Potassium Titanyl Phosphate($KTiOPO_4$, KTP)

Introduction

Potassium Titanyl Phosphate ($KTiOPO_4$ or KTP) is widely used in both commercial and military lasers including laboratory and medical systems, 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 20x20x40mm^3 and maximum length of 60mm;
- Quick delivery (2 weeks for polished only, 3 weeks for coated)
- Unbeatable price and quantity discount
- Technical support
- AR-coating, mounting and re-polishing service

Table 1. Chemical and Structural Properties

Crystal Structure	Orthorhombic, space group $Pna2_1$,point group mm2
Lattice Parameter	a=6.404Å, b=10.616Å, c=12.814Å, Z=8
Melting Point	About 1172°C
Mohs Hardness	5
Density	3.01 g/cm^3
Thermal Conductivity	13W/m/K
Thermal Expansion Coefficient	α_x=11x10^{-6}/^{0}C, α_y=9x10^{-6}/^{0}C, α_z=0.6x10^{-6}/^{0}C

Table 2. Optical and Nonlinear Optical Properties

Transparency Range	350-4500nm
SHG Phase Matchable Range	497-1800nm (Type II)
Therm-optic Coefficients ($/^0C$)	$dn_x/dT=1.1X10^{-5}$ $dn_y/dT=1.3X10^{-5}$ $dn_z/dT=1.6X10^{-5}$
Absorption Coefficients	<0.1%/cm at 1064nm <1%/cm at 532nm
For Type II SHG of a Nd:YAG laser at 1064nm	Temperature Acceptance: 24°C·cm Spectral Acceptance: 0.56nm·cm Angular Acceptance: 14.2mrad·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 d_{32}=5 pm/V d_{15}=6.1 pm/V d_{33}=13.7 pm/V
Sellmeier Equations (λin µm)	$n_x^2=3.0065+0.03901/(\lambda^2-0.04251)-0.01327\lambda^2$ $n_y^2=3.0333+0.04154/(\lambda^2-0.04547)-0.01408\lambda^2$ $n_z^2=3.0065+0.05694/(\lambda^2-0.05658)-0.01682\lambda^2$
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. To date, extra- and intra-cavity frequency doubled Nd:lasers using KTP have become a preferred pumping source for visible dye lasers and tunable Ti:Sapphire lasers as well as their amplifiers. They are also useful green sources for many research and industry applications.

- More than 80% conversion efficiency and 700mJ green laser were obtained with a 900mJ injection-seeded Q-switch Nd:YAG lasers by using extra-cavity KTP.
- 8W green laser was generated from a 15W LD pumped Nd:YVO_4 with intra-cavity KTP.
- 200mW green outputs are generated from 1W LD pumped Nd:YVO_4 lasers by using CASTECH's 2x2x5mm^3 KTP and 3x3x1mm^3 Nd:YVO_4.
- 2-5mw green outputs are generated from 180mw LD pumped Nd:YVO_4 and KTP glued crystals. For more details, please refer to P67.

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

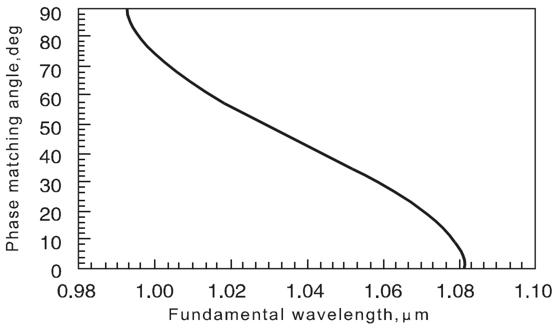

Fig. 1 Type II KTP SHG in XY Plane

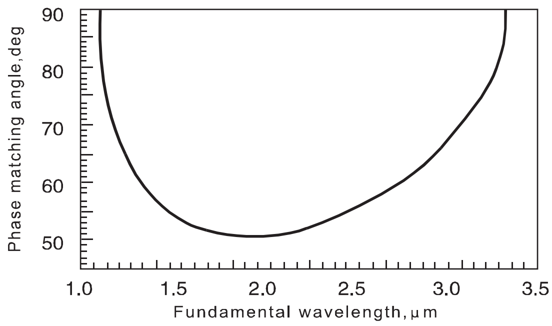

Fig. 2 Type II KTP SHG in XZ Plane

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 (600nm) to mid-IR (4500nm), 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 1064nm Nd:YAG laser has generated as high as above 66% efficiency for degenerately converting to 2120nm.

