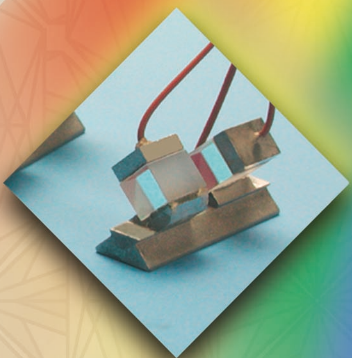
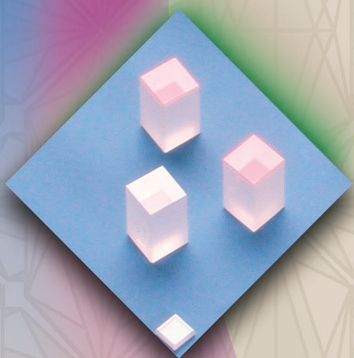
Raicol Crystals

RAICOL CRYSTALS





The Art of Crystals

NONLINEAR, ELECTROOPTIC CRYSTALS AND ELEMENTS

OUR POLICY.

We foster empowerment with accountability and recognition.
We have a high regard for "can do" attitudes.

We are passionate about customer service.
We wish to exceed our customer's expectations.

We work hard, smart, play to win and have fun.
We will offer competitive, performance-based compensation, training and mentoring and we believe in a sense of humor, optimism and celebration of success.

We treat customers, suppliers, and each other with respect.
We will conduct our business in a professional manner with all our constituents.

We demonstrate integrity in everything we say and do.
Honesty is the foundation upon which we as individuals and Raicol are built.

We built strength through diversity.
We value the collective backgrounds of our team and strive to create a receptive environment where individuals can grow contribute and prosper.

We create teamwork and collaboration through open communication.
We respect, encourage and promote the power of mutually supportive relationships in pursuit of our business objectives.

We foster focused innovation.
We seek to improve our results through new ideas fostered by employee, customer and supplier inclusion.

We add value to the communities where we work and live.

And we do all this .... WITH SPEED.

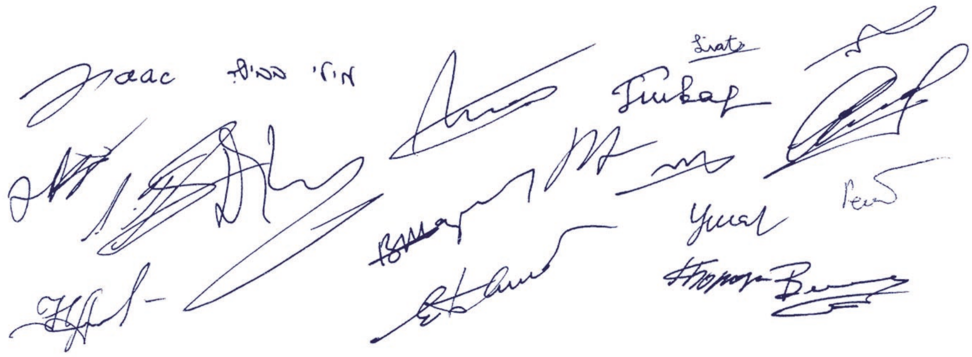


TABLE OF CONTENT

Raicol is committed to providing high quality nonlinear optical elements to the optics community, at a competitive price.

The company sets a high priority on development work, and works closely with customers to develop innovative products that meet their needs.

Raicol Crystals is pleased to present this booklet, which includes data sheets about our products, and test results for the various products. These test were performed either in Raicol's laboratory, at independent laboratories, or by some of our customers, who were kind enough to share their results with us.

Table of Contents

KTP Elements
for
SHG, SFM, DFM and OPO

Raicol produces high quality single domain KTP NLO elements. Our controlled growth methods ensure a reliable supply of KTP crystals of consistent quality.

SPECIFICATIONS

KTP Crystals

Absorption coefficient	α < 50 ppm cm^{-1} at 1064 nm and α < 2000 ppm cm^{-1} at 532 nm
Domain structure	Single domain
Guaranteed Damage threshold	600 MW/cm^2 (with coating) at 1064 nm, for 10 ns pulses

NLO Elements

Fabrication	Cut from single growth sector
Apertures	up to 30 x 30 mm^2
Length	up to 40 mm along X axis
AR coatings	dual band R < 0.2 %
Wave front distortion control	

Certified frequency conversion efficiency (upon request)

Optical Polishing Capabilities

Flatness	$\lambda/10$
Parallelism	5 arc sec
Perpendicularity	5 arc min.
Scratch/dig	None at x 100 magnification

KTP Substrates for Optical Waveguides and PPKTP

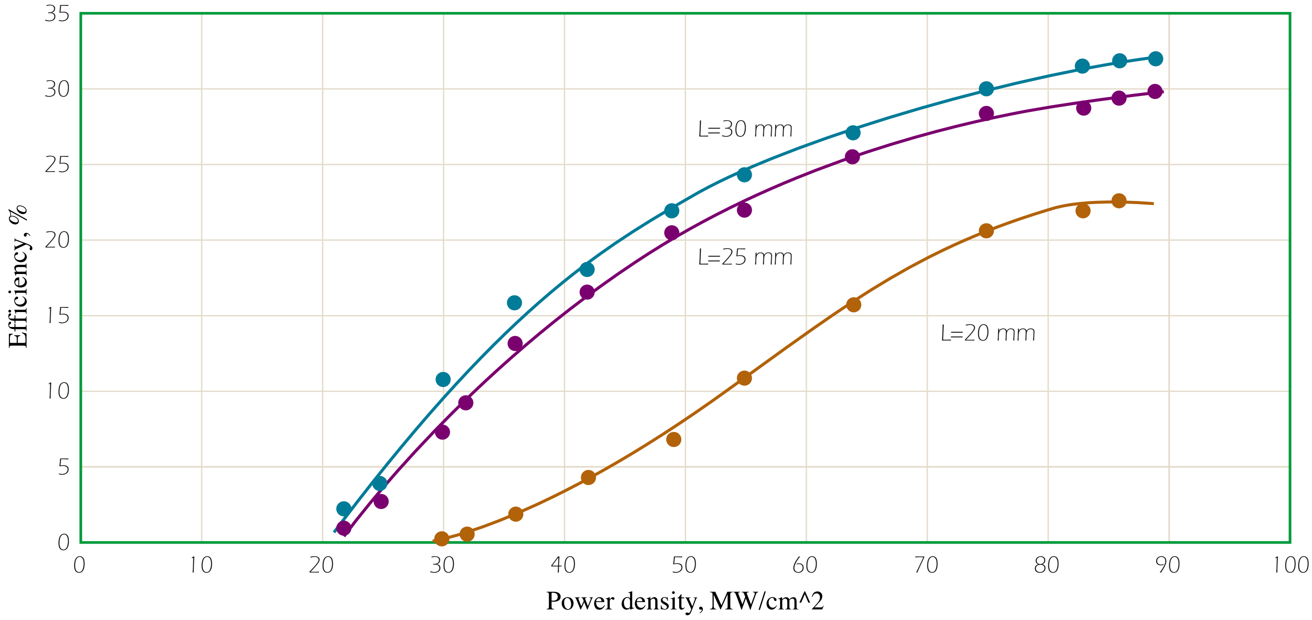
Area	Z-cut, up to 40 x 40 mm^2
Domain structure	Single domain

