

Sapphire is an anisotropic monoaxial crystal. It is one of the hardest and durable materials, chemically inert, with low friction coefficient, excellent optical and dielectrical characteristics, and thermal stability to 1600°C. Its abrasion stability is by 8 times higher than that of steel. Due to these unique properties and wide optical transmission range (0.17 - 5.5 μm) sapphire is used as the material for production of UV, visible, and NIR optics for operation under critical conditions like high temperature, high pressure, chemically aggressive or abrasive environment.



Physical properties of sapphire

Chemical formula	Al_2O_3
Crystal class	Hexagonal system, rhomboidal class 3 m
Lattice constants, Å	$a=4.758$ $c=12.991$
Density, g/cm ³	3.98
Hardness	2000 with 2000 gidenter (Knoop) 9 (Mohs)
Surface quality, scr/dig	60/40
Optical transmission range, μm	0.17-5.5
Refractive index at 0.532 μm	$n_o=1.7717$, $n_e=1.76355$
Water absorption	nil
Young Modulus, Gpa	345
Shear Modulus, Gpa	145
Bulk Modulus, Gpa	240
Bending Modulus (Modulus of Rupture), Mpa	420 at 20°C 280 at 500°C
Elastic Coefficient	$C_{11}=496$, $C_{12}=164$, $C_{13}=115$, $C_{33}=498$, $C_{44}=148$
Poisson ratio	0.25-0.30
Friction coefficient	0.15 on steel, 0.10 on sapphire

Thermal properties of sapphire

Melting point, K	2303
Specific heat, J/(kg x K)	105 at 91K, 761 at 291K
Thermal coefficient of linear expansion, K ⁻¹ , at 323K	6.66×10^{-6} parallel to optical axis, 5×10^{-6} perpendicular to optical axis
Thermal conductivity, W/(m x K) at 300K	23.1 parallel to optical axis, 25.2 perpendicular to optical axis

Electrical properties of sapphire

Resistivity, Ohm x cm at 200-500 °C	$10^{11} - 10^{16}$
Dielectric constant	10.0
Dielectric strength, V/cm	4×10^5
Loss tangent	1×10^{-4}

Sapphire stability parameters

Main properties preservation	to 1600°C
Solubility in water	insoluble
Solubility in (HNO_3 , H_2SO_4 , HCl, HF)	insoluble to 300°C
Solubility in alcalis	insoluble to 800-1000°C
Solubility in melts of metals (Mg, Al, Cr, Co, Ni, Na, K, Bi, Zn, Cs)	insoluble to 800°C
Radiation stability	No change in transmission above 2.5 μm after exposure to 10^7 Rads. No visible coloration after exposure to 10^8 Rads/hr for 60 minutes at - 195°C

Proton radiation stability	No change in transmission below 0.3 mm after exposure to 10^{12} proton/cm ² total dose
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Sapphire refractive index vs wavelength

λ , μm	No	Ne	λ , μm	No	Ne
0.193	1.92879	1.91743	0.670	1.76433	1.75632
0.213	1.88903	1.87839	0.694	1.76341	1.75542
0.222	1.87540	1.86504	0.755	1.76141	1.75346
0.226	1.87017	1.85991	0.780	1.76068	1.75274
0.244	1.85059	1.84075	0.800	1.76013	1.75222
0.248	1.84696	1.83719	0.820	1.75961	1.75168
0.257	1.83932	1.82972	0.980	1.75607	1.74819
0.266	1.83304	1.82358	1.064	1.75449	1.74663
0.280	1.82437	1.81509	1.320	1.75009	1.74227
0.308	1.81096	1.80198	1.550	1.74618	1.73838
0.325	1.80467	1.79582	2.010	1.73748	1.72973
0.337	1.80082	1.79206	2.249	1.73232	1.72432
0.351	1.79693	1.78825	2.703	1.719	1.711
0.355	1.79598	1.78732	2.941	1.712	1.704
0.442	1.78038	1.77206	3.333	1.701	1.693
0.458	1.77843	1.77015	3.704	1.687	1.679
0.488	1.77530	1.76711	4.000	1.674	1.666
0.515	1.77304	1.76486	4.348	1.658	1.65
0.532	1.77170	1.76355	4.762	1.636	1.628
0.590	1.76804	1.75996	5.000	1.623	1.615
0.633	1.76590	1.75787	5.263	1.607	1.599

