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PROPERTIES AND APPLICATIONS OF NONLINEAR BIAXIAL CRYSTAL POTASSIUM TITANYL PHOSPHATE

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ABSTRACT

Potassium titanyl phosphate ($KTiOPO_4$) or KTP is a nonlinear optical material which is commonly used for frequency doubling diode pumped solid-state lasers such as Nd:YAG and other neodymium-doped lasers. The material has a relatively high optical damage threshold (~15 J/cm²), a great optical nonlinearity and excellent thermal stability in theory. KTP is also attractive for various sum- and difference frequency and optical parametric applications over its entire transparency range from 0.35 to 4.5 um. The paper contains an analysis of nonlinear optical properties of **Potassium titanyl phosphate ($KTiOPO_4$ or KTP).**

KEYWORDS: Nonlinear Optics, KTP, Laser, Harmonic Generation.

Potassium Titanium Oxide Phosphate ($KTiOPO_4$), or KTP, is an efficient nonlinear optical crystal in the visible to infrared spectral region with relatively low cost. It has large nonlinear coefficient. The effective nonlinear optical coefficient of KTP d_{eff} at 1064nm is more than 1.5 times that of BBO. It's damage threshold is near 1 GW/cm^2 for 1 Hz 10 ns pulses at 1064nm. However, it is now limited to moderate to low power applications due to its gray-tracking problem. Recently gray-tracking-improved KTP (i-KTP) has been developed which has significantly raised the gray-tracking trigger power.

KTP is a efficient frequency converter and it's conversion efficiency for SHG of Nd: YAG laser is nearly 80%. It has large nonlinear optical coefficients (15 times that of KDP). It has Wide angular bandwidth and small walk-off angle. The crystal having Broad temperature and spectral bandwidth. Its thermal conductivity is very high (2 times that of BNN crystal). It is non hygroscopic crystals. It has minimum mismatch gradient and also have super polished optical surface. The crystal is mechanically very stable and its price is very low compare with BBO and LBO.

PROPERTIES OF KTP CRYSTAL

KTP is one of the best non-linear optical crystals and the best electro-optical crystals. It is widely used in various harmonic generations and OPOs. Details are given in **Table 1** and **Table 2.**

Table 1: Optical Properties

Transmitting Range:	350nm ~ 4500nm			
Refractive Indices:	@1064nm	n_x	n_y	n_z
		1.7400	1.7469	1.8304
	@532nm	1.7787	1.7924	1.8873
Sellmeier Equations (l in µm)	$N_x^2 = 2.10468 + 089342\lambda^2 / (\lambda^2 - 0.04438) - 0.01036 \lambda^2$			
	$N_y^2 = 2.14559 + 0.87629 \lambda^2 / (\lambda^2 - 0.0485) - 0.01173 \lambda^2$			
	$N_z^2 = 1.9446 + 1.3617 \lambda^2 / (\lambda^2 – 0.047) - 0.01491 \lambda^2$			
Absorption Coefficient:	a<1%/cm @1064nm and 532nm			
Thermo-optic coefficients	$dn_x/dT=1.1x10^{-5}/°C$ $dn_y/dT=1.3x10^{-5}/°C$ $dn_z/dT=1.6x10^{-5}/°C$			
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	
Damage Threshold @1064nm and @532nm	5 GW/cm^2 (10 ns); 10 GW/cm^2 (1.3 ns); 1 GW/cm^2 (10 ns);7 GW/cm^2 (250ps)			

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Nonlinear Properties				
Phase matching range	497nm – 3300 nm			
Nonlinear Optical Coefficients and Equation:	@1064nm	d_{31}=2.54pm/V d_{24}=3.64pm/V	d_{32}=4.35pm/V d_{15}=1.91pm/V	d_{33}=16.9pm/v
	$d_{eff}(II) \approx (d_{24} - d_{15})\sin 2\theta \sin 2\varphi - (d_{15}\sin^2\varphi + d_{24}\cos^2\theta)\sin\theta$			
Type-II SHG of 1064nm Laser				
Phase matching angle	$\theta=90^0$, $\varphi=23.2^0$			
Effective nonlinear optical coefficients	d_{eff} =8.3 x d_{36}(KDP)			
Angular acceptance	D_θ= 75 mrad D_φ= 18 mrad			
Temperature acceptance	25°C.cm			
Spectral acceptance	5.6 Åcm			
Walk-off angle	1 mrad			
Optical damage threshold	1.5-2.0MW/cm^2			

