KTP - Potassium Titanyl Phosphate ($KTiOPO_4$)

Introduction

Potassium Titanyl Phosphate ($KTiOPO_4$ or KTP) is widely used in both commercial and military lasers including laboratory and medical system, range-finders, LiDAR, optical communication and industrial systems.

CASTECH's KTP is featured by

- Large nonlinear optical coefficient
- Wide angular bandwidth and small walk-off angle
- Broad temperature and spectral bandwidth
- High electro-optic coefficient and low dielectric constant
- Large figure of merit
- Nonhydroscopic, chemically and mechanically stable.

CASTECH offers

- Strict quality control
- Large crystal size up to 20 × 20 × 40 mm^3 and maximum length of 60 mm
- Quick delivery (15 working days for polished only, 20 working days for coated)
- Unbeatable price and quantity discount
- Technical support
- AR-coating, mounting and re-working service

Basic Properties

Table 1. Chemical and Structural Properties

Crystal Structure	Orthorhombic, Space group $Pna2_1$, Point group mm2
Lattice Parameter	a = 6.404 Å, b = 10.616 Å, c = 12.814 Å, Z = 8
Melting Point	About 1172 °C
Mohs Hardness	5 Mohs
Density	3.01 g/cm^3
Thermal Conductivity	13 W/m/K
Thermal Expansion Coefficients	$\alpha_x = 11 \times 10^{-6}$ /°C, $\alpha_y = 9 \times 10^{-6}$ /°C, $\alpha_z = 0.6 \times 10^{-6}$ /°C

Table 2. Optical and Nonlinear Optical Properties

Transparency Range		350-4500 nm	
SHG Phase Matchable Range		497-1800 nm (Type II)	
Therm-optic Coefficient (λ in μm)		$dn_x/dT = 1.1 \times 10^{-5}$ /°C $dn_y/dT = 1.3 \times 10^{-5}$ /°C $dn_z/dT = 1.6 \times 10^{-5}$ /°C	
Absorption Coefficients		<0.1% /cm at 1064 nm, <1% /cm at 532 nm	
For Type II SHG of a Nd:YAG laser at 1064 nm	Temperature Acceptance	24 °C·cm	
	Spectral Acceptance	0.56 nm·cm	
	Angular Acceptance	14.2 mrad·cm (Φ); 55.3mrad·cm (θ)	
	Walk-off Angle	0.55 °	
NLO Coefficients		$d_{eff}(II) \approx (d_{24} - d_{15}) \sin 2\Phi \sin 2\theta - (d_{15} \sin^2\Phi + d_{24} \cos^2\Phi) \sin\theta$	
Non-vanished NLO Susceptibilities		d_{31} = 6.5 pm/V d_{32} = 5 pm/V d_{33} = 13.7 pm/V	d_{24} = 7.6 pm/V d_{15} = 6.1 pm/V
Sellmeier Equations (λ in μm)		$n_x^2 = 3.0065 + 0.03901 / (\lambda^2 - 0.04251) - 0.01327 \lambda^2$ $n_y^2 = 3.0333 + 0.04154 / (\lambda^2 - 0.04547) - 0.01408 \lambda^2$ $n_z^2 = 3.3134 + 0.05694 / (\lambda^2 - 0.05658) - 0.01682 \lambda^2$	
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
Dielectric Constant		$\varepsilon_{eff} = 13$	

Applications for SHG and SFG of Nd: Lasers

KTP is the most commonly used material for frequency doubling of Nd:YAG and other Nd-doped lasers, particularly when the power density is at a low or medium level. Up to now, Nd:lasers that use KTP for intra-cavity and extra-cavity frequency doubling have become a preferred pumping sources for visible Dye lasers and tunable Ti:sapphire lasers as well as their amplifiers. They are also used as green sources for many research and industry applications.

- Close to 80% conversion efficiency and 700 mJ green laser were obtained with a 900 mJ injection-seeded Q-switch Nd:YAG lasers by using extra-cavity KTP.
- 8 W green laser was generated from a 15 W LD pumped Nd:YVO_4 with intra-cavity KTP.

