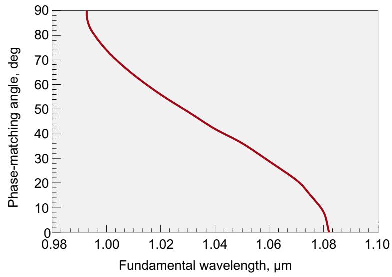


***Fig. 1.** Type 2 SHG in x-y plane*

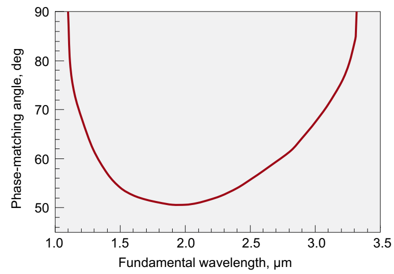


***Fig. 2.** Type 2 SHG in x-z plane*

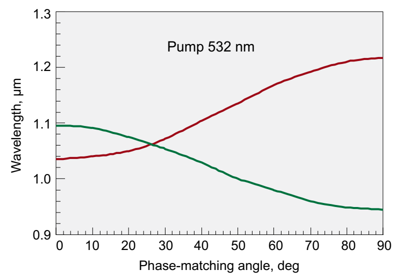


***Fig. 3.** OPO tuning curve in x-y plane*

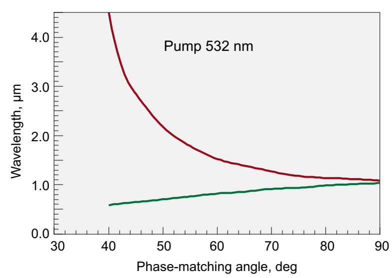


***Fig. 4.** OPO tuning curve in x-z plane*

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	Δθ = 55 mrad × cm
	Δφ = 10 mrad × cm
Thermal acceptance	ΔT = 22 K × cm
Spectral acceptance	Δv = 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}*

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

STANDARD CRYSTALS LIST

Code	Size, mm	θ	φ	Coating	Application
KTP-401	3x3x5	90	23.5	AR/AR @ 1064+532 nm	SHG @ 1064 nm
KTP-402	3x3x10	90	23.5	AR/AR @ 1064+532 nm	SHG @ 1064 nm
KTP-403	4x4x6	90	23.5	AR/AR @ 1064+532 nm	SHG @ 1064 nm
KTP-404	7x7x9	90	23.5	AR/AR @ 1064+532 nm	SHG @ 1064 nm

RELATED PRODUCTS

Crystal Oven TC1

See page 2.27

Ring Holders for Nonlinear Crystals

See page 2.24

Nonlinear Crystal Oven CH7

See page 2.30

Positioning Mount 840-0199 for Nonlinear Crystal Housing

See page 2.26

KTA POTASSIUM TITANYLE ARSENATE

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

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

EKSMA OPTICS OFFERS:

- KTA crystals size up to 15×15×30 mm
- AR and BBAR coatings for VIS-IR and mid IR ranges
- Standard and customized mounts and housings
- Technical consulting

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

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	$n_x^2 = 1.90713 + 1.23522 \times \lambda^2 / (\lambda^2 - 0.196922) - 0.01025 \times \lambda^2$
	$n_y^2 = 2.15912 + 1.00099 \times \lambda^2 / (\lambda^2 - 0.218442) - 0.01096 \times \lambda^2$
	$n_z^2 = 2.14768 + 1.29559 \times \lambda^2 / (\lambda^2 - 0.227192) - 0.01436 \times \lambda^2$
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}

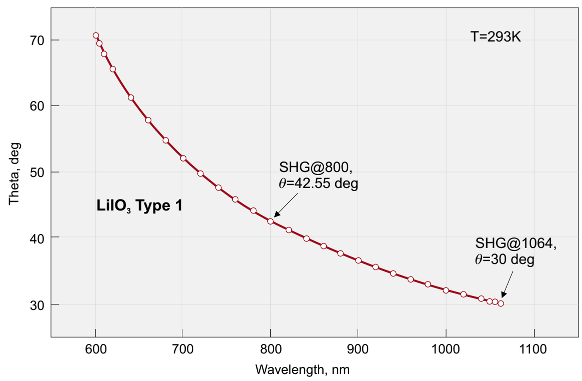
$LiIO_3$ LITHIUM IODATE

APPLICATIONS

- Harmonic generators
- Thin $LiIO_3$ for autocorrelation measurements

EKSMA OPTICS OFFERS:

- The mass production of $LiIO_3$ crystals
- Attractive discounts for OEM customers
- Different shapes (slabs, cylinders, Brewster ends) are available
- Standard open ring holders
- Recoating and repolishing service
- AR, BBAR and P - coatings according to customer's choice
- P-coatings optimised at pump wavelengths
- BBAR coatings for wavelength tuned Ti:Sapphire and other lasers.