Index	A	B	C	D
nx	3.006700	0.039500	0.042510	0.012470
ny	3.031900	0.041520	0.045860	0.013370
nz	3.313400	0.056940	0.059410	0.016713

KTP Elements for SHG, SFM, DFM and OPO

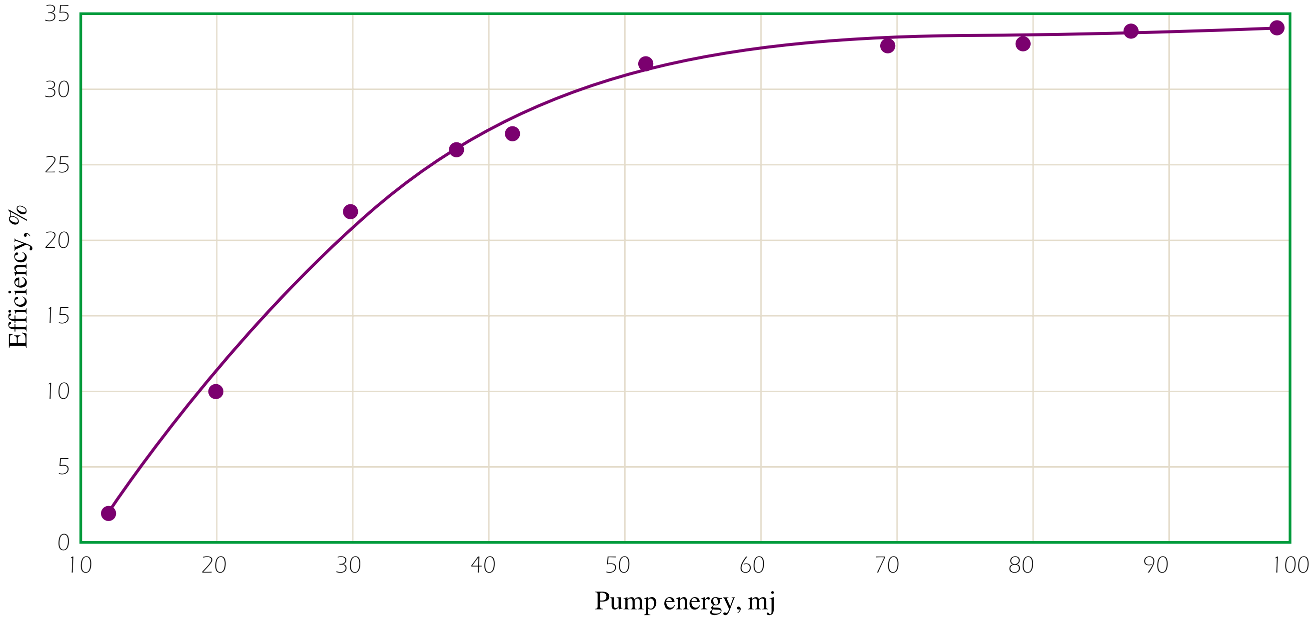
Efficiency of KTP elements in OPO 1064-1570 nm

(Resonator L=35mm, output mirror- 50%, τpulse=10ns, f=25Hz)



The above graph shows the increase in efficiency in OPO conversion achieved with increased KTP element length. In the past, OPO efficiency leveled off with 20 mm long elements, and actually dropped with longer elements. This was due to imperfections in the KTP elements. Raicol's crystal growth technology can provide long elements with few imperfections, which results in higher OPO efficiency.

Efficiency of KTP element (L =35.4 mm)in OPO 1064 -1570 nm



The increased efficiency of OPO conversion with a 35 mm long KTP element is shown above.
Raicol can provide KTP OPO elements up to 50 mm long. Large apertures are also available.

