SAPPHIRE CRYSTAL GROWTH METHODS:

A Brief Comparison

EFG (Edge-defined, Film-fed Growth)	KYROPOLOUS (KY)	HEM (Heat Exchanger Method)	FEATURE / ATTRIBUTE	HDSM (Bagdasarov)	VERNEUIL (Flame fusion)	CZOCHRALSKI (CZ)
Melt pulled through shape-specific die - sheet (ribbon), tube or rod	Top down, turn boule, fixed crucible, A axis	Bottom up, fixed furnace and crucible, A axis	GROWTH PROCESS	Melt pulled through hot zones horizontally	Sintering, pile of sapphire	Pull crystal from melt and turn; diameter determined by pull rate
Alumina oxide powder	Alumina oxide powder, densified pellets	Crackle	FEED MATERIAL	Multiple types	Compacted feedstock	Densified charge
Near net' shape - ribbon (sheet), tube, rod	Boule (ingot) 'oversized paint can'	Boule (ingot)	OUTPUT SHAPE	Slab	Long narrow ingot (boule)	Long narrow ingot (boule)
Tubes / Rods up to 30" (750+ mm) long; Sheets up to 18" dia x .400" thick	13-15" dia A plane; 12" C plane; tubes 8" long	13-15" dia A plane; 12" C plane; tubes 8" long	DIMENSIONS	350 x 500 x 40 mm, any orientation	13 mm dia x 50 mm length max	150 mm dia x 250 mm length
Low optical grade , structural / mechanical	Excellent, good clarity, consistent high optical quality	Excellent, pink tint w/o annealing Grade 1-4	OVERALL MATERIAL QUALITY	Excellent, good clarity, consistent high optical quality	Excellent, good clarity, consistent high optical quality	Excellent, good clarity, consistent high optical quality
High	Low	Low	DEFECT DENSITY	Medium	Low	Low
Low	Med/High	High	OPTICAL TRANSMISSION	Medium	High	High
Average	Excellent	Excellent	EASE OF FABRICATION	Good	Difficult	Average
Good for high volumes; ability to grow long tube, & rod; large sheet; low pricing	Excellent for optical applications; adequate for substrate material	Superior optical quality, transmission through entire spectrum; low cost	ADVANTAGES	Crystal dimensions not possible by any other growth methods; visual seed monitoring	High optical transmission, material consistency	Superior optical quality, transmission through entire spectrum; low cost
Poor optical quality, high defect density	Costly to fabricate, cannot produce long tubes	Costly to fabricate, cannot produce long tubes	DISADVANTAGES	Some geometries costly to fabricate	Small parts only	Small parts only
Low	Medium	High	PRICE LEVEL	Medium	Medium / High	High

NOTE: This is not a comprehensive list of every single crystal growth technology; there are some niche-growth operations, and others that are promising but still in development. S&D will update this list as other crystal growth technologies emerge. Follow us on Twitter @sanddmaterials to receive updates.