$LiIO_3$ Second harmonic generation phasematching

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_{15}, pm/V	2.2 (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)	
$n_o^2 = 2.083648 + \frac{1.332068\,\lambda^2}{\lambda^2 - 0.035306} - 0.008525\,\lambda^2$	$n_e^2 = 1.673463 + \frac{1.245229\,\lambda^2}{\lambda^2 - 0.028224} - 0.003641\,\lambda^2$

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

HOUSING ACCESSORIES

Ring Holders for Nonlinear Crystals

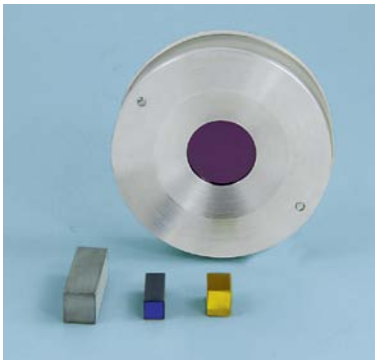
See page 2.24

Positioning Mount 840-0199 for Nonlinear Crystal Housing

See page 2.26

$ZnGeP_2$ • $AgGaSe_2$ $AgGaS_2$ • GaSe

INFRARED NONLINEAR CRYSTALS



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).

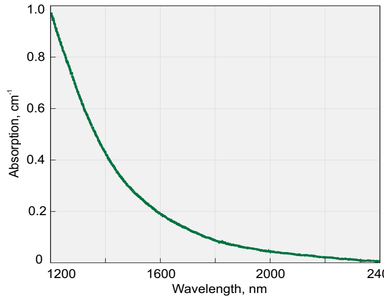
$ZnGeP_2$

$ZnGeP_2$ (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:

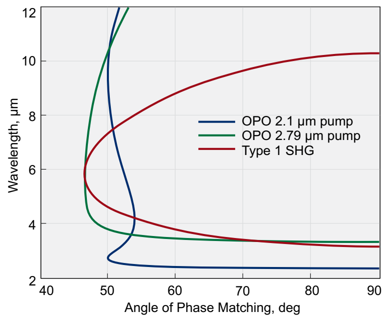
- up-conversion of CO_2 and CO laser radiation to near IR range via harmonics generation and mixing processes;
- efficient SHG of pulsed CO, CO_2 and chemical DF-laser;
- efficient down conversion of Holmium, Thulium and Erbium and laser wavelengths to mid infrared wavelength ranges by OPO process.

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.

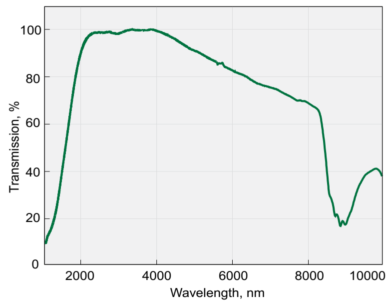
Typical absorption coefficient is <0.03 cm^{-1} at 2.5 - 8.2 µm range.



Absorption spectra of $ZnGeP_2$ crystal near 2 µm



Type 1 OPO and SHG tuning curves in $ZnGeP_2$



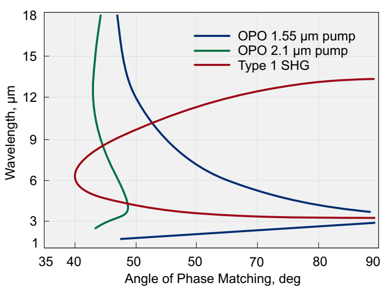
Transmission spectra of 15 mm long AR coated $ZnGeP_2$ crystal for OPO @ 2.1 µm

TYPE 1 $ZnGeP_2$ CRYSTALS for OPO at 3.5-5 µm range pumped at ~2.1 µm

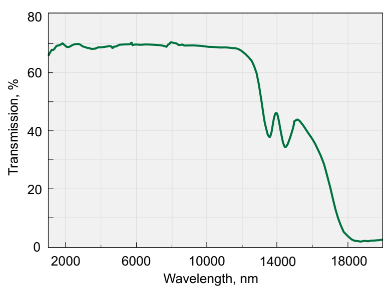
Catalogue number	Size, mm	θ, deg	φ, deg	Coating	Application
ZGP-401	7×5×15	54	0	AR @ 2.1 µm + BBAR @ 3.5-5 µm	OPO@2.1 → 3.5-5 µm
ZGP-402	7×5×20	54	0	AR @ 2.1 µm + BBAR @ 3.5-5 µm	OPO@2.1 → 3.5-5 µm
ZGP-403	7×5×25	54	0	AR @ 2.1 µm + BBAR @ 3.5-5 µm	OPO@2.1 → 3.5-5 µm

$AgGaSe_2$

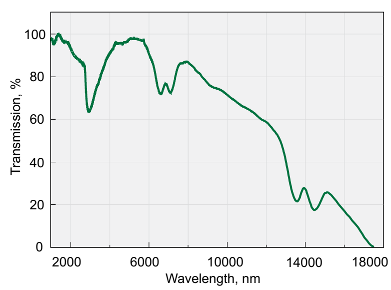
$AgGaSe_2$ has band edges at 0.73 and 18 µm. Its useful transmission range of 0.9–16 µm and wide phase matching capability provide excellent potential for OPO applications when pumped by a variety of currently available lasers. Tuning from 2.5–12 µm has been obtained when pumping by Ho:YLF laser at 2.05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