KTP is also being used for intracavity mixing of 0.81 μm diode and 1.064 μm Nd:YAG laser to generate blue light and intracavity SHG of Nd:YAG or Nd:YAP lasers at 1.3 μm to produce red light.

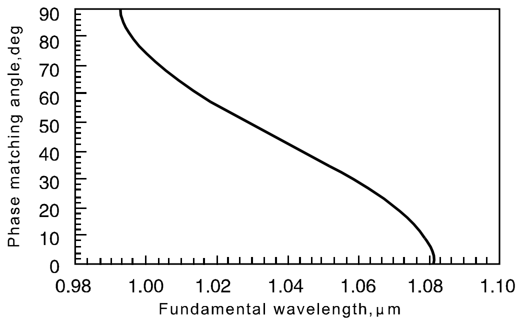

Fig. 1 Type II KTP SHG in XY Plane

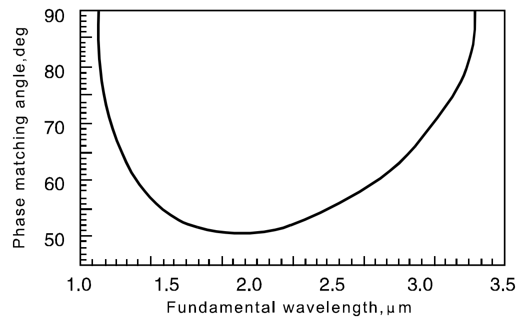

Fig.2 Type II SHG in XZ Plane

Applications for OPG, OPA and OPO

As an efficient OPO crystal pumped by a Nd:laser and its second harmonics, KTP plays an important role for parametric sources for tunable outputs from visible (600 nm) to mid-IR (4500 nm), as shown in Fig. 3 and Fig .4.

Generally, KTP's OPOs provide stable and continuous pulse outputs (signal and idler) in fs, with 10^8 Hz repetition rate and a miniwatt average power level. A KTP's OPO that are pumped by a 1064 nm Nd:YAG laser has generated as high as above 66% efficiency for degenerately converting to 2120 nm.

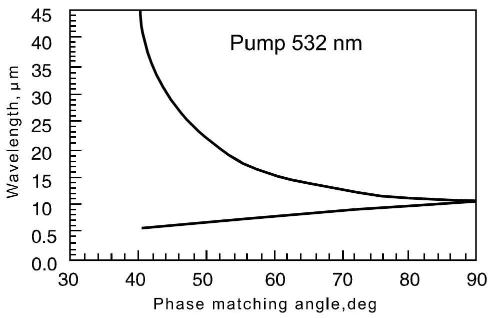

Fig.3 OPO pumped at 532 in X-Z plane

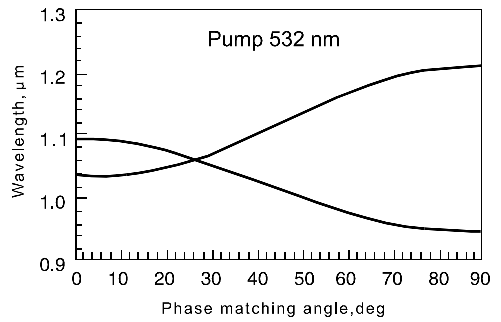

Fig.4 OPO pumped at 532 in X-Y plane

The novel developed application is the non-critical phase matched (NCPM) KTP's OPO/OPA. As shown in Fig.5, for pumping wavelength range from 0.7 μm to 1 μm, the output can cover from 1.04 μm to 1.45 μm (signal) and from 2.15 μm to 3.2 μm (idler). More than 45% conversion efficiency was obtained with narrow output bandwidth and good beam quality.