Table 2: Physical Properties

Crystal Structure:	Orthorhombic
Point Group	Mm2
Cell Parameters:	a=b=12.532Å, c=12.717Å, Z=7
Melting Point:	1172°C
Transition Point:	936°C
Mohs Hardness:	»5
Density:	2.945 g/cm^3
Color:	Colorless
Hygroscopic Susceptibility	No
Specific Heat:	0.1737 cal/g°C
Thermal Conductivity:	0.13 *Wc/m/°c*
Lattice parameters	Orthorhombic
Temperature of decomposition	Mm2
Cell Parameters:	a=b=12.532Å, c=12.717Å, Z=7
Melting Point:	1172°C
Transition Point:	936°C
Mohs Hardness:	»4.5
Density:	2.945 g/cm^3
Color:	Colorless
Hygroscopic Susceptibility	No
Specific Heat:	0.49 cal/g°C
Thermal Conductivity:	0.13 *Wc/m/°c*

NON-LINEAR OPTICAL APPLICATIONS

a. Applications for SHG and SFG of Nd: lasers

KTP is the most popular material for frequency doubling of Nd: YAG lasers and other Nd-doped lasers, particularly at the low or medium power density. So far, extra- and intra-cavity frequency doubled Nd: lasers using KTP have become a preferred green laser source for many R&D, medical, industrial and commercial applications. By using extracavity KTP SHG, over 80% conversion efficiency and 700mJ green laser are obtained with a 900mJ injection-seeded Q-switched Nd: YAG laser.

Applied to diode-pumped Nd: laser, KTP is a basic NLO crystal for the construction of compact visible solid state laser systems. Recent advances in intracavity-doubled Nd: YVO4 and Nd: YAG lasers have increased the demand for compact green lasers used in display, construction, optical disk and laser printer. Over 200mw TEM00 green outputs are available from LD pumped Nd: YVO4 and Nd: YAG lasers and 3W TEM00, mode-locked green laser was generated by intracavity SHG in a 5.3W mode-locked diode-laser pumped Nd:YAG laser. Moreover, 2.5mW green light is obtained from 50mW LD pumped and intracavity doubled Nd: YVO4 mini-lasers with a 9mm long cavity.

KTP is also a powerful crystal for SHG and SFG of laser with wavelength from about 1μm to 3.4μm. The SHG phase-matching angle and effective SHG coefficients (d_{eff}) of KTP in XY plane (0.9μm to 1.08μm) and XZ plane (1.1μm to 3.3μm) are shown as the figure 1 to figure 5. Although KTP cut in YZ plane can be phase-matched for SHG of 1μm to 3.45μm, it is seldom used in practices because of the low d_{eff}.

