

KTP - Potassium Titanyl Phosphate (KTiOPO₄)

Introduction

Potassium Titanyl Phosphate (KTiOPO₄ or KTP) is widely used in both commercial and scientific research 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
- Nonhygroscopic, chemically and mechanically stable.

CASTECH offers

- Strict quality control
- Large crystal size up to 20 × 20 × 40 mm³ 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	$\alpha_x = 11 \times 10^{-6}/^{\circ}\text{C}$, $\alpha_y = 9 \times 10^{-6}/^{\circ}\text{C}$, $\alpha_z = 0.6 \times 10^{-6}/^{\circ}\text{C}$

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)	$dn_x/dT = 1.1 \times 10^{-5}/^\circ\text{C}$ $dn_y/dT = 1.3 \times 10^{-5}/^\circ\text{C}$ $dn_z/dT = 1.6 \times 10^{-5}/^\circ\text{C}$	
Absorption Coefficients	$<0.1\% / \text{cm}$ at 1064 nm, $<1\% / \text{cm}$ at 532 nm	
For Type II SHG of a Nd:YAG laser at 1064 nm	Temperature Acceptance	24 $^\circ\text{C} \cdot \text{cm}$
	Spectral Acceptance	0.56 nm \cdot cm
	Angular Acceptance	14.2 mrad \cdot cm (Φ) ; 55.3mrad \cdot cm (θ)
	Walk-off Angle	0.55 $^\circ$
NLO Coefficients	$d_{\text{eff}}(\text{II}) \approx (d_{24} - d_{15}) \sin 2\Phi \sin 2\theta$ $- (d_{15} \sin^2\Phi + d_{24} \cos^2\Phi) \sin\theta$	
Non-vanished NLO Susceptibilities	$d_{31} = 6.5 \text{ pm/V}$ $d_{24} = 7.6 \text{ pm/V}$ $d_{32} = 5 \text{ pm/V}$ $d_{15} = 6.1 \text{ pm/V}$ $d_{33} = 13.7 \text{ pm/V}$	
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	$\epsilon_{\text{eff}} = 13$	

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:YVO₄ 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.

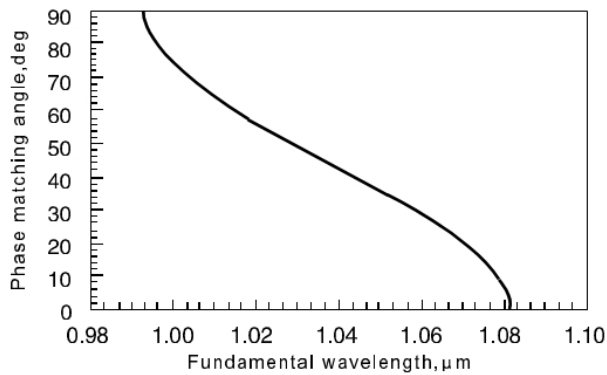


Fig. 1 Type II KTP SHG in XY Plane

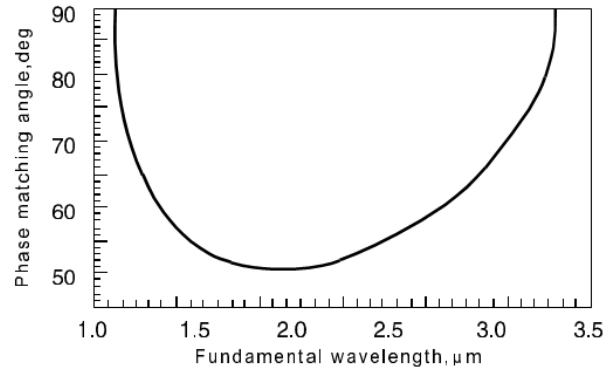


Fig.2 Type II SHG in XZ Plane

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.

