Potassium Titanyl Phosphate (KTP or KTiOPO₄) 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 / cm². 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

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula:</td>
<td>KTiOPO$_4$</td>
</tr>
<tr>
<td>Crystal Structure:</td>
<td>Orthorhombic, Space Group Pna 2</td>
</tr>
<tr>
<td>Lattice Parameters:</td>
<td>$a = 12.814\text{Å}$, $b = 6.404\text{Å}$, $c = 10.616\text{Å}$</td>
</tr>
<tr>
<td>Melting Point:</td>
<td>$\sim 1150{°}\text{C}$ with partial decomposition</td>
</tr>
<tr>
<td>Mohs Hardness:</td>
<td>$\sim 5$</td>
</tr>
<tr>
<td>Color:</td>
<td>colorless</td>
</tr>
<tr>
<td>Density (X-Ray):</td>
<td>$3.03 \text{ g / cm}^3$</td>
</tr>
<tr>
<td>Specific Heat:</td>
<td>$0.1737 \text{ cal / gm}^\circ\text{C}$</td>
</tr>
<tr>
<td>Thermal Conductivity:</td>
<td>$k_1 = 2.0$, $k_2 = 3.0$, $k_3 = 3.3 \times 10^{-2} \text{ W / cm / }\circ\text{C}$</td>
</tr>
<tr>
<td>Absorption Loss @ 1.064 µm:</td>
<td>$&lt; 1% / \text{cm}$</td>
</tr>
</tbody>
</table>

Table II
Nonlinear Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonlinear Optical Coefficients ($x 10^{-12} \text{ m / V}$):</td>
<td>$d_{31} = 6.5$, $d_{32} = 5.0$, $d_{33} = 13.7$, $d_{34} = 7.6$, $d_{15} = 6.1$</td>
</tr>
<tr>
<td>Refractive Indices @ 1.064 µm:</td>
<td>$n_x = 1.740$, $n_y = 1.747$, $n_z = 1.830$</td>
</tr>
<tr>
<td>Refractive Indices @ .532 µm:</td>
<td>$n_x = 1.779$, $n_y = 1.790$, $n_z = 1.887$</td>
</tr>
<tr>
<td>Type Phase Matching:</td>
<td>Type II</td>
</tr>
<tr>
<td>Phase Matching Angle (@1.064 µm):</td>
<td>24° to x in xy plane</td>
</tr>
<tr>
<td>Spectral Bandwidth (Å - cm):</td>
<td>5.6</td>
</tr>
<tr>
<td>Angular Bandwidth (mrad - cm):</td>
<td>15 - 68</td>
</tr>
<tr>
<td>Temperature Bandwidth (°C - cm):</td>
<td>25</td>
</tr>
<tr>
<td>Walk-off Angle (mrad):</td>
<td>1</td>
</tr>
</tbody>
</table>

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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/cm². 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 temperature 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.

KTP Properties

Absorption (single pass) $< 0.6\%$/cm @ 1.064 $\mu$m
(phase matched @ 1.064 $\mu$m $< 2.0\%$/cm @ .532 $\mu$m

Angular Bandwidth 15 - 68 mrad-cm

Chemical Stability Up to at least 600°C

Conductivity, Thermal $k_1 = 2.0 \times 10^{-2}$W/cm°C
$k_2 = 3.0 \times 10^{-2}$W/cm°C
$k_3 = 3.3 \times 10^{-2}$W/cm°C

Conductivity, Ionic $10^6$ (ohm/cm)$^{-1}$ when $C_p \times D > 1$
$10^8$ (ohm/cm)$^{-1}$ when $C_p \times D < 1$

Conversion Efficiency Up to 85% depending upon cube length and laser system.