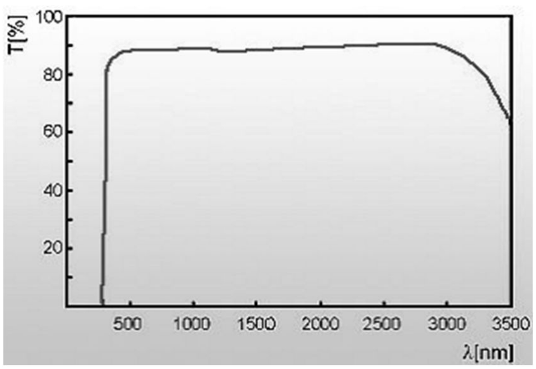

Figure 1: KTP Transparency Curve

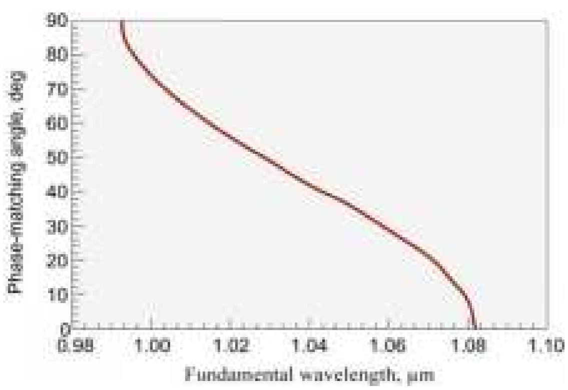

Figure 2: Type-II SHG in XY Plane

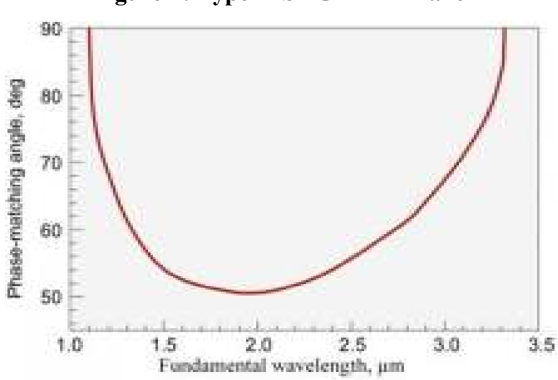

Figure 3: Type-II SHG in XZ Plane

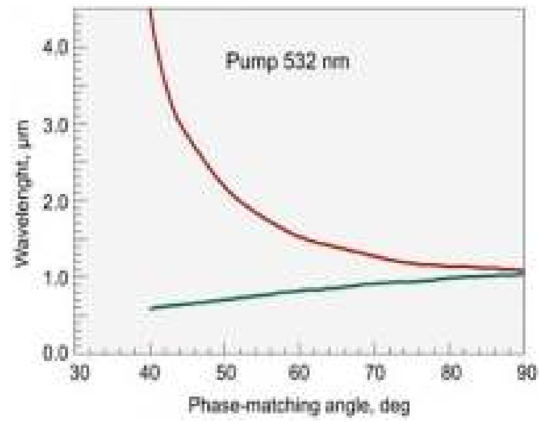

Figure 4: KTP OPO in Xz Plane

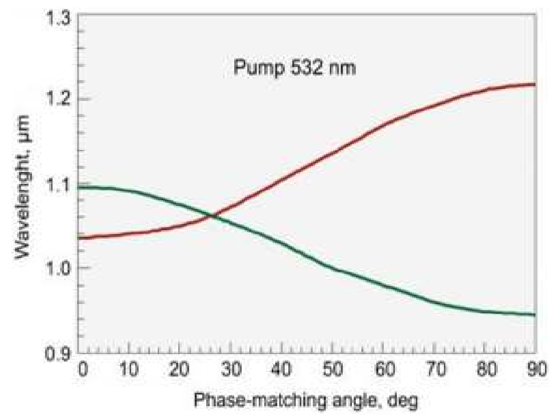

Figure 5: KTP OPO in XY Plane

b. Applications for OPG, OPA and OPO

As an efficient OPO crystal pumped by the fundamental and second harmonics of an Nd: YAG or Nd: YLF Laser, KTP plays an important role in parametric sources for tunable output from visible (0.6μm) to mid IR (4.5μm). The phase-matching angles and effective NLO coefficient for OPO/OPA pumped at 532nm and 1064nm in XZ plane are shown as following figures. NCPM KTP OPO pumped by 1064 nm, the signal output is around eye safe wavelength, applications are found in eye-safe devices. The OPO/OPA in XY and YZ is seldom employed because of their low effective non-linear coefficients and other limitations.

KTP's OPO results in stable, continuous outputs of femtosecond pulse of 10 Hz repetition rate and miliwatt average power levels in both signal and idler outputs. KTP's OPO pumped by a 1064nm Nd: laser has generated above 66% conversion efficiency for degenerate conversion from 1064 to 2120nm.

The recently developed new application is the Non-critical phase-matched (NCPM) KTP OPO/OPA pumped by the tunable lasers such as Ti:Sapphire, Alexandrite and Cr:LiSrAIF (see right figure). The NCPM KTP OPO keeps the KTP crystal fixed in X-axis and tunes the pumping wavelength. If a tunable Ti:Sapphire laser is used as a pumping source (0.7µm to 1µm), the output can cover the wavelength range from 1.04µm to 1.45µm (signal) and from 2.15µm to 3.2µm (idler). Due to the favourable NLO properties of NCPM KTP, as high as 45% conversion efficiency was obtained with narrow output bandwidth and good beam quality.

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CONCLUSION

As a result of its excellent properties KTP crystal has a number of advantages for different applications like second harmonic generation of Nd lasers emitting near 1 Atm. KTP is also attractive for various sum- and difference frequency and optical parametric applications over its entire transparency range from 0.35 to 4.5 um. Its combination of large electro-optic coefficients and low dielectric constants makes KTP potentially useful for various electrooptic applications, and, in particular, it has a figure of merit for an optical waveguide modulator that is nearly a factor of 2 larger than that for any other inorganic material.

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