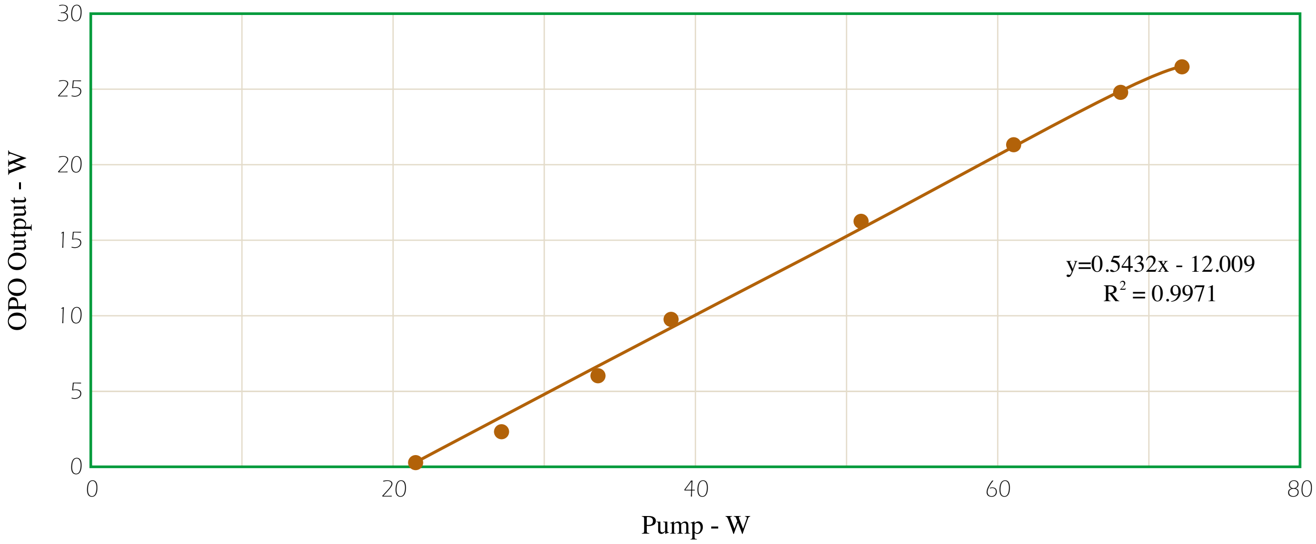
Raicol Crystals

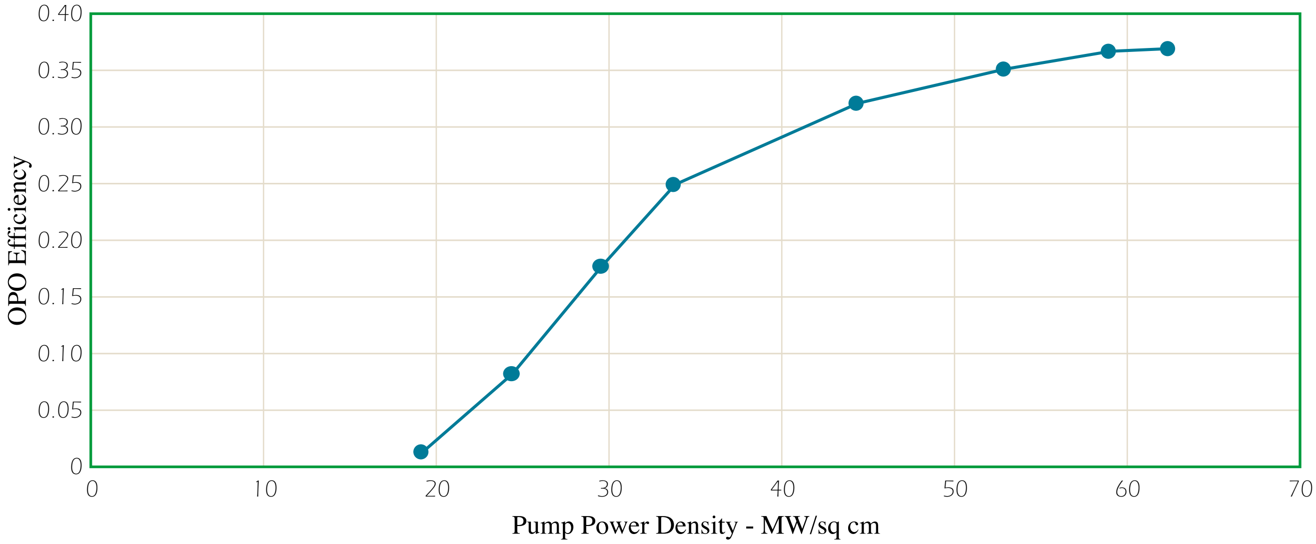
P.O.Box 2753 Industrial Zone, Yehud 56217, Israel
Tel: 972-3-9367412, Fax: 972-3-9068969
Email: info@raicol.com, Web: www.raicol.com

High Average Power KTP Ring OPO

Three 10x10x20 mm, DBAR 1.06 & 1.57 Raicol KTP Elements

100 pps rate, 2 hrs. Run time, No degradation





SCHWARTZ
ELECTRO-OPTICS, INC.
Aerospace Systems Division
Orlando, Florida

Raicol Crystals
P.O.Box 2753 Industrial Zone, Yehud 56217, Israel
Tel: 972-3-9367412, Fax: 972-3-9068969
Email: info@raicol.com, Web: www.raicol.com

High Gray Track Resistance KTP Elements (HGTR KTP)

Raicol produces KTP crystals with gray track resistance up to ten times greater than typical flux grown KTP. This is possible due to advances in the controlled growth of KTP crystals, using proprietary modified fluxes and heat treatment. These HGTR KTP elements are suitable for high power density applications, where many other KTP elements would suffer from gray tracks or photorefractive breakdown.

SPECIFICATIONS

KTP Crystals

Absorption coefficient	$\alpha < 10\text{-}5\ cm^{-1}$ at 1064 nm and $\alpha < 0.01\ cm^{-1}$ at 532 nm
Domain structure	Single domain
Guaranteed Damage threshold	600 MW/ cm^2 (with coating) at 1064 nm, for 10 ns pulses

KTP Elements for SHG, SFM, DFM and OPO

Fabrication	Cut from single growth sector
Apertures	up to 8 x 8 mm^2
Length	up to 12 mm along X axis
AR coatings	dual band R<0.2 %