Curie Temperature 936°C

Damage Resistance $> 20$J/cm$^2$
(relative optical)

Damage Threshold (bulk) Up to 30 GW/cm$^2$ (depending upon system parameters)

Damage Threshold (coated surface) Up to 500 MW/cm$^2$ (depending upon system parameters)

Density 2.945 to 3.03 g/cm$^3$

Dielectric Constant 11 = 11.6
(high frequency)
22 = 11.0
33 = 15.4

Elastic Coefficient $C_{11} = 159 \pm 3$ dyn/cm$^2$
$C_{22} = 154 \pm 3$ dyn/cm$^2$
$C_{33} = 175 \pm 3$ dyn/cm$^2$

Elastic Modulus (see Young’s Modulus)

Electro-Optic Coefficient $r_{13} = 8.8$ pm/V
(high frequency) $r_{13} = 8.8$ 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 calorimetrically)
Cr$^{4+}$: YAG - Passive Q-Switch

Passive Q-switches or saturable absorbers provide high power laser pulses without electro-optic Q-switches, thereby reducing the package size and eliminating a high voltage power supply. Cr$^{4+}$:YAG is more robust than dyes or color centers and is the material of choice for 1 micron Nd lasers.

A small fraction of the chromium ions in YAG can be induced to change valence from the normal Cr$^{3+}$ to Cr$^{4+}$ with the addition of charge compensating impurities such as Mg$^{2+}$ or Ca$^{2+}$. The convenient measure of the Cr$^{4+}$ concentration is the low power absorption coefficient $\alpha$ at 1064 nm. Typical $\alpha$ values vary from about 1.5 cm$^{-1}$ for tunable laser crystals to 3 - 6 cm$^{-1}$ for passive Q-switches. The actual Cr$^{4+}$ ion density $N$ in the crystal can be calculated from $N = \frac{\alpha}{\frac{1}{2}A}$ where $\frac{1}{2}A$ is the absorption cross-section with a value$^1$ of 5 x 10$^{-18}$ cm$^2$.

Passive Q-switches are typically specified by the low power optical density (or %T) at the laser wavelength. Synoptics measures the $\alpha$ value in the Cr$^{4+}$:YAG boule and adjusts the part thickness to the optical density specified. Thickness is a free parameter, but typically 1 - 5 mm.

**Specifications**

**SYNOPTICS Standards**

- Orientation: $< 100 >$
- Surfaces: flat / flat
- Coatings: AR $< 0.2\%$ at 1064 nm
- Damage Threshold: $> 500$ MW / cm$^2$

**Customer Values**

- Diameter: typical: 5 - 10 mm
- Optical Density: typical: 0.30, 0.40, 0.50, ±10% at 1064 nm:

**References**


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704-588-2340 • FAX 704-588-2516
1201 Continental Blvd., Charlotte, NC 28273
email: st.synoptics.sales@ngc.com
Terbium Gallium Garnet (TGG) is a crystal material for optical isolator devices. Optical isolator devices make use of the non-reciprocal Faraday effect in TGG. The Faraday effect is the rotation of the plane of polarization of a light beam as it is transmitted through a TGG crystal in the presence of an external magnetic field coaxial with the light. The polarization rotation is in the same sense regardless of the direction of propagation of the light. An optical isolator is a Faraday rotator combined with suitably aligned polarizers which allows light to pass in one direction only.

**Advantages Of TGG Include:**

*Superior to terbium-doped glasses*

- TGG has twice the Verdet constant of a Terbium-doped glass.
- The thermal conductivity of crystalline TGG is an order of magnitude greater than a typical glass.
- Optical losses are lower for TGG than Tb-doped glasses.
- The combination of the above factors make TGG better suited to high average power applications. The principal limiting factor is thermally induced beam distortion. Beam distortion is less for TGG than Tb-doped glasses under the same power loading level.
Standard Rod Specifications

Material Parameters
Crystal: Terbium Gallium Garnet (Tb₃Ga₅O₁₂)
Orientation: [111] within 5 degrees
Wavefront Distortion (measured at 632 nm):
  • Large rods with diameter > 3 mm or length > 25.4 mm: < 1/8 wave / inch
  • Small rods with diameter < 3 mm or length < 25.4 mm: < 1/8 wave total
Extinction Ratio: 30 dB over 2/3 clear aperture

Dimensional Tolerances
Diameter: +0.000” / -0.002”
Length: +0.010 / -0.010”
Barrel Finish: 55 ± 5 μinch (RMS)
Chamfer: 0.005” ± 0.003” at 45° ± 5°