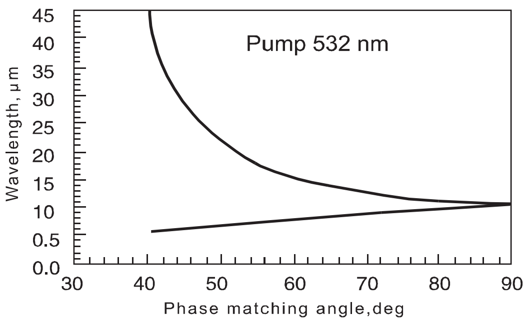

Fig. 3 OPO pumped at 532 in X-Z plane

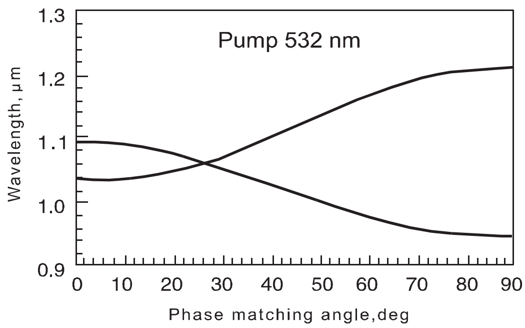

Fig. 4 OPO pumped at 532 in X-Y plane

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 0.7μm to 1μm, the output can cover from 1.04μm to 1.45μm (signal) and from 2.15μm to 3.2μm (idler). More than 45% conversion efficiency was obtained with narrow output bandwidth and good beam quality.

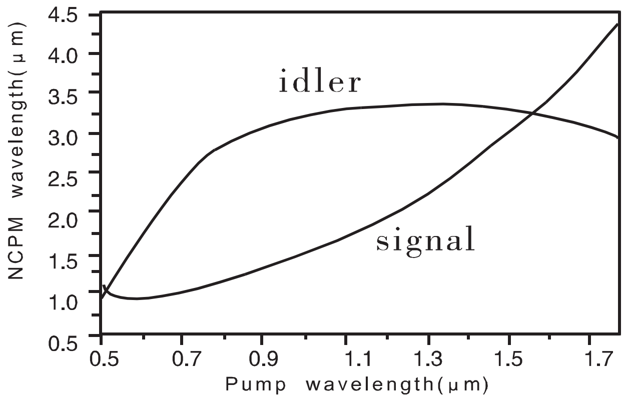

Fig. 5 Type II NCPM OPO

Applications for E-O Devices

In addition to unique NLO features, KTP also has promising E-O and dielectric properties that are comparable to $LiNbO_3$. These advantaged 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 1. Electro-Optic Modulator Materials

Material			Phase			Amplitude		
	ε	N	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
$LiNbO_3$	27.9	2.20	8.8	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

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 (>15GHZ), 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 waveguides have been applied to the type I quasi-phase-matchable SHG of a tunable Ti:Sapphire laser in the range of 760-960mm, and directly doubled diode lasers for the 400-430nm outputs.

Table 2. 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	17.3
$LiNbO_3$	29	2.20	37	8.3
$KNbO_3$	25	2.17	30	9.2
BNN	56	2.22	86	7.1
BN	56-1340	2.22	119-3400	5.1-0.14
GaAs	1.2	3.6	14	4.0
$BaTiO_3$	28	2.36	373	1.0

AR-coatings

CASTECH provides the following AR-coatings:

- Dual Band AR-coating (DBAR) of KTP for SHG of 1064nm.
  low reflectance (R<0.2% at 1064nm and R<0.5% at 532nm);
  high damage threshold (>300MW/cm2 at both wavelengths);
  long durability.

- Broad Band AR-coating (BBAR) of KTP for OPO applications.
- High reflectivity coating: HR1064nm&HT532nm, R>99.8%@1064nm, T>90%@532nm.
- Other coatings are available upon request.

CASTECH's Warranty on KTP Specifications

- Dimension tolerance: (W±0.1mm)x(H±0.1mm)x(L+0.5/-0.1mm) (L≥2.5mm)
  (W±0.1mm)x(H±0.1mm)x(L+0.1/-0.1mm) (L<2.5mm)
- Clear aperture: central 90% of the diameter
- No visible scattering paths or centers when inspected by a 50mW green laser
- Flatness: less than λ/8 @ 633nm
- Transmitting wavefront distortion: less than λ/8 @ 633nm
- Chamfer: ≤0.2mm x 45°
- Chip: ≤0.1mm
- Scratch/Dig code: better than 10/ 5 to MIL-PRF-13830B
- Parallelism: better than 20 arc seconds
- Perpendicularity: ≤5 arc minutes
- Angle tolerance: ≤0.25°
- Damage threshold[GW/cm^2]: >0.5 for 1064nm, TEM00, 10ns, 10HZ (AR-coated)
  >0.3 for 532nm, TEM00, 10ns, 10HZ (AR-coated)
- Quality Warranty Period: one year under proper use.