AOS Application Note:
Zero-Expansion Ceramic Optics

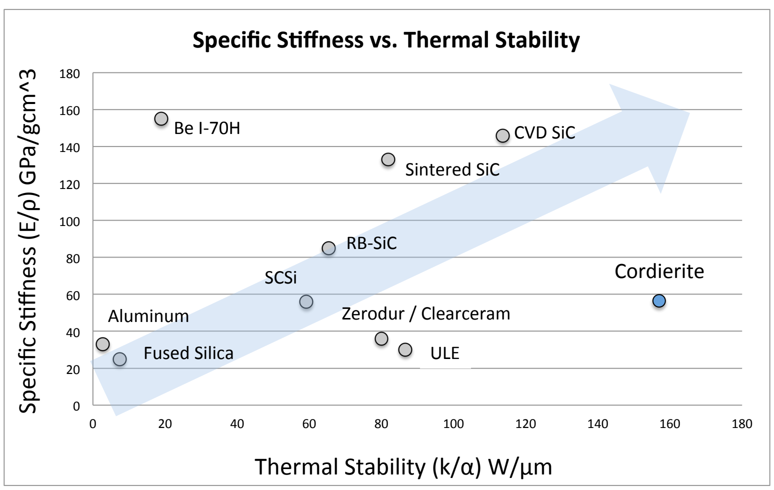
Aperture Optical Sciences

INTRODUCTION

Cordierite ($2MgO\text{-}2Al_2O_3\text{-}5SiO_2$) is the name for a variety of low expansion ceramics that can be used for optical applications with some highly compelling advantages. Cordierite material can be made with a nearly zero expansion coefficient and has higher modulus and thermal conductivity when compared with traditional glass-ceramics. As a sintered material, lightweight structures can be efficiently machined in the "green" pre-sintered state and options for fusing components are possible during sintering. Cordierite materials were introduced in the 1990's for semiconductor wafer chucks and coordinate reference mirrors. AOS now offers cordierite as a material option for precision optics. The following technical note explores additional technical data and applications.

MECHANICAL PROPERTIES FOR MIRRORS

Cordierite has several interesting advantages over traditional materials that can be seen by examining the figures of merit known as specific stiffness and thermal stability. Specific Stiffness is calculated as Young's Modulus divided by density and is a measure of the efficiency of the material for lightweight mirrors. The higher specific stiffness the less material is needed to maintain mirror form quality under load. Cordierite outperforms all glass materials including Zerodur and Clearceram. The other important quantity is the Thermal Stability calculated as the thermal conductivity divided by the thermal expansion coefficient. Materials with a high thermal conductivity and low thermal expansion will equilibrate quickly to changes in temperature with minimal deformation to the surface. Cordierite has the highest thermal stability ratio of any comparable mirror material.



Density	g/cm^3	2.5
Young's Modulus	Gpa	143
3-point Bending Strength	Mpa	230
Fracture Toughness	Mpa^1/2	1-1.5
Vickers Hardness	Gpa	8-8.5
Thermal Exp. Coefficient	x 10^-6/K	0.03
Thermal Conductivity	W/m K	4.7
Specific Heat	J/g K	0.8-4
Dielectric Constant	-	3.7-4.2
Electric Resistivity	Ohm cm	10^12 - 10^15

Figure 1: Material Figures of Merit for Lightweight Mirrors & Cordierite Properties

The preferred combination of these figures of merit make Cordierite an attractive material for laboratory reference mirrors, optics for airborne systems, lightweight optical structures, satellite telescopes, and optical systems used in varying thermal environments.

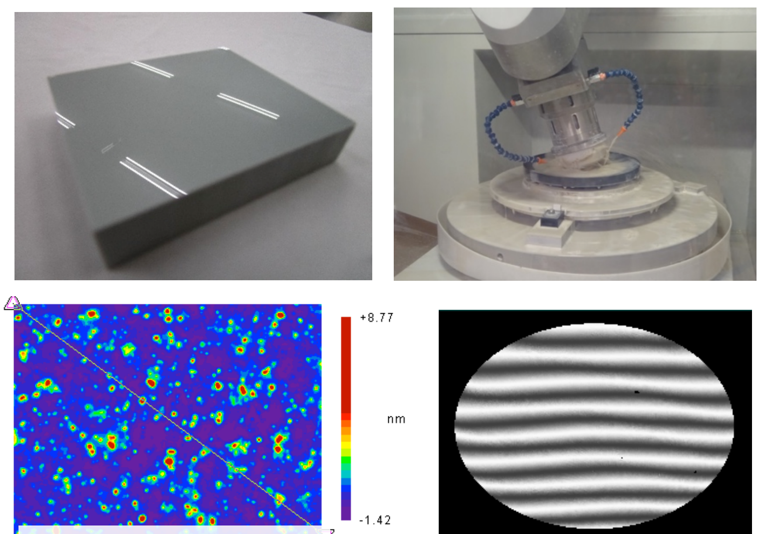
MANUFACTURING FORMS

Cordierite is available in monolithic forms up to 1.5 meters. Aperture Optical Sciences offers flat, spherical and aspheric mirrors in sizes from 50-mm up through 800-mm. As a sintered material, lightweighting may be economically milled in the green state allowing for rapid manufacturing processes. Assemblies may be

© 2017 Aperture Optical Sciences Inc.

constructed by fusing components together during sintering. This allows for the manufacture of closed-back structures and complex structures. The low porosity and fine grain structure enable polishing with conventional processes to obtain roughness under 1 nm RMS and form tolerances equivalent to other optical mirror materials. No cladding is required for polishing, as the bulk material properties are sufficient to achieve final surface tolerances for roughness. Cost of lightweight mirrors made from Cordierite are comparable to those of glass and glass-ceramics. Figures 2 and 3 show example data on roughness and surface form obtained by Aperture Optical Sciences. Figure 5 shows a Cordierite Mirror on one of AOS's robotic polishing machines.

APPLICATION EXAMPLE: *Lightweight Reference Mirrors*[1]



RMS Roughness 0.7 nm

CONCLUSIONS

1. When contemplating material selections for lightweight mirrors or thermally stable optical components, designers should now consider Cordierite as an advantageous alternative.
2. Cordierite has the highest Thermal Stability of any precision optical material available today.
3. Cordierite mirrors may be polished to equivalent quality as traditional materials, have equivalent density, but significantly higher stiffness. This makes cordierite a highly efficient lightweight mirror material.

AUTHOR

Flemming Tinker, President, Aperture Optical Sciences Inc.

Flemming Tinker has been working in the field of optics engineering and manufacturing for over 30 years and holds degrees in Optics from the University of Rochester, and Manufacturing Engineering from Boston University. Mr. Tinker is a specialist in optics manufacturing & management involving innovative technologies.

[1] Data and samples provided by Kyocera Incorporated

© 2017 Aperture Optical Sciences Inc.