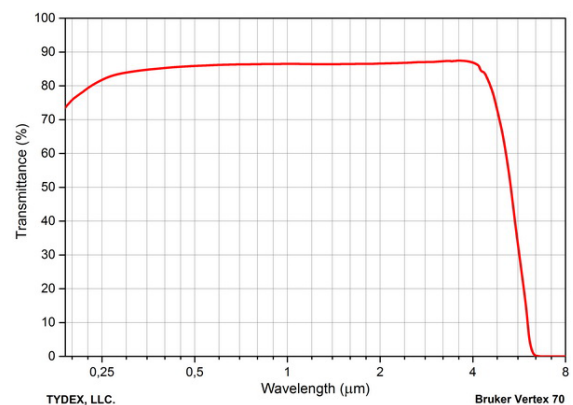
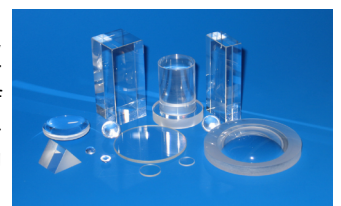


Fig. 1 Transmission spectrum of 3 mm-thick sapphire window.

For production of optics we use sapphire grown by Musatov method (Russian modification of Kyropulos method). We also offer shaped sapphire grown by Stepanov method (analogue of EFG process).

Musatov sapphire

Musatov sapphire is characterized by superior crystalline perfection, high optical homogeneity and minor internal defects. Advanced level of growth technology and special post-growth treatment allow getting UV-stable material. Great demand for the material nowadays and

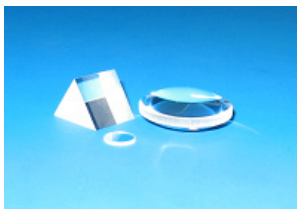


significant improvements both in technology and machining made it possible to get sapphire boules with the following overall dimensions – D300 mm and up to 250 mm length (along growth direction).

Sapphire is a slightly birefringent material and basically an application dictates the requirements to its orientation. For majority cases type of orientation is not so important and it is selected upon our choice basing on existing polishing technology. For laser application, sensors, illuminators as well as other viewing windows when the birefringence effect must be minimized we use C-axis (<0001>) sapphire. For specific applications a precise orientation to meet customer' needs is also provided.

We had developed and have been using chemical-mechanical polishing process. Together with some improvements of the technology it allows us to produce high quality optical components (surface quality 20/10scr/dig, surface accuracy $\lambda/10$ @ 632 nm) which both are required for most exacting laser applications.

We offer the following products made of high quality Musatov sapphire:



Optics for laser and spectroscopy applications

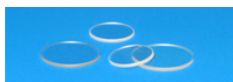


Waveguides (lightguides) for medical application (for skin treatment and epilation)

Range of the products for these applications is wide and herewith we only highlight our standard specifications as well as demonstrate some photos.

Windows for Nd:YAG laser

Specification:

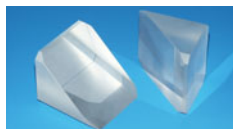


Material	Optical grade sapphire
Orientation	C-axis
Tolerance for overall dimensions, mm	+0/-0.12
Clear aperture, %	>90
Tolerance for thickness, mm	+/-0.1
Surface quality, scr/dig	20/10
Surface accuracy, fringes (N)	<=6
Wedge, arc. min.	< 5
Coating	AR/AR @ 1064 nm, R <=0,6% per side

Sapphire windows with overall dimensions D10.5 x 1 mm as well as D8 x 1 mm are available from stock anytime.