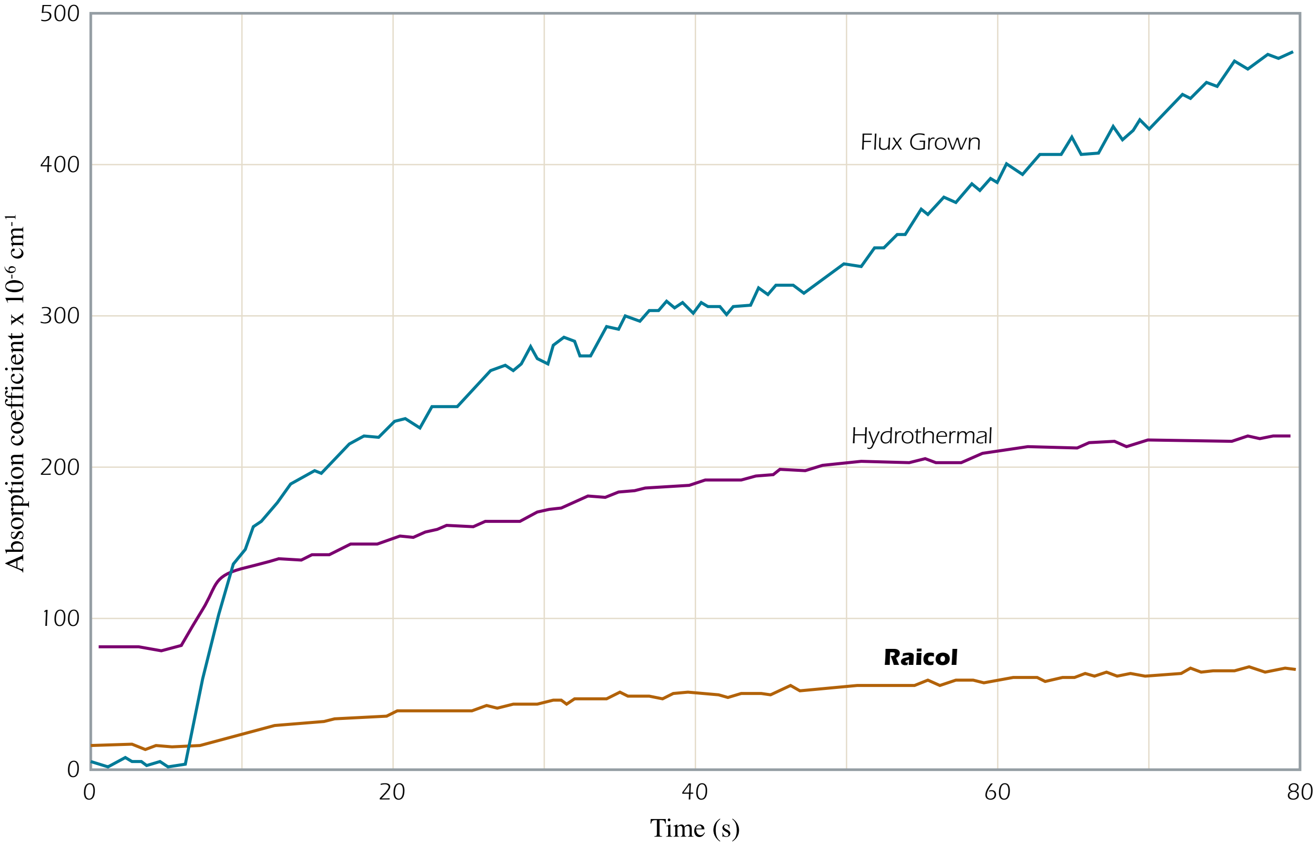
Optical Polishing Capabilities

Flatness	$\lambda/10$
Parallelism	5 arc sec
Perpendicularity	5 arc min.
Scratch/dig	None at x100 magnification

High Gray Track Resistance KTP Elements (HGTR KTP)

Gray-tracking Effect in KPT Crystals

IR (1064 nm) absorption growth under 10 KW/cm² of green light (514 nm)



In the GRIIRA (Green Induced Infrared Absorption) test, an infrared laser beam passes through the KTP element.

The initial measurement (at time 0) is the infrared absorption of the crystal. After a few seconds, a green laser beam is allowed to go through the crystal as well. The green light causes an increase in the IR absorption of the crystal. This effect has been show to correlate with gray tracking in KTP crystals.

The above graph shows that the Raicol HGTR KTP elements have both a lower initial IR absorption, and are affected less by the green laser. Thus, Raicol HGTR KTP is expected to have a higher gray track resistance than regular flux grown crystals or hydrothermally grown crystals.

Raicol Crystals
P.O.Box 2753 Industrial Zone, Yehud 56217, Israel
Tel: 972-3-9367412, Fax: 972-3-9068969
Email: info@raicol.com, Web: www.raicol.com

Periodically Poled KTP (PPKTP)

Periodically Poled KTP is an entirely new type of non-linear material. It can be tailor- made for all non-linear applications within the transparency range of KTP, without the phase matching limitations of bulk KTP. It's effective non linear coefficient is about three times larger than that of bulk KTP.

Raicol offers PPKTP in large production quantities, as well as small quantities for development work.

KTP is a ferroelectric crystal. In the classic use of bulk KTP, it is important to have a single domain crystal. In PPKTP, a periodic domain structure is artificially induced in the crystal. The exact spacing of these periods depends on the application, and ranges from a few microns to tens of microns. The period is induced in the direction in the crystal that has the highest non-linear coefficient, as opposed to the bulk crystal, where the direction is dictated by the phase matching constraints.

Some degree of crystal temperature control is necessary in using PPKTP.

PPKTP is produced in a multi-step process. An electrode of the desired structure is deposited on the surface of a KTP wafer, using micro lithographic techniques. An electric field is applied to the crystal under carefully controlled conditions, thus inducing the desired change in domain structure. The resulting KTP is then tested, cut into appropriate pieces, polished and coated.

The technique lends itself to mass production at a reasonable cost.

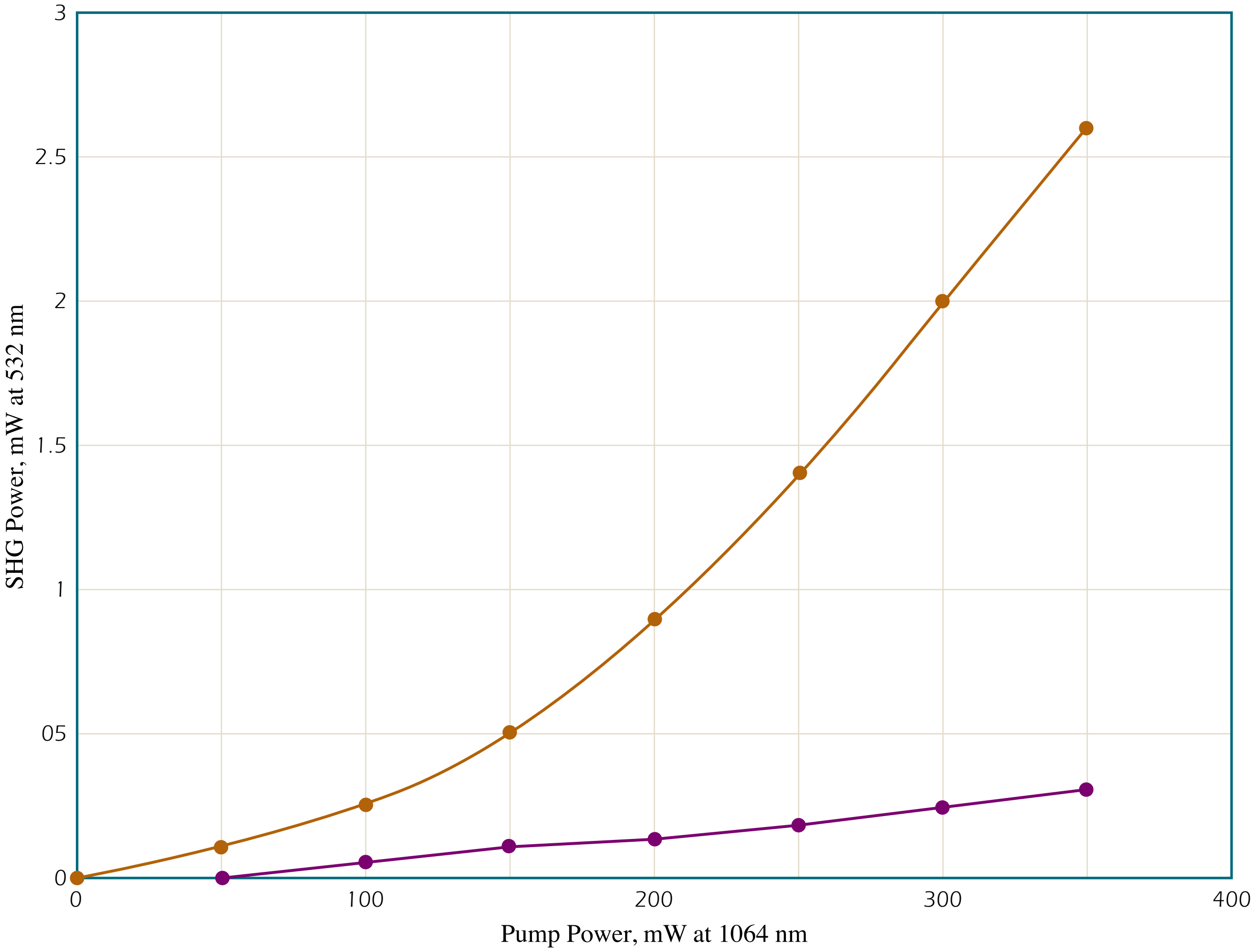
PPKTP is available in standard elements for some common applications, such as second harmonic generation of 1064 nm and 946 nm. It can be also be specially designed and manufactured for specific applications.

