KTP

Potassium Titanyl Phosphate (**$KTiOPO_4$, KTP**) is the most commonly used in both commercial and military lasers, including laboratory and medical systems, range-finders, lidars, industry systems, and optical communication.

KTP is a positive biaxial crystal, with the principal axes X, Y, and Z ($n_z>n_y>n_x$) parallel to the crystallographic axes a, b, and c, respectively.

To overcome the gray track or photorefractive breakdown problem for KTP commonly used in practices, AOTK has developed one improved technique to grow Super-KTP, which has up to 1.3-1.5 times higher gray track resistance comparing with common flux grown KTP, for high power density laser systems applications. For more information, please feel free to contact AOTK.

AOTK's KTP advanced properties

- Large nonlinear optical coefficients
- Broad temperature and spectral bandwidth
- Wide angular bandwidth and small walk-off angle
- High electro-optic coefficient and low dielectric constant
- Large figure of merit for an optical waveguide modulator
- Non-hygroscopic, chemically and mechanically stable

Typical applications of KTP

- Frequency doubling (SHG) of Nd-doped lasers for green/red output
- Frequency mixing (SFM) of Nd laser and diode laser for blue output
- Parametric sources (OPG, OPA and OPO) for 600 nm-4500 nm tunable output
- E-O modulators, optical switches, directional couplers
- Optical waveguides for integrated NLO and E-O devices

Basic Properties

1. Structural and Physical Properties

Crystal Structure	Orthorhombic, point group mm2
Lattice Parameters	a = 6.404Å, b = 10.616Å, c = 12.814Å, Z = 8
Density	3.01 g/cm³
Mohs Hardness	≈ 5
Melting Point	~1172°C
Transition Temperature	936°C
Specific Heat	0.1643 cal/g°C
Thermal Conductivity	0.13 W/cm/°K
Electrical Conductivity	$3.5x10^{-8}$s/cm (c-axis, 22°C, 1KHz)
Hygroscopic Susceptibility	No
Dielectric Constant	ε_{eff} = 13.0, ε_{11} = 11.6, ε_{22} = 11.0, ε_{33} = 15.4
Color	Colorless

2. Linear Optical Properties

Transparency Region	350 - 4500 nm
Refractive Indexes at 1064 nm at 532 nm	 n_x = 1.7377, n_y = 1.7453, n_z = 1.8297 n_x = 1.7780, n_y = 1.7886, n_z = 1.8887

Sellmeier Equations (λ in μm)	$n_x^2 = 3.0065+0.03901/(\lambda^2-0.04251)-0.01327\lambda^2$ $n_y^2 = 3.0333+0.04154/(\lambda^2-0.04547)-0.01408\lambda^2$ $n_z^2 = 3.3134+0.05694/(\lambda^2-0.05658)-0.01682\lambda^2$
Therm-Optic Coefficients	$dn_x/dT = 1.1 \times 10^{-5}/°C$ $dn_y/dT = 1.3 \times 10^{-5}/°C$ $dn_z/dT = 1.6 \times 10^{-5}/°C$

3. NonLinear Optical Properties

Phase Matching SHG Wavelength	497 - 1800nm	
Nonlinear Coefficients	d_{31} = 6.5 pm/v d_{32} = 5.0 pm/v d_{33} = 13.7pm/v d_{24} = 7.6 pm/v d_{15} = 6.1 pm/v	
Effective Nonlinearity Expressions	$d_{eff}(II) \approx (d_{24} - d_{15})\sin2\phi\sin2\theta - (d_{15}\sin^2\phi + d_{24}\cos^2\phi)\sin\theta$	
For type II SHG of a Nd:YAG Laser at 1064nm	PM angle: $\theta = 90°$, $\phi = 23.5°$ Effective SHG coefficient: $d_{eff} \approx$ 8.3xd36(KDP) Angular acceptance: 20 mrad-cm Temperature acceptance: 25°C-cm Spectral acceptance: 5.6 Å -cm Walk-off angle: 4.5 mrad (0.26°)	
Electro-Optic Coefficients	Low frequency (pm/v)	High frequency (pm/v)
r_{13}	9.5	8.8
r_{23}	15.7	13.8
r_{33}	36.3	35.0
r_{51}	7.3	6.9
r_{42}	9.3	8.8
Optical Damage Threshold	> 450MW/cm², (@ 1064nm, 10ns, 10Hz)	

Main Applications

I. SHG and SFG of Nd:Lasers

KTP exhibits the superior nonlinear and electroptic properties. A combination of high nonlinear coefficient, wide transparency range, and broad angular as well as thermal acceptances makes KTP very attractive for intracavity and extracavity frequency doubler of Nd:YAG laser and other Nd-doped laser applications. The major NLO properties of KTP for frequency-doubling of Nd:YAG or Nd:YVO_4 lasers are listed as following table.

