# 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 |
| 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) | | $dn_x/dT = 1.1\times10^{-5}$ /°C<br>$dn_y/dT = 1.3\times10^{-5}$ /°C<br>$dn_z/dT = 1.6\times10^{-5}$ /°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 | | $d_{eff}(II) \approx (d_{24} - d_{15}) \sin2\Phi \sin2\theta - (d_{15} \sin^2\Phi + d_{24} \cos^2\Phi) \sin\theta$ |
| Non-vanished NLO Susceptibilities | | $d_{31} = 6.5$ pm/V  $d_{24} = 7.6$ pm/V<br>$d_{32} = 5$ pm/V  $d_{15} = 6.1$ pm/V<br>$d_{33} = 13.7$ pm/V |
| Sellmeier Equations (λ in μm) | | $n_x^2 = 3.0065 + 0.03901 / (\lambda^2 - 0.04251) - 0.01327 \lambda^2$<br>$n_y^2 = 3.0333 + 0.04154 / (\lambda^2 - 0.04547) - 0.01408 \lambda^2$<br>$n_z^2 = 3.3134 + 0.05694 / (\lambda^2 - 0.05658) - 0.01682 \lambda^2$ |
| 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.

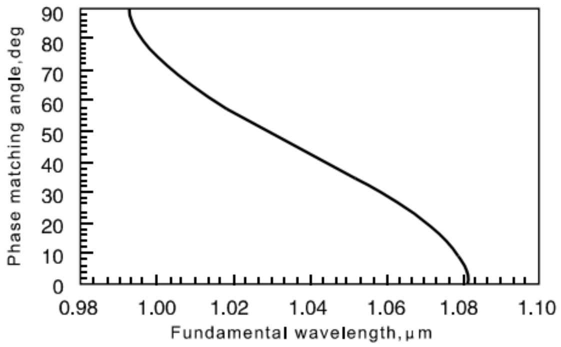


Fig. 1 Type II KTP SHG in XY Plane

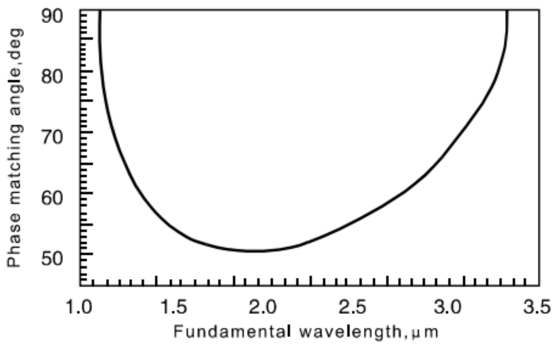


Fig.2 Type II SHG in XZ Plane

## 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.

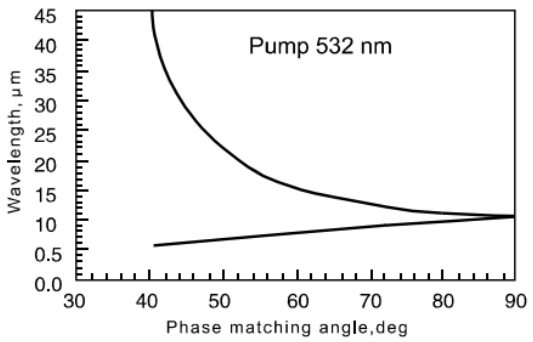


Fig.3 OPO pumped at 532 in X-Z plane

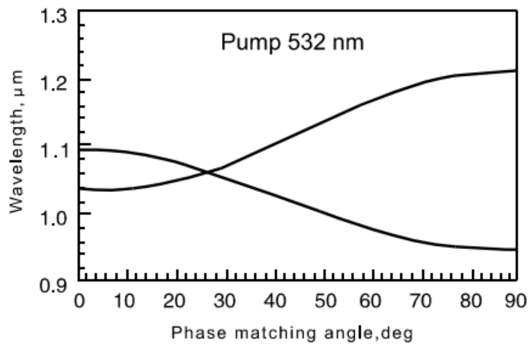


Fig.4 OPO pumped at 532 in X-Y plane

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.

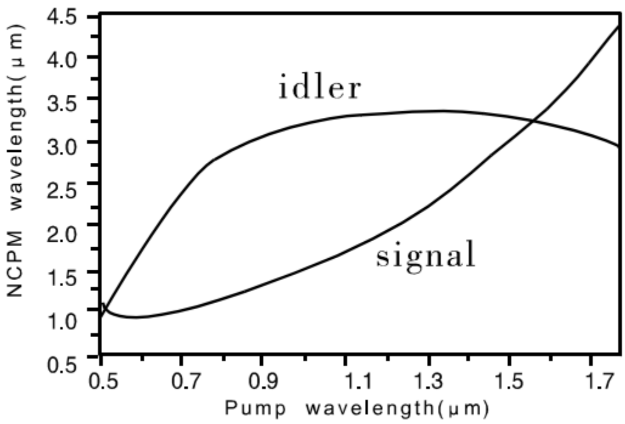


Fig.5 Type II NCPM OPO

# 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 1 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) | $N^7r^2/\varepsilon$ $(pm/V)^2$ | r (pm/V) | K ($10^{-6}$/°C) | $n^7r^2/\varepsilon$ $(pm/V)^2$ |
| 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 1, 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 2 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 | $\varepsilon_{eff}(\varepsilon_{11}\varepsilon_{33})^{1/2}$ | $n^3r/\varepsilon_{eff}$(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)<br>(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/cm² @1064 nm, 10 ns, 10 Hz (AR-coated)<br>＞0.3 GW/cm² @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/cm² at both wavelengths)
- Long durability
- Other coatings are available upon request.