TYPICAL SPECIFICATIONS:

Wavelength Range	0.400 to 4.0 micron
Dimensions:	
Thickness (typical)	1 mm
Width (typical)	2 mm
Length	up to 30 mm

Periodically Poled KTP
(PPKTP)

Second Harmonic Generation in Periodically Poled and Bulk KTP



Test Conditions:

Crystal length = 10 mm

τ = 10 ns

Pulse frequency = 2 kHz

Raicol Crystals

P.O.Box 2753 Industrial Zone, Yehud 56217, Israel
Tel: 972-3-9367412, Fax: 972-3-9068969
Email: info@raicol.com, Web: www.raicol.com

RTP
(Rubidium Titanyl Phosphate)

RTP, which has only recently become commercially available, is the material of choice for many NLO and electrooptic applications. It's high optical damage threshold makes it especially useful in high power SHG and OPO applications. RTP's high electrical resistivity is important for many electrooptic applications, and in the production of Periodically Poled RTP elements.

RTP vs. KTP Comparison Chart

Property	*KTP*	*RTP*
Type II SHG at 1064 nm		
Phase matchable range (nm)	980-1080	1050-1140
Nonlinear coefficients (pm/V)		
d_{33}	16.9	17.1
d_{31}	2.5	3.3
d_{32}	4.4	4.1
d_{eff}	3.34	2.45
Phase matching angle (deg)	22-25	58
Walk-off angle (deg)	0.26	0.4
Angular acceptance (mrad cm)	20	20
Temperature acceptance (°C cm)	25	40
Transparency range (nm)	350-4500	350-4500
Other Properties		
Wavelength of noncritical OPO 1064nm (nm)	1570/3300	1600/3200
Electro optical coefficients (pm/V)		
r_{33}	36.3	39.6
r_{13}	9.5	12.5
r_{23}	15.7	17.1
Dielectric constant ε_{eff}	13	13
Optical damage ratio (to KTP)	1	1.8
Electrical conductivity along Z axis (Ω^{-1} cm^{-1})	10^{-6}-10^{-7}	10^{-11}-10^{-12}
Pyroelectric coefficient (C/cm^2 K)	7×10^{-9}	4×10^{-9}

RTP Electrooptic Q-Switch

The Q-Switch is built using 2 RTP (Rubidium Titanyl Phosphate) elements in a temperature compensating design.
The unique properties of RTP, including high electrical resistivity (~10^{12} Ω-cm) and a high damage threshold, result in a Q-switch with excellent properties.

ADVANTAGES

- High Damage Threshold
- Low Insertion Loss
- Non-hygroscopic
- No Piezoelectric Ringing
- Thermal Compensating Design

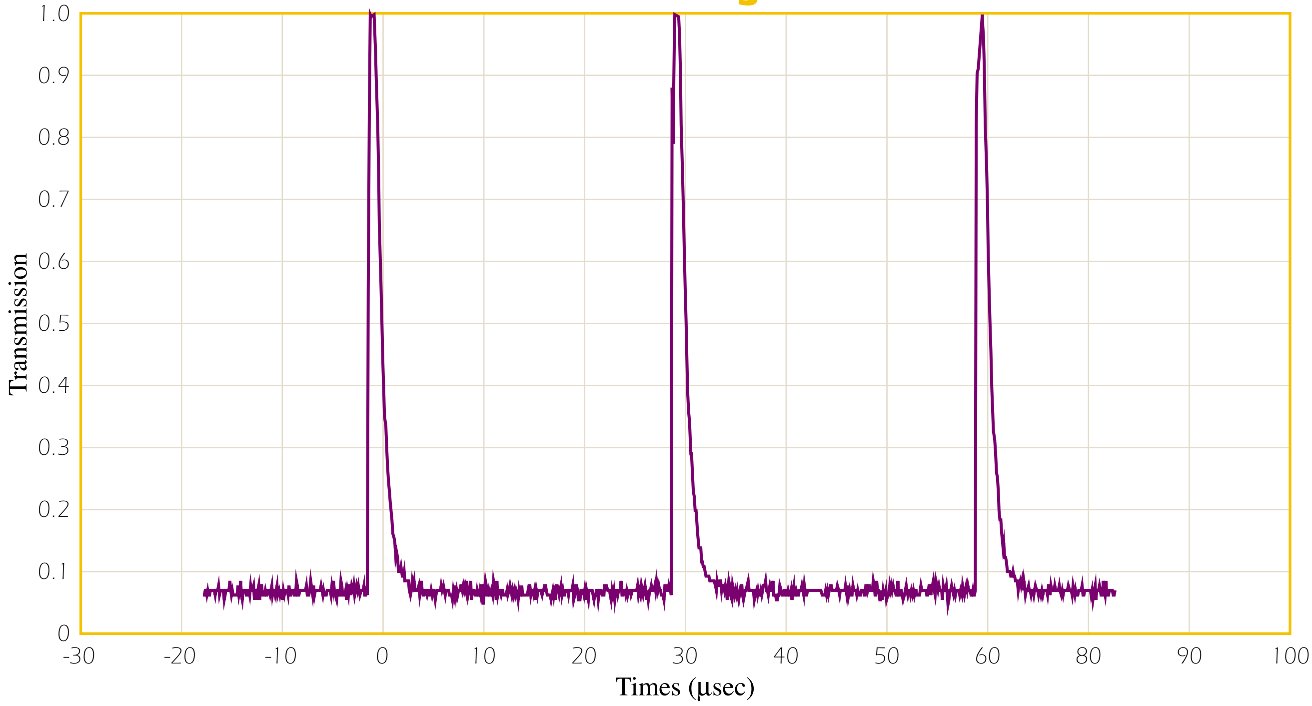
SPECIFICATIONS

Transmission at 1064 nm	> 98.5 %
Half Wave Voltage at 1064 nm, for 9x9x25 nm Q switch	1.3 - 1.5 KV
Contrast Ratio	> 20 dB
Clear Aperture	From 2x2 to 15x15 mm
Acceptance Angle	> 1 degree
AR coatings	R < 0.2% at 1064 nm
Damage threshold	> 600 MW/cm² at 1064 nm (τ=10 ns)

