Improved Characteristics of ULE® Glass for Meeting EUVL Needs

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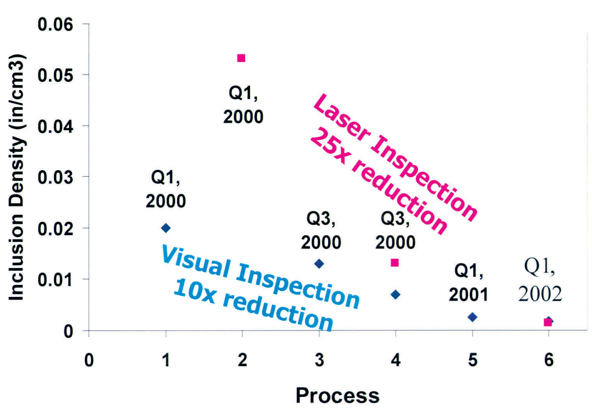
Introduction:

ULE® Glass is a low expansion silicate glass that has been historically used for ground and space based telescope mirrors. Industry experts have now identified ULE Glass as a material of choice for EUVL, with some property improvement required. Striae and homogeneity are two properties which require improvement for optics applications. Striae in standard ULE glass has been found to impact mid spatial frequency roughness of optics. EUVL grade ULE Glass has been tailored to eliminate this issue. Metrology tools are being developed to meet homogeneity needs.

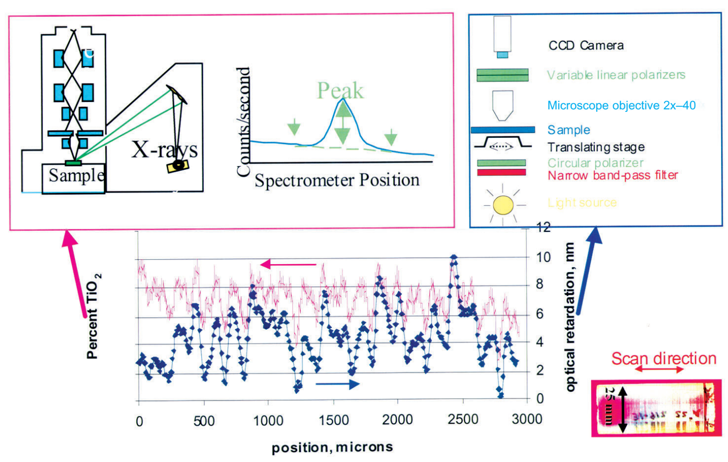
Inclusion Reduction ... Results from 1999–2002



Metrology Improvement:
Laser system increases detection limit from 80 µm to 1 µm.

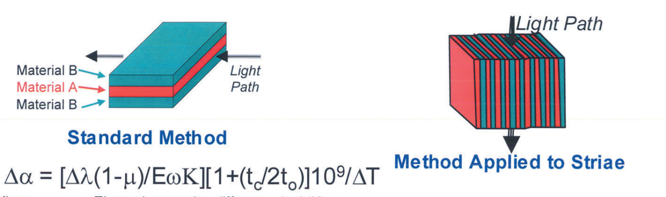
Material Improvement:
Shows inclusions reduced 10 to 25x.

Further Characterizing of Striae



Striae characterized as compositional differences and also stress differences within glass.

Evaluatin Striae with: Sandwich Seal* Test



$$\Delta\alpha = [\Delta\lambda(1-\mu)/E\omega K][1+(t_c/2t_o)]10^9/\Delta T$$

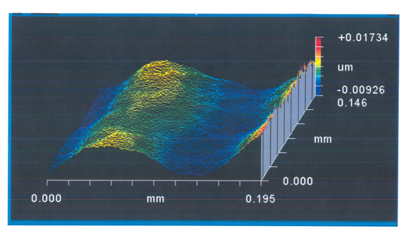
Where: $\Delta\alpha$ = Thermal expansion difference (ppb/K)
$\Delta\lambda$ = optical retardation (nm)
μ = Poisson ratio, (0.17)
E = Young's modulus, (67.6GPa)
ω = Width of seal (path length), cm
K= Stress Optic Coefficient of glass, 0.290 nm/cm/psi (ULE Glass)
t_c = Thickness of central seal member, cm
t_o = Thickness of outer seal member, cm
ΔT= Temperature difference from RT to setting point, 925-25°C = 900°C

Sandwich seal approximations used to estimate the CTE differences within striae layers based on Stresses between layers.

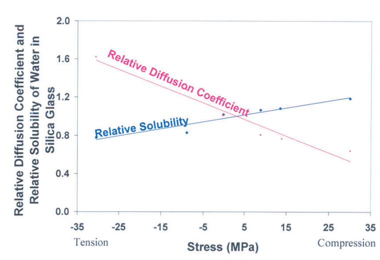
~Δ1 MPa stress ≈ Δ20.5 ppb/K CTE

*Hagy, Applied Optics, 12 [7] (1973).

CMP Polishing



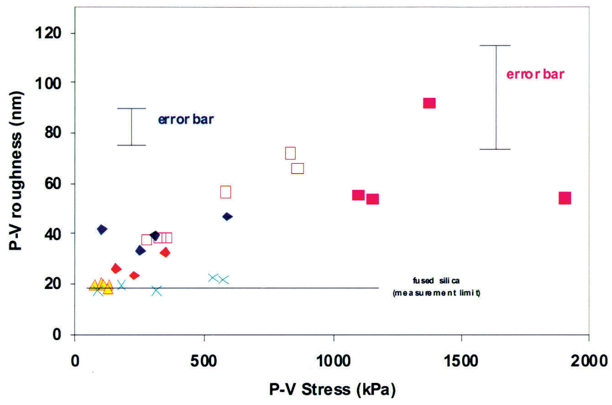
Smoothness of surface suggests primarily chemical removal during super-polishing (lack of fracture surfaces).