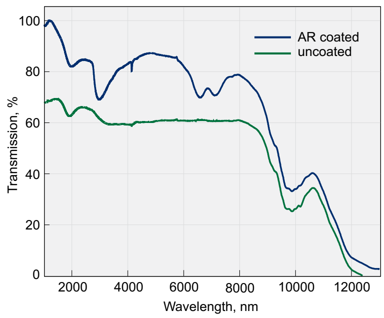
Transmission spectra of 18 mm long uncoated $AgGaSe_2$ crystal



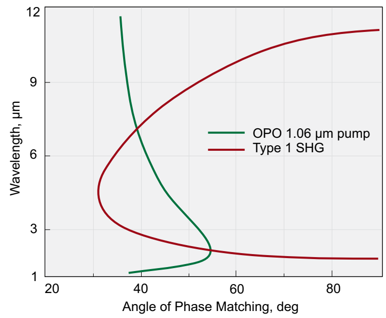
Transmission spectra of 25 mm long AR coated $AgGaSe_2$ crystal

$AgGaS_2$

$AgGaS_2$ 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 counter-measure 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 $AgGaS_2$

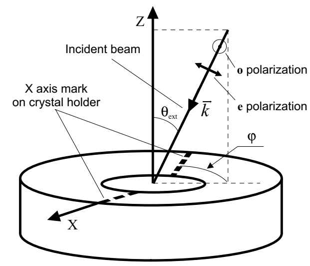
LIST OF STANDARD $AgGaS_2$ CRYSTALS

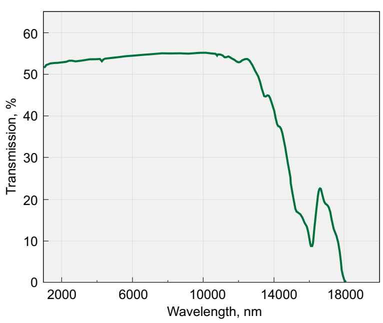
Code	Size, mm	θ, deg	φ, deg	Coating	Application
AGS-401H	5×5×1	39	45	BBAR/BBAR @ 1.1-2.6 / 2.6-11 µm	OPO @ 1.2-2.4 µm -> 2.4-11 µm
AGS-402H	6×6×2	50	0	BBAR/BBAR @ 1.1-2.6 / 2.6-11 µm	OPO @ 1.2-2.4 µm -> 2.4-11 µm

Crystals are mounted into open ring holders (see page 2.24).

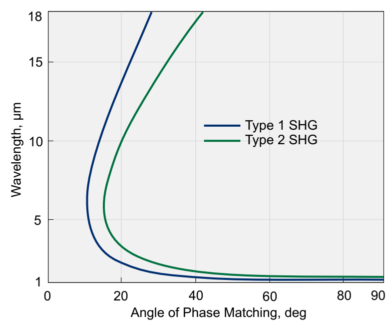
GaSe

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.

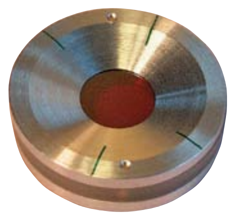




Transmission spectra of 17 mm long uncoated GaSe crystal



Type 1 and Type 2 SHG tuning curves in GaSe



Cleaved GaSe crystal glued into special ring holder

GaSe, Z-CUT

Catalogue number	Clear aperture, mm	Thickness, µm
GaSe-30	Ø7	30
GaSe-100	Ø7	100
GaSe-1000	Ø7	1000

RELATED PRODUCTS

Ring Holders for Nonlinear Crystals

See page 2.24

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	5.465	5.9901	5.757	3.742
	c	10.771	10.8823	10.305	15.918
Density, g/cm^3		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	3.2324	2.7005	2.4508	2.9082
	n_e	3.2786	2.6759	2.3966	2.5676
5.3 µm	n_o	3.1141	2.6140	2.3954	2.8340
	n_e	3.1524	2.5823	2.3421	2.4599
10.6 µm	n_o	3.0725	2.5915	2.3466	2.8158
	n_e	3.1119	2.5585	2.2924	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/cm²	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

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Free standing crystals

The crystals of thickness down to 100 µm can be 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	5×5 mm	20×20 mm	0.1 mm
LBO	5×5 mm	30×30 mm	0.1 mm
KDP	4×4 mm	100×100 mm	0.1 mm*
$LiIO_3$	4×4 mm	50×50 mm	0.1 mm*
$AgGaS_2$	5×5 mm	15×15 mm	0.1 mm
GaSe	Ø5 mm	Ø7 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	10×10 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 5.25; 5.32*

Ring Holders for Nonlinear Crystals
See page 2.24

Positioning Mount 840-0199 for Nonlinear Crystal Housing
See page 2.26