Potassium Titanyl Phosphate - KTP

Potassium Titanyl Phosphate (KTP or $KTiOPO_4$) is a nonlinear optical material suitable for use in many optical systems. Its most popular application is as a frequency doubler utilizing the 1.06 μm output of a Nd:YAG laser. The conversion efficiency to 0.53 μm is up to 60% at 250 MW / cm^2. KTP's properties also make it superior as an electro-optic modulator, optical parametric generation and optical waveguiding. SYNOPTICS has spent many years on the crystal growth and development of KTP. We are pleased to offer the following background data to assist in its use.

Applications

KTP's unique combination of properties, high nonlinear coefficients, high damage threshold, and the fact that it is nonhygroscopic as well, suit it to those laser systems applications requiring high power, high efficiency, and/or durability. It can be used in both commercial and military lasers including medical and laboratory systems, range-finders, designators and systems for use in the semiconductor industry. Any export or re-export of this product requires U.S. Government approval.

Crystal Growth

SYNOPTICS' growth of KTP for nonlinear applications utilizes the hydrothermal process. In this technique crystals are grown in seeded aqueous solutions of KTP at elevated pressures and temperatures. Seed orientation makes use of the growth directions perpendicular to the (011) face. Typical crystal sizes of 15 x 20 x 40 mm are obtained using this technique.

Crystal Structure

Structurally, Potassium Titanyl Phosphate (KTP) is orthorhombic and belongs to the acentric point group mm2. Its complicated structure is characterized by chains of TiO_6 octahedral linked at two corners by alternating long and short Ti-O bonds. The analysis of Zumsteg et al indicates that it is primarily these short Ti-O bonds that give rise to the large nonlinear optical effects observed in KTP. Some of the more useful physical properties of the material are given in *Table I*.

Table I

Physical and Chemical Properties

Formula:	$KTiOPO_4$
Crystal Structure:	Orthorhombic, Space Group Pna 2_1
Lattice Parameters:	a = 12.814Å b = 6.404Å c = 10.616Å
Melting Point:	~ 1150°C with partial decomposition
Mohs Hardness:	~ 5
Color:	colorless
Density (X-Ray):	3.03 g / cm^3
Specific Heat:	0.1737 cal / gm°C
Thermal Conductivity:	k_1= 2.0, k_2= 3.0 k_3= 3.3 (x10^{-2} W / cm / °C)
Absorption Loss @ 1.064 μm:	< 1% / cm

Table II

Nonlinear Properties

Property	Value
Nonlinear Optical Coefficients (x 10^{-12} m / V):	d_{31} = 6.5, d_{32} = 5.0, d_{33} = 13.7, d_{24} = 7.6, d_{15} = 6.1
Refractive Indices @ 1.064 μm:	n_x = 1.740, n_y = 1.747, n_z = 1.830
Refractive Indices @ .532 μm:	n_x = 1.779, n_y = 1.790, n_z = 1.887
Type Phase Matching:	Type II
Phase Matching Angle (@1.064 μm):	24° to x in xy plane
Spectral Bandwidth (Å - cm):	5.6
Angular Bandwidth (mrad - cm):	15 - 68
Temperature Bandwidth (°C - cm):	25
Walk-off Angle (mrad):	1

KTP

Introduction

Potassium Titanyl Phosphate (KTiOPO4'KTP) - was first synthesized in 1890 by L. Ouvard but it wasn't until the 1970's that Zumsteg, Bierlein and Gier at E.I. DuPoint identified the nonlinear optical properties of this crystal. These properties proved to be extremely desirable for several solid state laser applications. In the late 1970's, SYNOPTICS joined forces with DuPont to pursue the advanced development of this material. Since then, SYNOPTICS has spent many years developing the crystal growth and fabrication of KTP, and today, at our facility our fully equipped laboratories are capable of high volume hydrothermal growth, macro/micro-fabrication and active/passive testing with stringent in-house quality control.

Applications

KTP's unique combination of properties (high nonlinear coefficients, high damage threshold and non-hygroscopicity) make it well suited for laser system applications requiring high power, high efficiency and/or durability. Commercial and military applications range from medical, industrial and laboratory systems to rangefinders, designators and systems used in the semi-conductor industry. Export and re-export of this product may require U.S. Government approval.