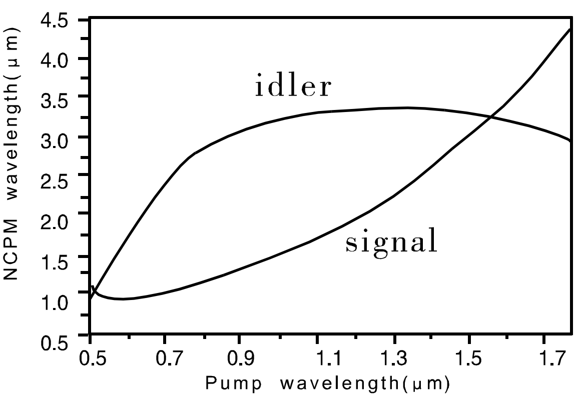

Fig.5 Type II NCPM OPO

Applications for E-O Devices

In addition to unique features, KTP also has promising E-O and dielectric properties that are comparable to $LiNbO_3$. These excellent properties make KTP extremely useful to various E-O devices. Table 3 is a comparison of KTP with other E-O modulator materials commonly used:

Table 3. Electro-Optic Modulator Materials

Materials	ε	N	Phase			Amplitude		
			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
$LiNbO_3$	27.90	2.20	8.8	82	7410	20.1	42.0	3500
KD*P	48.00	1.47	24.0	9	178	24.0	8.0	178
$LiIO_3$	5.90	1.74	6.4	24	335	1.2	15.0	124

From Table 3, clearly, KTP is expected to replace $LiNbO_3$ crystal in the considerable volume application of E-O modulators, when other merits of KTP are combined into account, such as high damage threshold, wide optical bandwidth (>15 GHZ), thermal and mechanical stability, and low loss, etc.

Applications for Optical Waveguides

Based on the ion-exchange process on KTP substrate, low loss optical waveguides developed for KTP have created novel applications in integrated optics. Table 4 gives a comparison of KTP with other optical waveguide materials. Recently, a type II SHG conversion efficiency of 20% /W/cm^2 was achieved by the balanced phase matching, in which the phase mismatch from one section was balanced against a phase mismatch in the opposite sign from the second. Furthermore, segmented KTP waveguide have been applied to the type I quasi-phase-matchable SHG of a tunable Ti:Sapphire laser in the range of 760-960 mm, and directly doubled diode lasers for the 400-430 nm outputs.

Table 4. Electro-Optic Waveguide Materials

Materials	r (pm/V)	n	$\varepsilon_{eff}(\varepsilon_{11}\varepsilon_{33})^{1/2}$	n^3r/ε_{eff} (pm/V)
KTP	35	1.86	13	17.30
$LiNbO_3$	29	2.20	37	8.30
$KNbO_3$	25	2.17	30	9.20
BNN	56	2.22	86	7.10
BN	56-1340	2.22	119-3400	5.1-0.14
GaAs	1.2	3.60	14	4.00
$BaTiO_3$	28	2.36	373	1.00

KTP's Parameters

Table 5. Specifications

Dimension Tolerance	(W ± 0.1 mm) × (H ± 0.1 mm) × (L + 0.5/-0.1 mm) × (L≧2.5 mm) (W ± 0.1 mm) × (H ± 0.1 mm) × (L + 0.1/-0.1 mm) × (L＜2.5 mm)
Clear Aperture	Central 90% of the diameter
Internal Quality	No visible scattering paths or centers when inspected by a 50 mW green laser
Surface Quality (Scratch/Dig)	10/5 to MIL-PRF-13830B
Flatness	≦λ/8 @633 nm
Transmitted Wavefront Distortion	≦λ/8 @633 nm
Parallelism	20 arc sec
Perpendicularity	≦15 arc min
Angle Tolerance	≦0.25 °
Chamfer	≦0.2 mm × 45 °
Chip	≦0.1 mm
Damage Threshold	＞1 GW/cm^2 @1064 nm, 10 ns, 10 Hz (AR-coated) ＞0.3 GW/cm^2 @532 nm, 10 ns, 10 Hz (AR-coated)
Quality Warranty Period	One year under proper use.

AR-coatings

CASTECH provides the following AR-coatings:

- Dual Band AR-coating (DBAR) of KTP for SHG of 1064 nm; low reflectance (R<0.2% @1064 nm and R<0.5% @532 nm)
- High reflectivity coating: HR 1064 nm & HT 532 nm, R>99.8% @1064nm, T>90% @532 nm
- Broad Band AR-coating (BBAR) of KTP for OPO applications.
- High damage threshold (>300 MW/cm^2 at both wavelengths)
- Long durability
- Other coatings are available upon request.