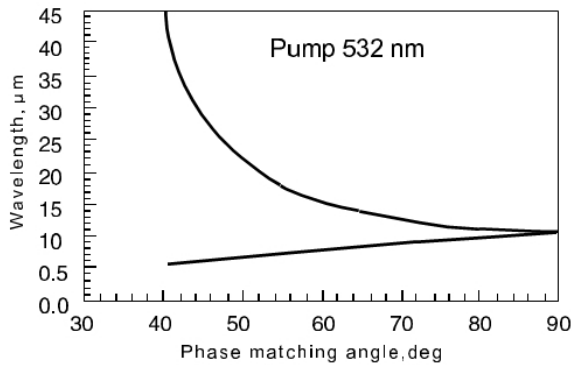


Fig.3 OPO pumped at 532 in X-Z plane

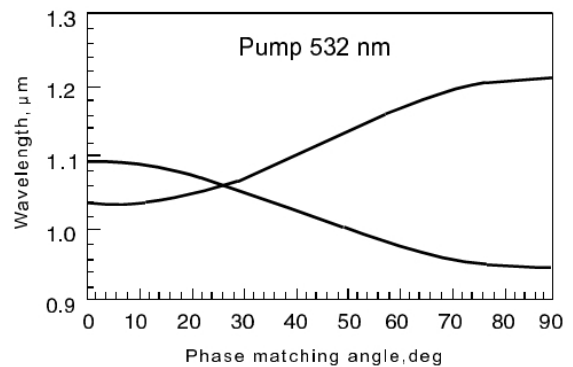


Fig.4 OPO pumped at 532 in X-Y plane

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 micrometers to 1 micrometers, the output can cover from 1.04 micrometers to 1.45 micrometers (signal) and from 2.15 micrometers to 3.2 micrometers (idler). More than 45% conversion efficiency was obtained with narrow output bandwidth and good beam quality.

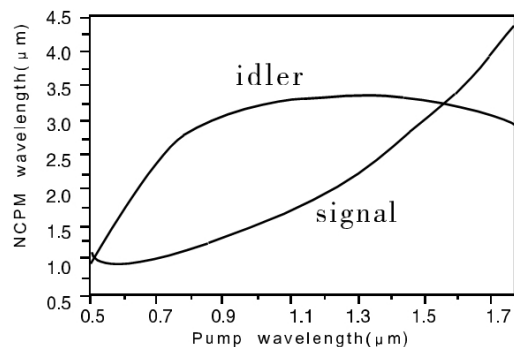


Fig.5 Type II NCPM OPO

NLO Crystals

Applications for E-O Devices

In addition to unique features, KTP also has promising E-O and dielectric properties that are comparable to LiNbO₃. 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)	$N^7 r^2 / \epsilon$ (pm/V) ²	r (pm/V)	K (10 ⁻⁶ /°C)	$n^7 r^2 / \epsilon$ (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 LiNbO₃ 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/cm² 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 nm, and directly doubled diode lasers for the 400-430 nm outputs.

Table 4. Electro-Optic Waveguide Materials

Materials	r (pm/V)	n	$\epsilon_{\text{eff}}(\epsilon_{11}\epsilon_{33})^{1/2}$	$n^3 r / \epsilon_{\text{eff}}$ (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	$(W \pm 0.1 \text{ mm}) \times (H \pm 0.1 \text{ mm}) \times (L + 0.5/-0.1 \text{ mm}) \times (L \geq 2.5 \text{ mm})$ $(W \pm 0.1 \text{ mm}) \times (H \pm 0.1 \text{ mm}) \times (L + 0.1/-0.1 \text{ mm}) \times (L < 2.5 \text{ mm})$
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	$\leq \lambda/8$ @633 nm
Transmitted Wavefront Distortion	$\leq \lambda/8$ @633 nm
Parallelism	20 arc sec
Perpendicularity	≤ 15 arc min
Angle Tolerance	$\leq 0.25^\circ$
Chamfer	$\leq 0.2 \text{ mm} \times 45^\circ$
Chip	$\leq 0.1 \text{ mm}$
Damage Threshold	$> 1 \text{ GW/cm}^2$ @1064 nm, 10 ns, 10 Hz (AR-coated) $> 0.3 \text{ GW/cm}^2$ @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 ($R < 0.2\%$ @ 1064nm 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 ($> 300 \text{ MW/cm}^2$ at both wavelengths)
- Long durability
- Other coatings are available upon request.