PM Angle	$\theta = 90°$, $\phi = 23.5°$; where q and f are polar angles referring to Z and X axis
Effective SHG Coefficient	$d_{eff} \approx$ 8.3xd36(KDP)
Angular Acceptance	20 mrad-cm
Temperature Acceptance	25°C-cm
Spectral Acceptance	5.6 Å -cm
Walk-off Angle	4.5 mrad (0.26°)

KTP is also being applied successfully for intracavity mixing of 808 nm diode and 1064 nm Nd:YAG laser to generate blue light and intracavity SHG of Nd:YAG or Nd:YAP lasers at 1300 nm to produce red light. With the development of diode-pumped Nd:lasers, KTP play more and more important role in the construction of the compact visible solid-state lasers. There are some typical results listed as follows:

- 20W green output was generated from CW Nd: YAG laser with intracavity KTP.
- More than 80% conversion efficiency and 700mJ green laser were obtained with a 900mJ injection-seeded Q-switch Nd:YAG laser with extracavity KTP SHG.
- 3W TEM_{00} mode-locked green laser was generated by intracavity SHG in a 5.3W mode-locked diode-pumped Nd:YAG laser.

- More than 600mW TEM_{00} green lasers are obtained from diode-pumped Nd:YAG and Nd:YVO4 lasers.
- 2.8mW green light was obtained from 50mW LD pumped intracavity Nd: YVO4 mini- lasers with a 8.5mm long cavity.
- KTP also exhibits its powerful applications for SHG and SFG laser with wavelength 1000-3400 nm.

Fig.1 shows Type II SHG phase-matching angle of KTP in X-Y plane. In X-Y plane the slope $\partial(\Delta k)/\partial\theta$ is small. It corresponds to quasi-angular noncritical phase matching, which ensures the double advantage of a small walk off and a large acceptance angle. 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 the 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. Fig.2 shows Type II SHG phase-matching angle of KTP in X-Z plane (1.1- 3.4 μm). KTP is seldom used to be phase-matched for SHG of 1.0- 3.45 μm in practices by cut in Y-Z plane, due to its very low non-linear coefficients.

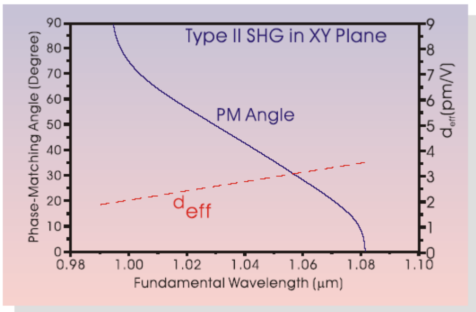

Fig. 1. Type II KTP SHG in X-Y Plane

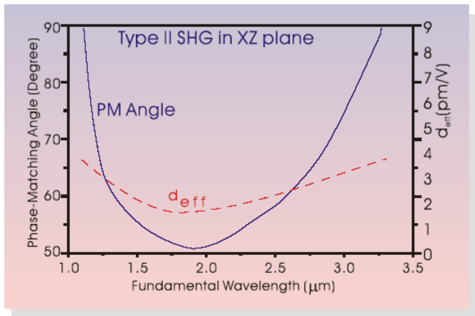

Fig. 2. Type II KTP SHG in X-Z Plane

II. OPG, OPA and OPO

As a lasing material for OPG, OPA or OPO , KTP can most usefully be pumped by the fundamental and second harmonics of a Nd:lasers, or any other source with intermediate wavelength, such as a Dye laser (near 600 nm) and Ti:Sapphire laser (near 700-1000 nm), in parametric sources for tunable output from visible (600 nm) to mid-IR (4500 nm). KTP's OPO results in stable, continuous outputs of fs pulse of 10^8 Hz repetition rate and miliwatt average power levels in both signal and idler output. KTP's OPO pumped by a 1064 nm Nd:laser has generated more than 66% conversion efficiency for degenerately converting range 1064-2120 nm. Fig.3 & Fig. 4 show KTP OPO pumped by 532 nm & 1064 nm tuning curve in XZ Plane respectively.

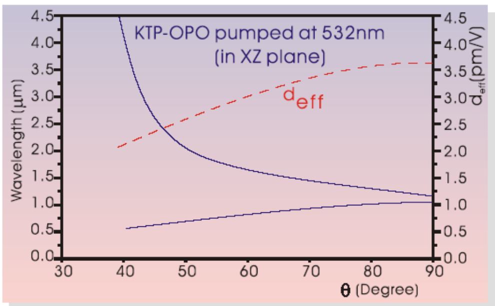

Fig.3 KTP OPO Pumped by 532 nm
Tuning Curves in X-Z Plane

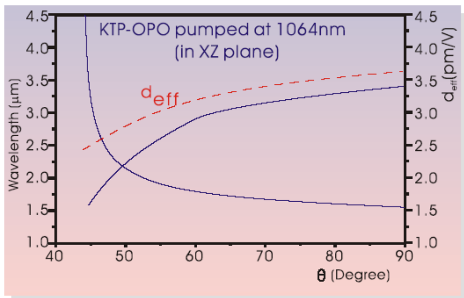

Fig.4 KTP OPO Pumped by 1064 nm
Tuning Curves in X-Z Plane

The new and effective application is the non-critical phase-matched (NCPM) KTP OPO/OPA pumped by the tunable lasers (as shown in Fig.5). The output can cover wavelength range from 1040 nm to 1450 mm (signal) and from 2150 nm to 3200 nm (idler), by fixed the NCPM KTP crystal fixed in X-axis, and tunes pumping wavelength (700 nm to 1000 nm). Due to the favorable NLO properties of NCPM KTP, as high as 45% conversion efficiency was obtained with narrow output bandwidth and good beam quality.

