New Technologies for Future Space X-Ray Telescopes

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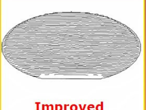
Si wafers & X-ray Optics

- The production of Si wafers is a complex process. The recent Si wafers are optimized for semiconductor industry, not for X-ray optics.
- Si wafers parameters need to be optimized for X-ray optics application already at the production stage.
- Si wafers should be shaped stress-free to precise optical shapes.

Development of improved Si wafers for X-ray optics applications

Standard

Flatness of standard silicon wafer used for technologies with photolithographic detail ~ 5 μm, 150 mm diameter. Thickness in the wafer center: Cen. THK 628.81 μm, minimal measured thickness: Min. THK 630.40 μm, maximal measured thickness: Max. THK 632.50 μm. Total thickness variation: TTV = (Max. THK) – (Min. THK) = 2.10 μm. TIR: 1.76 μm.



Improved

Flatness of highly flat silicon wafer developed for sub-micron technologies in ON Semiconductor, 150 mm diameter. Thickness in the wafer center: Cen. THK 610.92 μm, minimal measured thickness: Min. THK 610.58 μm, maximal measured thickness: Max. THK 611.03 μm. Total thickness variation: TTV = (Max. THK) – (Min. THK) = 0.45 μm. TIR: 0.29 μm.

Measurement of flatness

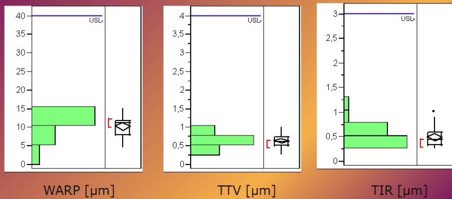
	Standard Si wafer	Improved Si wafer
Diameter [mm]	150	150
Cen. THK [μm]	628.8	610.9
Min. THK [μm]	630.4	610.6
Max. THK [μm]	632.5	611.0
TTV [μm]	2.10	0.45
TIR [μm]	1.76	0.29

Flatness of standard silicon wafer is used for technologies with photolithographic detail ~ 5 μm.

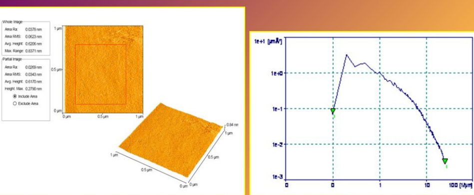
Method for high flatness of silicon wafers has been developed by ON Semiconductor Czech Republic: improvement by factor of 5!

Improved Si wafers

Measurement of 24 silicon wafers flatness, upper specification limit (USL) for semiconductor application is indicated. Wafers were manufactured with novel method for high flatness.



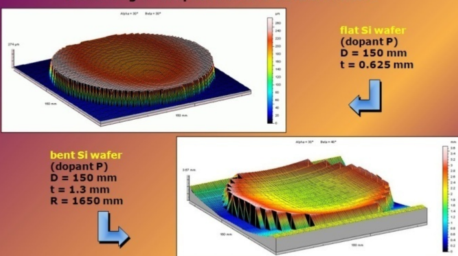
Improved Si wafers



Surface roughness of polished Si wafer measured with AFM microscopy (left). Crystallographic orientation (100), CZ wafer is heavily doped with arsenic. Measured area 1 μm x 1 μm, Ra = 0.04 nm, RMS = 0.06 nm. Power Spectral Density (PSD) function was calculated for these data.