End Configuration
Flatness: λ / 10 wave at 633 nm wavelength
Parallelism: < 1 minutes of arc
Perpendicularity: < 10 minutes of arc
Surface Quality: 10 - 5 scratch-dig per MIL-0-13830A

Anti-Reflection Coatings
Reflectivity: < 0.25% at 1064 nm
Adhesion and Durability: meets MIL-C-48497A standards
Pulsed Damage Threshold: 10 J / cm²

Comparison Of TGG And TB-Doped Glass Properties At 1064 nm

<table>
<thead>
<tr>
<th></th>
<th>TGG</th>
<th>Tb-glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verdet Constant, V</td>
<td>-40</td>
<td>-20</td>
</tr>
<tr>
<td>@ 1064 nm:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ 632 nm:</td>
<td>-134</td>
<td>-70</td>
</tr>
<tr>
<td>Absorption Coefficient, ¦:</td>
<td>0.0015</td>
<td>0.003</td>
</tr>
<tr>
<td>Thermal Conductivity, κ:</td>
<td>7.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Refractive Index, n:</td>
<td>1.95</td>
<td>–</td>
</tr>
<tr>
<td>Nonlinear Index, n₂:</td>
<td>8.0</td>
<td>2.45</td>
</tr>
<tr>
<td>Figure of Merit (¹), V/¦:</td>
<td>27</td>
<td>7</td>
</tr>
<tr>
<td>Figure of Merit (²), V/n₂:</td>
<td>5</td>
<td>8</td>
</tr>
</tbody>
</table>

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Undoped YAG

Undoped YAG is a substrate material that can be used for both UV and IR optics. It is particularly useful for applications in the 2 - 3 µm region where glasses tend to be highly absorbent due to the strong H₂O band. YAG shows no trace absorption in this region. Sapphire has traditionally been the substrate of choice for such applications; however, it is difficult to polish Sapphire to a 10 - 5 scratch-dig laser grade finish. Sapphire is also slightly birefringent. YAG is non-birefringent, almost as durable, and can readily be polished to a 10 - 5 surface quality.

Due to the high strength of YAG, very thin windows can be fabricated allowing for use at wavelengths that approach both the IR and UV cutoffs.

Finally, its high index of refraction will reduce spherical aberrations in lenses by 25% over typical glass lenses.

Advantages Of Undoped YAG Include:

Wide Transmission Range
• Useful from 250 - 5000 nm
• No absorption in the 2 µm - 3 µm region

Excellent Thermal and Opto-Mechanical Properties
• High thermal conductivity, 10 times better than most glasses
• Extremely hard and durable allowing for thin highly polished substrates to be fabricated
• High index of refraction, facilitating low aberration lens design
• High bulk damage threshold
• Non-birefringent
Standard Mirror And Window Specifications

Material Parameters
Crystal Formula: Yttrium Aluminum Garnet (Y₃Al₅O₁₂)
Orientation: [111] within 5 degrees
Wavefront Distortion: less than 1/2 wave per inch of length (measured at 1064 nm)

Dimensional Tolerances
Diameter: +0.000" / -0.002"
Thickness: +0.040" / -0.000"

End Configuration
Flatness: within λ/ 10 wave at 633 nm wavelength
Scratch-Dig: 10 - 5 per MIL-0-13830A

Anti-Reflection Coatings
Reflectivity: less than 0.25% at Specified Wavelength
Partial and High Reflector Coatings Available Upon Request

Properties Of Undoped YAG

Spectral Properties
Transmission Range: 250 - 500 nm
Index of Refraction: 1.82 (@ 1064 nm)
Damage Threshold: > 15 J / cm²

Mechanical Properties
Mohs Hardness: 8 - 8.5
Thermal Expansion: 6.9 x 10⁻⁶°C⁻¹
Thermal Conductivity: 13 W m⁻¹ K⁻¹
dn / dt: 7.4 x 10⁻⁶°C⁻¹
Passive Q-switches or saturable absorbers generate high power laser pulses without the use of electro-optic Q-switches, thereby reducing the package size and eliminating a high voltage power supply. \(\text{Co}^{2+}:\text{Spinel} (\text{MgAl}_2\text{O}_4)\) is the material of choice for the important eye-safe wavelengths near 1.5 microns. It has useful absorption that covers 1.2 to 1.6 micron laser transitions. Spinel is a hard, stable crystal that polishes well.