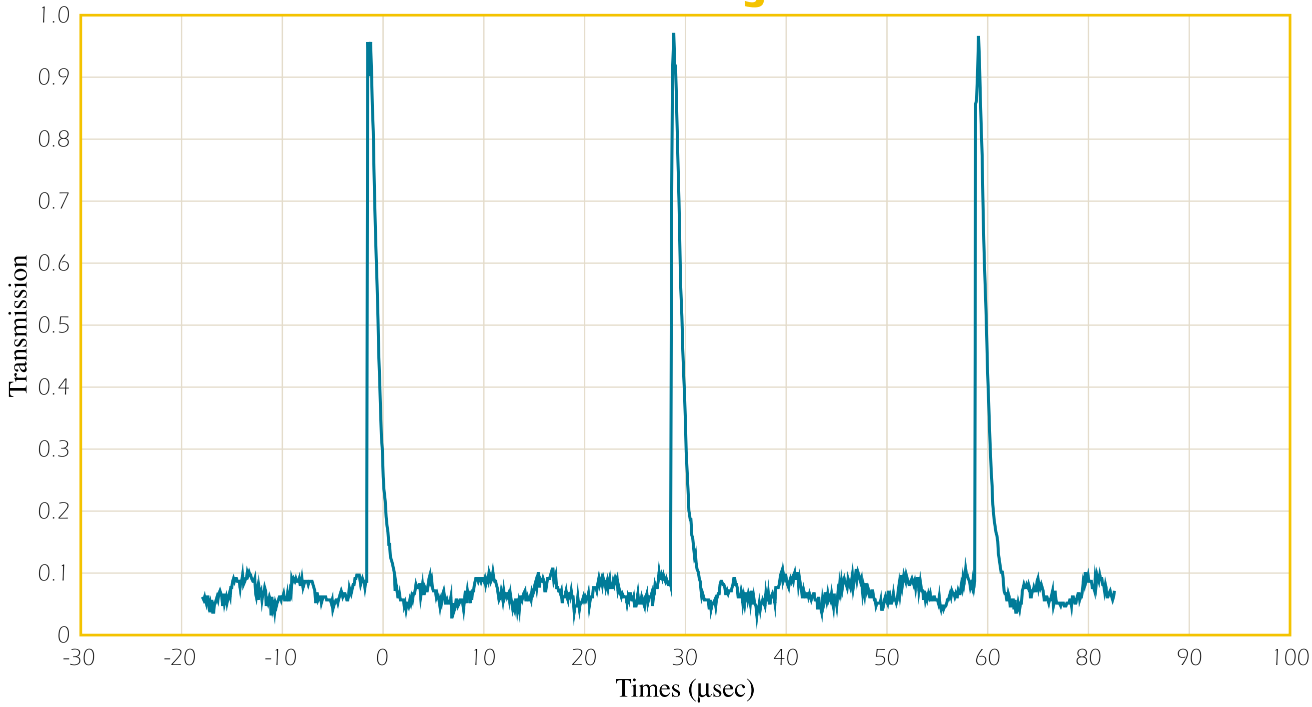
RTP Q-Switch

RTP Electrooptic Q-Switch

RTP Q-switch working at 30kHz.



BBO Q-switch working at 30kHz.



The graphs above show the behavior of RTP and BBO Q switches at high repetition rates. In particular, the BBO shows Piezoelectric ringing at 30 kHz, while the RTP Q switch shows no ringing at this frequency.
The BBO Q switch has a 2.5x2.5x25 mm element, while the RTP Q switch has two 6x6x7mm elements.

Raicol Crystals
P.O.Box 2753 Industrial Zone, Yehud 56217, Israel
Tel: 972-3-9367412, Fax: 972-3-9068969
Email: info@raicol.com, Web: www.raicol.com

Monolithic KTP / OPO

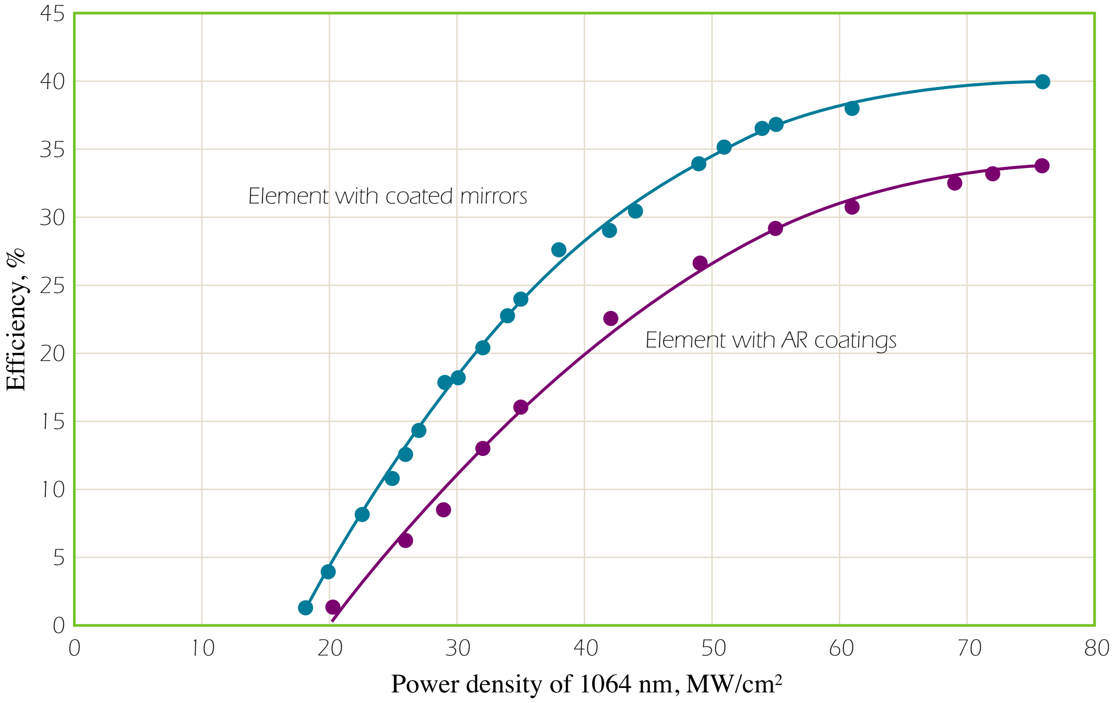
Some applications of OPO require compact size and vibrationless operation, which may be achieved by using a monolithic design of the OPO element. External (cavity) mirrors are eliminated in this design, and the mirrors are evaporated onto the KTP crystal input and output faces directly. In addition, a higher frequency conversion efficiency can be achieved (see a figure on next page).