Prisms

Specification:



Material	Optical grade sapphire
Tolerance for linear dimensions, mm	+0/-0.2
Clear aperture, %	>85
Surface quality, scr/dig	40/20
Surface accuracy, fringes (N)	<=4

Tolerance for angular dimensions, arc. min.	+/-10
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Lenses (plano-convex, plano-concave, meniscus)

Specification:



Material	Optical grade sapphire
Tolerance for diameter, mm	+0/-0.2
Clear aperture, %	>90
Effective focal length (EFL) tolerance, %	+/-2
Tolerance for thickness, mm	+/-0.2
Surface quality, scr/dig	40/20
Surface accuracy, fringes (N)	<=4
Edge thickness variation (ETV), mm	<=0.05

Protective windows for sensors

Specification:



Material	Optical grade sapphire
Tolerance for overall dimensions, mm	+0/-0.25
Clear aperture, %	>90
Tolerance for thickness, mm	+/-0.25
Surface quality, scr/dig	40/20
Wedge, arc. min.	< 5

Sapphire windows with D25.4mm and D32mm of various thicknesses are available from stock anytime.

Special optics for spectroscopy (ATR elements)

ATR elements made of sapphire are unexpendable and used when an application dictates the exaggerated requirements to durability of the material, its chemical stability and non-toxicity. Upon customer' demand we drill the internal holes (both blind and through) into these parts, for example to place a thermocouple inside (see the photo). Minimal diameter is 0.5 mm.



Specification:

Material	Optical grade sapphire
Tolerance for linear dimensions, mm	+/-0.1
Clear aperture, %	>85
Tolerance for angular dimensions, arc. min.	+/- 6
Surface quality: plano surfaces, scr/dig	60/40
Surface quality: barrel	fine ground

Hyper-hemispherical, hemispherical, hypo-hemispherical, and balls

Specification:



Material	Optical grade sapphire
Available diameters, mm	+/-0.25
Tolerance for overall dimensions, mm	2-25



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Surface quality, scr/dig	80/50
Surface accuracy, mm	0.01 deviation from ideal sphere and plane

Such parts are widely used and depending on application can be classified as commodity goods. On the contrary Tydex specializes in production of custom-made elements in small and medium quantities (several tens per month). Recently it was discovered that similar sapphire parts can be successfully utilized as optics for THz range.

Precisely-oriented seeds to grow crystals

To grow some crystalline materials, for example Musatov sapphire boules, precisely-oriented seeds are required. Orientation tolerance of as grown crystal is caused by initial orientation of the seed. Our best achievable orientation tolerance is ± 10 arc. min.



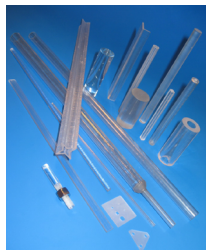
Specification:

Material	Optical grade sapphire
Orientation	C -, A -, R-axis along a part' length (is specified by customer)
Orientation tolerance, arc. min.	± 12
Wedge between the opposite surfaces, arc. min.	< 3
Tolerance for overall dimensions, mm	± 0.25
Surface quality	Fine ground
Groove (for technological reasons)	is specified by customer

For production of high quality optical components we use optical grades 1 - 4 (please see the classification of sapphire grades in the end of the chapter). For less exacting applications and upon negotiation with a customer both technical grades (5 - 6) are used.

Stepanov shaped sapphire

Machining of sapphire is limited by material hardness. Stepanov' technology provides control of both shape and orientation of sapphire crystal during its growth. It allows one to grow ribbons, rods, tubes, etc. Such parts require minimal post-growth machining or even do not require it at all. On one hand, this extends sapphire application fields considerably. On the other hand, this results in significant reduction of material and work consumption and, therefore, in the price reduction. Sapphire of optical quality (grades 3-4) as well as cost-effective construction grades are available.