Cobalt substitutes readily for magnesium in the Spinel host without the need for additional charge compensation ions. A convenient measure of the \(\text{Co}^{2+}\) concentration is the low power absorption coefficient \(\kappa\) at, for example, 1533 nm, a typical wavelength for Erbium phosphate glass. SYNOPTICS grows crystals for passive Q-switches with \(\kappa\) values from about 0.5 to 3 cm\(^{-1}\). The actual \(\text{Co}^{2+}\) ion density \(N\) in the crystal can be calculated from \(N = \frac{\kappa}{\frac{1}{2}\text{GSA}}\) where \(\frac{1}{2}\text{GSA}\) is the ground-state absorption cross-section with a value\(^1\) of \(3.5 \times 10^{-19}\) cm\(^2\). This absorption is high enough to permit Q-switching of Erbium glass without intracavity focussing.

Passive Q-switches are typically specified by the low power Optical Density (or \%T) at the laser wavelength. SYNOPTICS measures the \(\kappa\) value in the crystal and adjusts the part thickness to the optical density specified. Thickness is therefore a free parameter, but typically 1 - 5 mm.
### Specifications

**SYNOPTICS Standard**
- Orientation: <100>
- Surfaces: flat / flat
- Coatings: AR < 0.25% at 1533 nm
- Damage Threshold: > 500 MW / cm²

**Customer Values**
- Diameter: typical: 5 - 10 mm
- Optical Density: typical: 0.70, 0.80, 0.90
  at 1064 nm

### References

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Gadolinium vanadate doped with neodymium, Nd:GdVO₄, is a promising material for diode pumped lasers. Like neodymium doped yttrium vanadate, the gadolinium vanadate exhibits a larger absorption and emission cross section compared to Nd:YAG. In fact, Nd:GdVO₄ has a 7-times higher absorption cross section at 808nm and a 3-times larger emission cross section at 1.06µm than does Nd:YAG (Ref. 1). Nd:GdVO₄ has the additional advantage over Nd:YVO₄ of a much higher thermal conductivity.

Nd:GdVO₄ was first introduced as a laser material in 1992 by Zagumennyi, et al. (Ref. 2). Consequently, much less laser development and testing has occurred with gadolinium vanadate. The early results are, however, quite promising. Wang, et al. compared Nd:GdVO₄ and Nd:YVO₄ in a diode pumped arrangement (Ref. 3). In each case of cw laser performance at 1.06µm and 1.34µm and intracavity doubling with KTP and LBO, the gadolinium vanadate had a higher slope efficiency or optical conversion efficiency than did yttrium vanadate.

SYNOPTICS uses the Czochralski method to grow gadolinium vanadate. The crystal is tetragonal which means that there are two equivalent “a” directions and a “c” direction, all mutually orthogonal. A typical laser rod is oriented with the rod axis along an a-axis of the crystal. Maximum absorption of pump light occurs for polarization along the c-axis.

**Demonstrated performance in diode pumped laser systems**

<table>
<thead>
<tr>
<th>Laser Operation</th>
<th>Output Wavelength (µm)</th>
<th>Frequency Doubler</th>
<th>Slope Efficiency (%)</th>
<th>Max Optical Conversion Efficiency (%)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>cw</td>
<td>1.06</td>
<td>none</td>
<td>44.6</td>
<td>n/a</td>
<td>3</td>
</tr>
<tr>
<td>cw</td>
<td>1.06</td>
<td>none</td>
<td>42.9</td>
<td>38.1</td>
<td>4</td>
</tr>
<tr>
<td>cw</td>
<td>1.34</td>
<td>none</td>
<td>40.2</td>
<td>n/a</td>
<td>3</td>
</tr>
<tr>
<td>cw</td>
<td>0.53</td>
<td>KTP</td>
<td>n/a</td>
<td>21.0</td>
<td>3</td>
</tr>
<tr>
<td>cw</td>
<td>0.67</td>
<td>LBO</td>
<td>n/a</td>
<td>2.8</td>
<td>3</td>
</tr>
<tr>
<td>Q-switched</td>
<td>1.06</td>
<td>none</td>
<td>31.6</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td>Q-switched</td>
<td>0.53</td>
<td>KTP</td>
<td>n/a</td>
<td>25.0</td>
<td>4</td>
</tr>
</tbody>
</table>
# Information Regarding Neodymium Laser Host Crystals