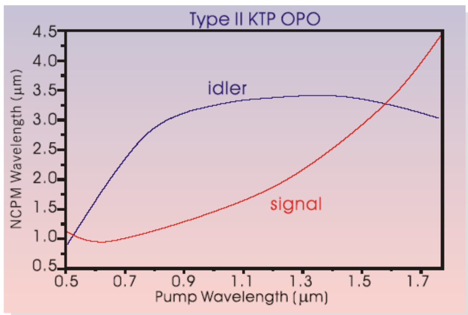

Fig.5 Type II KTP NCPM OPO

III. Quasi-Phase-Matched Waveguide

On low optical absorption and high damage threshold, the low optical loss waveguide fabricated by applying relatively simple ion-exchange process on KTP substrate, has created novel applications of integrated optics. Following table shows the comparison of KTP with other optical waveguide materials.

Recently, Type II SHG conversion efficiency of above 20%/W/cm² was obtained by balanced phase matching, in which the phase mismatch from one was balanced against a phase mismatch of opposite sign from a second section. Furthermore, segmented KTP waveguides have been applied to type I quasi-phase-matchable SHG of 760-960 nm for tunable Ti:Sapphire laser and directly doubled diode laser for 400-430 nm output. Conversion efficiency in excess of 100%/W/cm² have been obtained.

As large as 35x35x1 mm KTP with Z-cut or both surfaces polished for waveguide applications can be provided by AOTK. Other sizes of course available upon request.

Electro-Optic Waveguide Materials

Materials	$n^3\gamma/\varepsilon_{eff}$(pm/V)	g (pm/V)	ε_{eff} $(\varepsilon_{11}\varepsilon_{33})^{1/2}$	n
KTP	17.3	35	13	1.86
$KNbO_3$	9.2	25	30	2.17
$LiNbO_3$	8.3	29	37	2.20
$Ba_2NaNb_5O_{15}$	7.1	56	86	2.22
SBN(25-75)	5.1-0.14	56-1340	119-3400	2.22
GaAS	4.0	1.2	14	3.60
$BaTiO_3$	1.0	28	373	2.36

IV. E-O Devices

KTP's unique NLO features and E-O and dielectric properties make it extremely useful to various E-O devices. Table gives the comparison of KTP with those commonly used E-O modulator materials.

Electro-Optic Modulator Materials

			Phase			Amplitude		
Materials	ε	n	r pm/v	K 10^{-6}/°C	n^7r^2/ε (pm/v)²	r pm/v	K 10^{-6}/°C	n^7r^2/ε (pm/v)²
KTP	15.42	1.80	35.0	31	6130	27.0	11.7	3650
$LiNbO_3$	27.9	2.20	28.8	82	7410	20.1	42	3500
KD*P	48.0	1.47	24.0	9	178	24.0	8	178
$LiIO_3$	5.9	1.74	6.4	24	335	1.2	15	124

When these properties are combined with wide optical bandwidth (>15GHz), low loss, high damage threshold, thermal and mechanical stability, KTP can be expected to replace a considerable volume of $LiNbO_3$ crystals as E-O modulators, especially for mode-locking diode laser pumped Nd:YAG and Nd:YLF lasers as well as Ti:Sapphire and Cr:LiSrAlF$_6$ laser.

Standard Specifications

Dimensional Tolerance	(W ± 0.1mm) x (H ± 0.1mm) x (L +0.2/-0.1 mm)
Wavefront Distortion	< λ/8 @633 nm
Angle Tolerance	Δθ < ± 0.2°, Δφ < ± 0.2°
Flatness	λ/10 @633 nm
Surface Quality	10/5 Scratch/Dig per MIL-O-13830A
Parallelism	< 10 arc seconds
Perpendicularity	< 5 arc minutes
Clear Aperture	> 90% central area
AR Coating	R < 0.1% @1064nm, R < 0.3% @532nm per surface
Quality Warranty Period	one year under proper use

Standard Products

Part No.	Dimension	Application	Coating	Type
KTPS203	2x2x3mm	SHG@1064nm	AR/HR coating	II
KTPS205	2x2x5mm	SHG@1064nm	DBAR coating	II
KTPS305	3x3x5mm	SHG@1064nm	DBAR-coating	II
KTPS310	3x3x10mm	SHG@1064nm	DBAR-coating	II
KTPS705	7x7x5mm	SHG@1064nm	DBAR-coating	II
KTPS805	8x8x5mm	SHG@1064nm	DBAR-coating	II
KTPS907	9x9x7mm	SHG@1064nm	DBAR-coating	II
KTPO720	7x7x20mm	OPO for 1064nm pumped, 1570nm output	AR coating	II

- DBAR Coating: AR@1064nm&532nm;   HR Coating: HR@1064nm&HT@532nm;   AR coatings:AR@1064nm&1570nm

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