Elements with flat mirrors are a standard product. A curved mirrors design is under development and it is aimed to achieve a narrower divergence angle of the monolithic OPO element.

SPECIFICATIONS

Apertures	up to 10 x 10 mm²
Length	up to 35 mm along X-axis
Flatness	l/10
Parallelism	< 5 arc sec
Input mirror	> 99.5 % @ wavelength upon request
Output mirror	upon request

Efficiency of KTP elements (L = 35 mm) by OPO 1064/1576 nm



Comparison of Electrooptic Materials

Property	Units	RTP	KD*P	$LiNbO_3$	$LiTaO_3$	BBO	KTP	RTA
Transparency range	µm	0.35-4.3	0.2-2.15	0.35-5.5	0.3-5.5	0.19-2.6	0.35-4.3	0.35-5.3
Refractive index		1.9	1.5	2.2	2.2	1.6	1.9	1.9
$V_{\lambda/2}$ (1064nm) (L=d) - static	kV	8*	9	8.5	5	46	8*	8*
Temperature coefficient of $V_{\lambda/2}$	%/°C	small	large	small	small	0.1	small	small
Dielectric constant, ε		11	48	27.9	45	6.7	15.4	11
Laser damage threshold (AR coated)	MW/cm²	600	500	280	400	1000	600	400
Conductivity, σ_{33}	S/cm	$\sim 10^{-11}$	$<10^{-12}$	$<10^{-12}$	$<10^{-12}$	$<10^{-12}$	$<10^{-6}$	$<10^{-9}$
Optical Homogeneity		good	excellent	fair	fair	excellent	good	good
Acoustic ringing		no	yes	yes	no	small	no	no
Temperature stability		good	problem	problem	good	good	good	good
Hygroscopic		no	yes	no	no	slight	no	no

Comparison of Electrooptic Materials

* $V_{\lambda/2}$ measured for light propagating in the x direction

Cr^{4+}:YAG Crystal - Passive Q-Switch

Cr^{4+}:YAG is an ideal material for Q-switching of Nd:YAG, and other Nd and Yb doped lasers.
The crystals are effective Q-switches in the wavelength range of 0.9 to 1.2 m.
Cr^{4+}:YAG is also a useful lasing material, with output from 1.35µ to 1.6µ (tunable).

SPECIFICATIONS

Doping level	up to 4 mole %
Size	up to 12 x12 mm aperture
Flatness	λ/10
Parallelism	5 arc sec
Scratch/dig	None at x100 magnification
AR Coating	< 0.15% @1064 nm
Initial Transmission	1% to 99%, per customer specification
Damage Threshold	1 GW/cm² at 1064 nm, τ = 10 ns

BBO Elements

BBO crystals combine very wide transparency, moderately high nonlinear coupling, high damage threshold and good chemical and mechanical properties. BBO phase matches over a wide range, yielding SHG from 0.19 to 1.75 microns.

APPLICATIONS

- *2nd, 3rd, 4th and 5th Harmonic Generation of Nd lasers*
- *2nd, 3rd and 4th Harmonic Generation of Ti: Sapphire and Alexandrite Lasers*
- *SHG of Argon, Cu vapor and Ruby lasers*
- *OPO and OPA*

Specifications - BBO Elements

Wavefront Distortion	*$\lambda/5$ at $\lambda = 0.633\mu$*
Absorption coefficient	*$\alpha < 0.005\ cm^{-1}$ from 0.2µ to 3.5µ*
Damage threshold	*1 GW/cm^2 at 1.064m, $\tau = 1$ ns*
Bubbles, inclusions, etc.	*none*
Apertures	*up to 20 x 20 mm^2*
Length	*up to 20 mm*
AR coatings	*dual band R < 0.2%*
	Damage Threshold 1GW/cm^2, 10 ns pulse, 10Hz

Certified frequency conversion efficiency (upon request)

Optical Polishing Capabilities

Flatness	*$\lambda/10$*
Parallelism	*5 arc sec*
Perpendicularity	*5 arc min.*
Scratch/dig	*None at x 100 magnification*

LBO (Lithium Triborate) Elements

LBO crystals combine wide transparency, moderately high nonlinear coupling, high damage threshold and good chemical and mechanical properties.

APPLICATIONS

SHG of:

Nd: TAG	Alexandrite	Ti:Sapphire
Nd:YLF	Cr:LiSAF	Dye Lasers

Ultrashort Pulses

Third Harmonic Generation of Nd:YAG and Nd:YLF

OPO and OPA

Specifications - LBO Elements

Wavefront Distortion	$\lambda/10$ at $\lambda = 0.633$m
Absorption coefficient	$\alpha < 0.005$ cm^{-1} from 0.2μ to 2.5μ
Bubbles, inclusions, etc.	none
Apertures	up to 20 x 20 mm^2
Length	up to 20 mm along X axis
AR coatings	dual band $R < 0.2\%$
Damage threshold, coating	1 GW/cm^2 at 1064 nm, $\tau = 10$ ns
Damage threshold, crystal	> 10 GW/ cm^2

Certified frequency conversion efficiency (upon request)

Optical Polishing Capabilities

Flatness	$\lambda/10$
Parallelism	5 arc sec
Perpendicularity	5 arc min.
Scratch/dig	None at x 100 magnification

Barium Nitrate (BN) Raman Crystals

Barium Nitrate monocrystals are one of the best solid state materials for shifting the emission frequency of lasers to different spectral region using Stimulated Raman Scattering effect.

The Raicol advanced crystal growing technique based on the water solution method yields large transparent BN crystals.