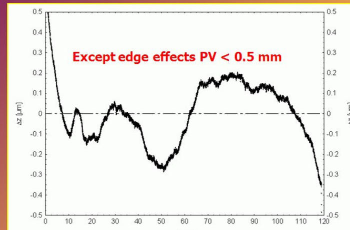
Precise shaping of Si wafers

Measuring of shapes: flat and bent Si wafers



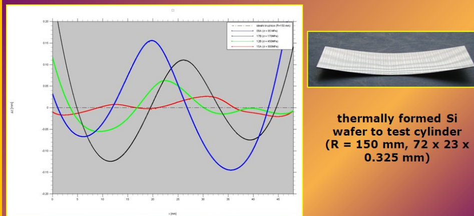
Bent Si wafers - Technology II

Taylor-Hobson profilometer – deviation from ideal shape
D = 150 mm, t = 0.625 mm, parabolic shape



Bent Si wafers – Thermal Forming

Optimizing parameters of thermal forming of Si wafers

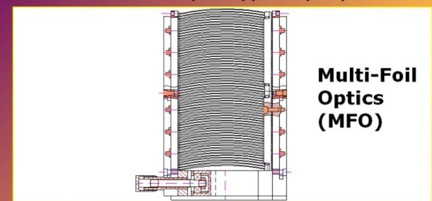


thermally formed Si wafer to test cylinder (R = 150 mm, 72 x 23 x 0.325 mm)

The effect of elastic tension on deviation from ideal surface (thermal forming of Si wafers).

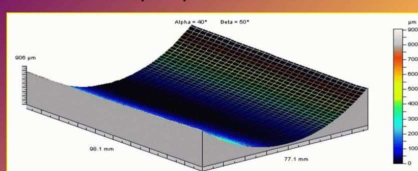
Alternative Si wafer X-ray MFO

Stacked module based on (before) precisely shaped Si wafers



Glass thermal forming (GTF)

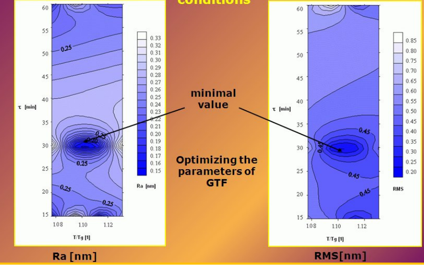
Measuring of shape
Still optical profilometer – 3D chart



thermally formed glass, parabolic profile
R = 150 mm, 100 x 150 x 0.75 mm, PV from ideal shape ~ 0.7 μm in the best case recently

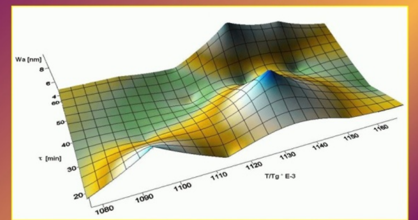
Measuring of the roughness after slumping – Optimizing GTF parameters

Interferometer Zygo, bent glass, 75 x 25 x 0.75 mm, optimization using > 100 samples formed at different conditions



Waviness of the surface as function of time and temperature of GTF

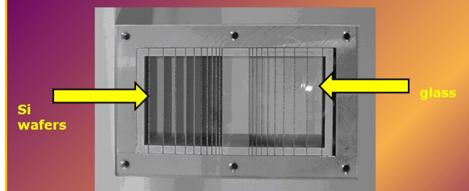
based on TH profilometer measurements of numerous samples (75 x 25 x 0.75 mm, R = 150 mm) - optimization



Si vs. Glass

	Si	Glass
Price per unit substrate	-	+
Range of available thicknesses	-	+
Surface microroughness	+	-
Possible irradiation damages	+	-
Bending to precise surfaces	-	+
Volume density	+	-
Thermal expansion	+	-
Long-term stability	+	-
Stiffness	+	-

Si vs. Glass Test Module



Test module for tests performance of glass foils vs. shaped Si wafers. Test elliptical Kirkpatrick-Baez optical system, focus 0.5 m, 58 x 50 x 100 mm, glass foils 40 x 40 x 0.3mm, Si wafers 40 x 40 x 0.4 mm

Summary

- Samples of test X-ray mirrors have been produced by using novel technologies.
- Shaped thin glass mirrors and Si mirrors have been successfully produced.
- Both approaches show promising results with PV values around 1 μm justifying further efforts in these directions.
- Improved Si wafers with parameters better suited to meet the X-ray optics applications developed and tested.