<table>
<thead>
<tr>
<th></th>
<th>Nd:YVO$_4$</th>
<th>Nd:GdVO$_4$</th>
<th>Nd:YAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser wavelengths (Ref. 5)</td>
<td>1064.3 nm</td>
<td>1062.9 nm</td>
<td>1064.2 nm</td>
</tr>
<tr>
<td></td>
<td>1342.0 nm</td>
<td>~1340 nm</td>
<td>1338.2 nm</td>
</tr>
<tr>
<td>Emission bandwidth (linewidth at 1064 nm)</td>
<td>0.8 nm</td>
<td>No Data</td>
<td>0.45 nm</td>
</tr>
<tr>
<td>Effective laser cross section (emission cross section at 1064 nm)</td>
<td>$15.6 \times 10^{-19}$ cm$^2$ (Ref.5)</td>
<td>$7.6 \times 10^{-19}$ cm$^2$ (Ref.5)</td>
<td>$6.5 \times 10^{-19}$ cm$^2$</td>
</tr>
<tr>
<td>Polarization</td>
<td>Parallel to c-axis</td>
<td>Parallel to c-axis</td>
<td>Unpolarized</td>
</tr>
<tr>
<td>Radiative lifetime (microseconds) at 1% Nd doping</td>
<td>~100µs (Ref. 5)</td>
<td>~95µs (Ref. 5)</td>
<td>230µs</td>
</tr>
<tr>
<td>Pump wavelength (Ref. 5)</td>
<td>808.5 nm</td>
<td>808.4 nm</td>
<td>807.5 nm</td>
</tr>
<tr>
<td>Peak pump absorption at 1% doping (Ref. 5)</td>
<td>~41 cm$^{-1}$</td>
<td>~57 cm$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>Thermal conductivity, W/mK</td>
<td>5.1</td>
<td>11.7</td>
<td>14</td>
</tr>
<tr>
<td>Doping conception range</td>
<td>0.1 - 3.0%</td>
<td>0.1 - 3.0%</td>
<td>0.1 - 2.0%</td>
</tr>
<tr>
<td>Other possible dopants</td>
<td>Tm, Ho, Er</td>
<td>Tm, Ho, Er</td>
<td>Cr, Tm, Ho, Er, Yb</td>
</tr>
</tbody>
</table>

## Material Properties: Comparing Nd:GdVO$_4$ and Nd:YVO$_4$

<table>
<thead>
<tr>
<th></th>
<th>Nd:GdVO$_4$</th>
<th>Nd:GdVO$_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal structure, Space group</td>
<td>Trtragonal. I$_4$/amd (Ref.4)</td>
<td>Trtragonal. I$_4$/amd (Ref.4)</td>
</tr>
<tr>
<td>Lattice constants, nm</td>
<td>a</td>
<td>0.721</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>0.635</td>
</tr>
<tr>
<td>Melting temperature, °C</td>
<td>1780</td>
<td>1825</td>
</tr>
<tr>
<td></td>
<td>(Ref.6)</td>
<td></td>
</tr>
<tr>
<td>Thermal expansion @ 25°C, $x 10^6/°C$</td>
<td>a</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td>(Ref.4)</td>
<td></td>
</tr>
<tr>
<td>Specific heat @25°C, cal/mol K</td>
<td>32.6</td>
<td>24.6</td>
</tr>
<tr>
<td></td>
<td>(Ref.4)</td>
<td></td>
</tr>
<tr>
<td>dn/dt, $x 10^6/°C$</td>
<td>4.7</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>(Ref.4)</td>
<td></td>
</tr>
</tbody>
</table>

## References:

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