BASIC PROPERTIES

Chemical formula	$Ba(NO_3)_2$
Crystal structure	Cubic, space group $P2_13$
Cell parameter	8.11 A
Density	3.244 g/cm^3
Mohs Hardness	2.5-3
Thermal Conductivity	1.17 W/m/°C @ 25°C
Thermal Expansion Coefficient	1.3 x 10^{-5}/°C @ 25°C

OPTICAL AND RAMAN PROPERTIES

Transmitting range	350 - 1800 nm
Refractive indexes	1.575 @ 532 nm, 1.555 @ 1064 nm
Raman frequency Stokes shift	1047.3 cm^{-1}
Raman Linewidth	0.4 cm^{-1}
The wavelengths of Stock components for Nd:YAG lasers	@ 532 nm: 504 nm, 563 nm, 599 nm, 639 nm @ 1064 nm: 957 nm,1197 nm, 1369 nm 1598 nm @ 1319 nm: 1159 nm, 1530 nm, 1822 nm, 2252 nm
Conversion efficiency	up to 60%
Laser damage threshold	> 500 MW/cm^2 for 10 ns pulse @ 1064 nm

SPECIFICATIONS

Aperture	up to 15 x 15 mm
Length	up to 100 mm
Flatness	λ/4
Parallelism	30 arc sec
Perpendicularity	5 arc min
Scrath/dig	20/10
Extinction ratio	> 20 dB
AR coating	on request

NOTES

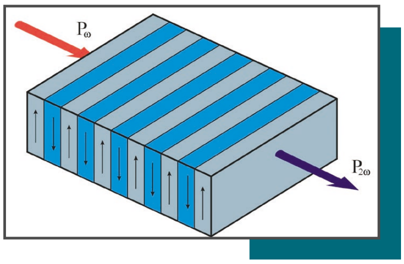
NOTES

Raicol Crystals

OUR PRODUCTS

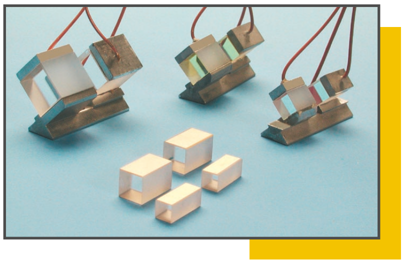
Periodically Poled KTP (PPKTP)

Periodically Poled KTP is an entirely new type of nonlinear material. It can be tailor-made for all non-linear applications within the transparency range of KTP, without the phase matching limitations of bulk KTP. It's effective non linear coefficient is about three times larger than that of bulk KTP. Raicol offers PPKTP in large production quantities, as well as small quantities for R&D work.



RTP Electrooptic Q-Switch

The Q-switch is built using 2 RTP elements in a temperature compensating design. The unique properties of RTP, including high electrical resistivity ($\sim10^{11}$-10^{12} Ohm*cm) and a high damage threshold, result in a Q-switch with outstanding properties. These Q-switches have been tested at 100 kHz, with no sign of piezoelectric ringing.

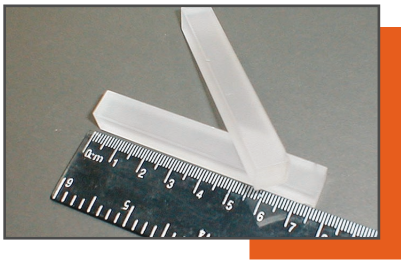


KTP Elements for OPO, SHG

Raicol's KTP elements are recognized in the world due to its high quality and reliability. Our controlled growth methods ensure a reliable supply of KTP crystals possessing very low absorption coefficient $a < 5{\cdot}10^{-5}$ cm^{-1}@ 1064 nm and $a < 2{\cdot}10^{-3}$ cm^{-1}@ 532 nm.

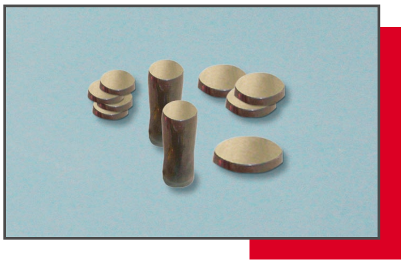
Barium Nitrate (BN) Raman Crystals

Barium Nitrate monocrystals are one of the best solid state materials for shifting the emission frequency of lasers to different spectral region using Stimulated Raman Scattering effect.
With Raicol advanced crystal growing technique large transparent BN crystals are grown.



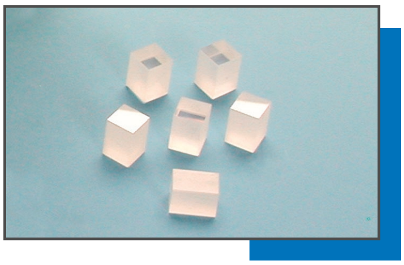
Cr^{4+}:YAG Passive Q-switch

Cr^{4+}:YAG is an ideal material for passive Q switching of Nd:YAG, and other Nd and Yb doped lasers, in the wavelength range of 900 nm to 1200 nm. Cr^{4+}:YAG is also a useful lasing material, with output from 1350 nm to 1600 nm (tunable).



BBO Elements

BBO (Beta Barium Borate) crystals combine very wide transparency, moderately high nonlinear coupling, high damage threshold and good chemical and mechanical properties. BBO phase matches over a wide spectral range, yielding SHG from 190-1780 nm.



Raicol Crystals Ltd., a privately owned hi-tech company based in Israel, is a leading manufacturer of nonlinear optical materials and devices. Raicol's flux-grown KTP and RTP crystal products are world renowned for their high quality and reliability.
The company's unique crystal growth technology ensures that its customers receive highest quality robust Gray-Track-Resistant KTP elements for intra-cavity CW and high average power SHG @1064 nm.

Raicol's patented technology for the fabrication of periodically poled KTP (PPKTP) enables the production of nonlinear elements for applications in diverse wavelengths, ranging from visible to infra-red.

With its meticulous supervision over crystal growth and comprehensive quality control over all stages of the fabrication process, Raicol received ISO 9001:2000 certification.

Raicol's dynamic and energetic team, including specialists in crystal growth technologies, technicians, production workers and members of the marketing and managerial team, ensures excellent technical support to its clients. The company's state-of-the-art facilities in Israel house its cutting and polishing machinery, X-ray measurements systems, clean room and optical workshop, integrated to ensure world-class quality and reliability for clients and OEMs.
In a separate laboratory, Raicol conducts intensive research in the development of new materials and devices as well as the improvement of existing products and technologies.

P.O.Box 2753 Industrial Zone, Yehud 56217, Israel
Tel: 972-3-9367412, Fax: 972-3-9068969
Email: info@raicol.com, Web: www.raicol.com

Raicol Crystals