Crystal Properties

Structural:

KTP is orthorhombic in structure and belongs to the accentric point group mm2. Its complicated structure is characterized by chains of TiO6 octahedra linked at two corners by alternating long and short Ti-O bonds that give rise to the large nonlinear optical effects observed in KTP. The constant growth rate of the hydrothermal process insures homogeneity throughout the crystal bulk.

Optical:

KTP possesses optical properties that allow it to be used for both intra- and extracavity laser applications. It is optically transparent from .35 μ to 3.5 μ. The optical spectrum is structure-free except for traces of OH-absorption bands observed at 2.8 μ and 3.8 μ. Crystals with little or no scatter have been produced with very low strain. Damage thresholds have been measured well in excess of 1GW/cm^2. The refractive indices vary slowly with changes in wavelength and temperature.

Nonlinear Optical

The nonlinear optical coefficients are comparable to those of Ba2NaNb5015 and KTP can be phase matched at 1.06 μ using either Type I or Type II interactions. In Type II interactions, KTP has large angular and temperture bandwidths as well as high nonlinear coefficients and damage thresholds. It has a high conversion efficiency for second harmonic generation (SHG) of laser light with fundamental wavelengths between .994 and 2.5 μ. This material is also well suited for use as an optical parametric oscillator (OPO). KTP's wide tuning range and high conversion efficiencies mean that short crystals can be used in this application. Another application well suited for KTP is quasi phase matching (QPM). In this process z-oriented waveguides of KTP are periodically poled and pumped with diode lasers to generate blue to near UV wavelengths.*

Electro-Optical (E-O):

KTP possesses E-O properties comparable to those of LiNbO3 for bulk modulator applications with a figure of merit (n7r2/) of 3650 (pm/v)2. KTP is also a superior material for waveguide E-O modulators with a figure of merit (n3r/ eff) of 17.3 pm/v. When these properties are coupled with KTP's high damage threshold, wide optical bandwidth (>15GHz), thermal and mechanical stability, the combination makes it a unique material for modulator applications.

*...Ref. "W.P. Risk and S.D. Lau, Opt. Lett., vol. 18, p. 272, 1993."

KTP Properties

Absorption (single pass) (phase matched @ 1.064 μ	< 0.6%/cm @ 1.064 μ < 2.0%/cm @ .532 μ
Angular Bandwidth	15 - 68 mrad-cm
Chemical Stability	Up to at least 600°C
Conductivity, Thermal	k_1 = 2.0 x 10^{-2}W/cm°C k_2 = 3.0 x 10^{-2}W/cm°C k_3 = 3.3 x 10^{-2}W/cm°C
Conductivity, Ionic	10^{-6} $(ohm/cm)^{-1}$ when Cp x D > 1 10^{-8} $(ohm/cm)^{-1}$ when Cp x D < 1
Conversion Efficiency	Up to 85% depending upon cube length and lser system.
Curie Temperature	936°C
Damage Resistance (relative optical)	> 20J/cm^2
Damage Threshold (bulk)	Up to 30 GW/cm2 (depending upon system parameters)
Damage Threshold (coated surface)	Up to 500 MW/cm2 (depending upon system parameters)
Density	2.945 to 3.03 g/cm^3
Dielectric Constant (high frequency)	11 = 11.6 22 = 11.0 33 = 15.4
Elastic Coefficient	C_{11} = 159 ± 3 dyn/cm^2 C_{22} = 154 ± 3 dyn/cm^2 C_{33} = 175 ± 3 dyn/cm^2
Elastic Modulus	(see Young's Modulus)
Electro-Optic Coefficient (high frequency)	r_{13} = 8.8 pm/V r_{13} = 8.8 pm/V r_{13} = 8.8 pm/V r_{13} = 8.8 pm/V r_{13} = 8.8 pm/V
Expansion Coefficient (thermal) Fracture Toughness	
Hardness (Mohs scale)	
Lattice Constants (unit cell dimensions)	
Loss Coefficient (as measured calormetrically)	

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