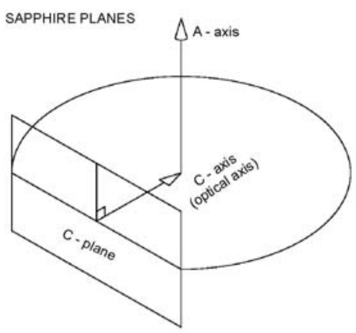
CRYSTRAN'S ROUGH GUIDE TO OPTICAL SAPPHIRE

Sapphire is one of the hardest optical materials in general use, surpassed only by diamond. Here we discuss some of the properties. We believe the points made to be true but they represent only the hints we have collected from manufacturers and crystal growers over years of handling sapphire.

CRYSTALLINITY: Sapphire is slightly birefringent and so for critical optical or mechanical applications, the windows should be specified as 'zero degree', or 'c-cut', meaning that the optical axis of the material should be perpendicular to the plane of the window. If unspecified, the component will be of 'random' cut, but its worth noting that this is nearly always 60° to the optic axis as this is the 'softest' direction for the saw. Note that all sapphire is always single crystal, sub-grains are always avoided in the cut.



C-plane (0,0,0,1)	= Z-cut	
A-plane (1,1,-2,0)	= Y-cut	
M-Plane (1,0,-1,0)	= X-cut	R-Plane (1,0,-1,0)

Manufacturers seem unable to agree on the thermal expansion coefficient of sapphire, figures from 5.6 to 8.4 x 10^{-6} K are given. While there may be some variation due to the method of growth, and certainly due to the axis of cut, this variation is inexplicable.

CRYSTAL GROWTH: Much small diameter sapphire is produced in Switzerland by the Verneuil growth process, which seems to introduce a natural cleavage plane down the centre of the ingot. It appears that these 'half-ingots' are often used to good effect for windows of diameter smaller than 20mm. See also the later note on UV performance. Larger ingots are grown in the USA by a patented method. In the case of these large ingots, it seems that the manufacturer selects from ingots into three grades according to structure. The top two of these grades probably being the best (and most expensive) available. Sapphire is also produced by a ribbon process which can yield large sheets in standard thicknesses, of minimal optical quality.

POLISH: Sapphire can be polished to a high standard, but because of its hardness, must be subjected to high forces during the process. Thus if good flatness is required, the window thickness should be at least 10% of diameter

TRANSMISSION: Use in the IR is restricted to about 5µm and little difficulty is encountered with any optical grade. It is in the UV range that caution must be observed as the transmission from 140nm through to 240nm is extremely sensitive to small levels of impurity and also to interstitial vacancies.

From the early 1990s, there is an indication that the quality of raw materials available to crystal growers may have deteriorated and exacerbated this problem, but this is unconfirmed. 'Normal' material certainly shows a poor UV performance 160nm to 240nm, although small windows made from the Verneuil 'half-boules' mentioned above often give good transmission.

Apart from impurity considerations, the main reason for poor UV is a broad absorption at 205nm caused by interstitial vacancies. And even the highest optical quality material, grown from the purest starting materials, does not give the best UV transmission without further treatment. There exists a treatment process for converting 'standard' material into UV grade. The details of this process are not generally available, but it can be speculated that the process involves heat treatment to remove interstitials as it is apparently reversible by heat. Thus, the sealing of windows into mountings will degrade the UV performance unless correctly performed with minimum heat treatment.

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