Sapphire rods, tubes (including those sealed at one end), ribbons, as well as crystals with complicated cross-sections are available.

We may highlight such applications of single crystal shaped sapphire as protective envelopment for vapour lamps, high temperature electrical insulators, crucibles, optical light pipes, etc. It finds its place in nuclear, medical, research, industry and others fields.

Available sizes are:

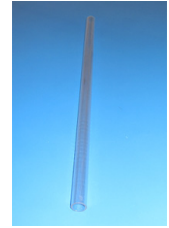
- Length: to 1 meter;
- Cross section: 2-40 mm with tolerance ± 0.05 mm;
- Weight: to 1 kg.

Additional parameters for tubes - minimal wall thickness is 0.5 mm, minimal inner diameter - 0.8 mm.

We offer the following products made of Stepanov sapphire:



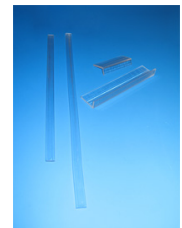
Rods for subsequent production of lightguides, scalpels, cutters, and other components for various applications including medicine (ophthalmology, neurosurgery, cosmetology etc.)



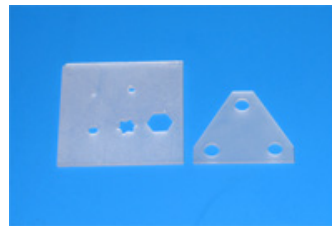
Tubes, including ones to be used as chemical utensils as well as seeds to grow nonlinear crystals



Tubes with variation of cross-section along their length including ones for utilization in MOCVD equipment used for epitaxial crystal growth



Ribbons to be used as tracks to guide the units of multi-coordinate equipment



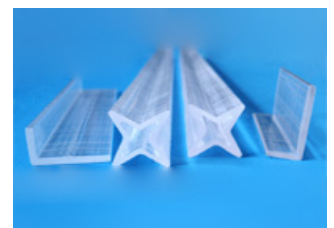
Electrical insulators working at wide temperature and pressure ranges (parts of complex cross-section as well as drilled ones are available upon inquiry)



Capillaries and multi-channel tubes for thermocouple covers. High thermal stability and durability of the sapphire make it key material for various critical applications



Parts with external thread



Various parts of complicated design

Sapphire quality grades

Grade 1: free of insertions, block boundaries, twins, microbubbles and scattering centers;

Grade 2: free of insertions, block boundaries, twins; individual scattering centers (microbubbles $< 10 \mu\text{m}$ located not closer than 10 mm) are allowed;

Grade 3: free of insertions, block boundaries, twins; individual bubbles $< 20 \mu\text{m}$ located not closer than 10 mm to each other are allowed;

Grade 4: free of insertions, block boundaries, twins; bubbles $< 20 \mu\text{m}$





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located not closer than 2mm from one another as well as bubbles clusters (which may include individual bubbles to 50 μm) of size < 200 μm scattered not closer than 10 mm to each other within the effective volume 20x20x20 mm are allowed;

Grade 5: free of insertions, block boundaries, twins; bubbles < 20 μm located not closer than 2mm from one another as well as bubbles clusters (which may include individual bubbles to 50 μm) of size < 500 μm scattered not closer than 5 mm to each other within the effective volume 20x20x20 mm are allowed;

Grade 6: free of insertions, block boundaries, twins; defective areas with bubbles clusters of size > 500 μm are allowed.

We consider 1-4 grades as optical ones; 5-6 as technical (construction) ones. For all optical grades blue and green coloration is not allowed. For all technical grades coloration is not controlled. Insertions, block boundaries and twins inside the material are controlled visually between crossed polarizers.

Please pay attention that this article is only for your information. We do not supply sapphire in boules, ingots as well as semi-finished products. Our standard products are finished (polished, coated) parts.

For price quotation and delivery please fill in request form at our website.