Nogami and Tomozawa, J. Am. Cer. Soc. 1984.

Stress state in silica glass known to impact diffusion and solubility of water into glass*.

Correlating Roughness to Stress within Striae

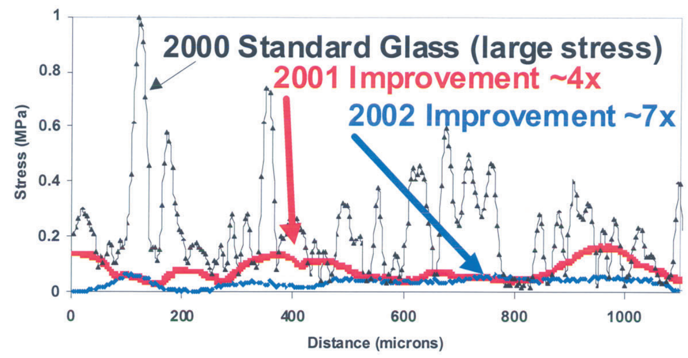


Conclusions:

Reduced stress within striae reduces roughness.

P-V roughness sensitive to polish procedures.

Striae Reduction ... Results from 2001–2002



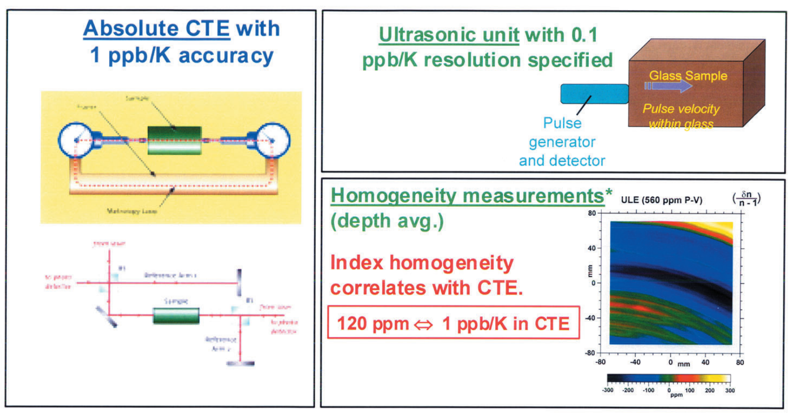
Metrology Implementation:

Microprobe and polarimeter identified as metrology tools.

Material Improvement:

Shows striae stress levels reduced 7x

Metrology Improvements Needed ... 2002–2004



**Data and graph courtesy of M. Johnson, and G. Sommargen.*

Metrology:

Identified new equipment required to meet EUVL specifications.

Construction and purchase of equipment precedes material improvements.

Material:

CTE low frequency homogeneity improvements required.

Property and Characterization Roadmap

	2000	2001	2002	2003	2004	2005
CTE crossover *Mask Class A (ppb/K)*	±5	±5	±5	±5	±4 *TBD*	±3 *TBD*
CTE TSR *Mask Class A (ppb/K)*	10	6	6	5	4	3
Inclusions *(> 1micron) #/cm3*	0.02	0.002	0.002	0.002	0.001	0
Inclusions *Mask Failure Predictions*	1 in 25	1 in 300	1 in 300	1 in 300	1 in 600	None
Striae *(p-v Mpa)*	±1.00	±0.20	±0.10	±0.05	±0.04 *TBD*	±0.04 *TBD*
CTE Homogeneity Optics *radial p-v (ppb/K)*	10 *ULE Premium Grade*	10 *ULE Premium Grade*	8 *ULE EUV Grade*	5 *ULE EUV Grade*	5 *ULE EUV Grade*	5 *ULE EUV Grade*
CTE Homogeneity Optics *axial p-v (ppb/K)*	16 *ULE Premium Grade*	14 *ULE Premium Grade*	10 *ULE EUV Grade*	9 *ULE EUV Grade*	8 *ULE EUV Grade*	6 *TBD* *ULE EUV Grade*
CTE Crossover Optics *(ppb/K)*	---	±5	±5	±4	±3	±2 *TBD*
Birefringence *(nm/cm)*	10 *ULE Premium Grade*	10 *ULE Premium Grade*	4 *ULE EUV Grade*	<3 *ULE EUV Grade*	<2 *ULE EUV Grade*	<1 *ULE EUV Grade*
Index Homogeneity *masks (ppm)*	---	---	600 *ULE EUV Grade*	TBD	TBD	TBD
CTE Metrology *ultrasonic Precision (100mm)*	±0.4 ppb/K	Evaluate	Specify Equipment	±0.2 ppb/K	±0.1 ppb/K	±0.1 ppb/K
CTE Metrology *Index Homogeneity*	---	---	Evaluate	±0.1 ppb/K	±0.1 ppb/K	±0.05 ppb/K
CTE Metrology *Microprobe Precision*	±2 ppb/K	±2 ppb/K	±2 ppb/K	±2 ppb/K	±2 ppb/K	±2 ppb/K
CTE Metrology *XRF Precision*	±2 ppb/K	±2 ppb/K	±2 ppb/K	±2 ppb/K	±2 ppb/K	±2 ppb/K
CTE Metrology *Absolute*	---	Evaluate	Design and Build	Debug and Correlate	Quality control	Operational studies

Summary and Conclusions:

EUVL grade ULE Glass is an appropriate material for EUV applications. A roadmap for glass quality and metrology improvements is being pursued. Striae effect on surface roughness has been investigated and the impact reduced. This was accomplished by characterizing the striae, developing the proper metrology tools and improving the forming process. Future work will focus on improving the low frequency CTE homogeneity within ULE and the development of appropriate metrology tools.