High Accuracy Measurement of Thermal Expansion

EUVL Mask 30

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SCHOTT glass made of ideas

Introduction

Substrate materials for EUV masks and optics have to fulfill extremely tight specifications regarding Coefficient of Thermal Expansion (CTE) and homogeneity. Measurement techniques have to be established which guarantee determination of the absolute value of CTE with an accuracy of few ppb/K.

To assure homogeneity of the CTE a reproducibility of about 1 ppb/K is necessary.

Techniques allowing fast measurement of small and easy to prepare samples have to be available to assure system performance.

CTE homogeneity is necessary to preserve MSFR and figure of mirrors and masks despite the heating up upon irradiation. A direct measure is surface change during heating. This was realized to confirm the homogeneity results obtained by CTE measurement.

The correlation between CTE deviations inside a substrate and surface deformation has to be established by appropriate models.

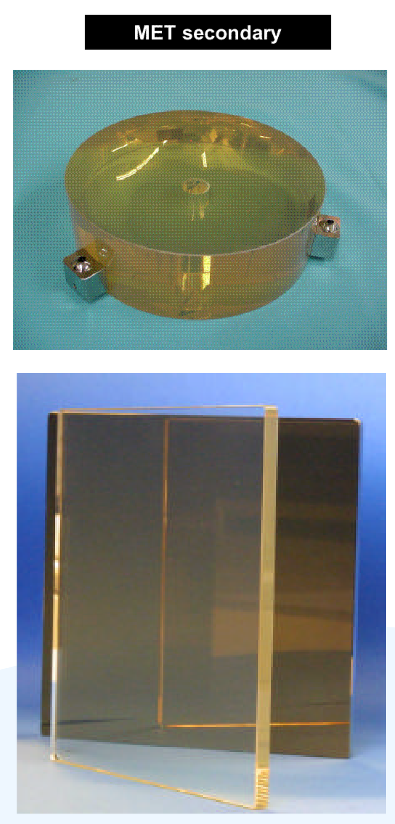

Figure 1: EUV-Mirror and mask substrate made of Zerodur®

CTE Homogeneity - Dilatometry

For an accurate determination of the coefficient of thermal expansion (CTE) by dilatometry the length changes relative to a reference sample have to be measured as a function of the temperature (fig. 2).

The repeatability of the Schott dilatometry was improved by introducing a new interferometric system to detect length changes of samples with an resolution of 0.1 nm (rods of 100 mm length). CTE homogeneity can now be measured at the 1 ppb/K level. Even at that level there was no CTE inhomogeneity detectable in Zerodur® samples as described earlier [1].

The CTE(T) of the reference sample was measured with an ultra precise absolute interferometer which was developed at PTB with sub-nm uncertainty (up to 0.1 nm, fig. 3).

The resulting accuracy of the dilatometry of < 2 ppb/K corresponds to an error of CTE(T) zero crossing temperature of < 1 °C.

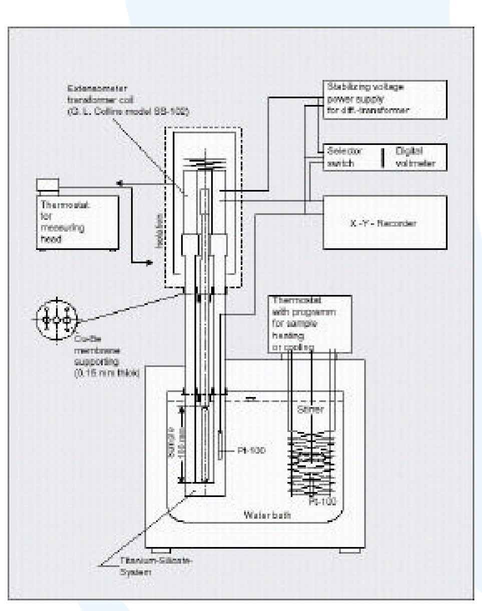

Figure 2: Push Rod Dilatometer at Schott

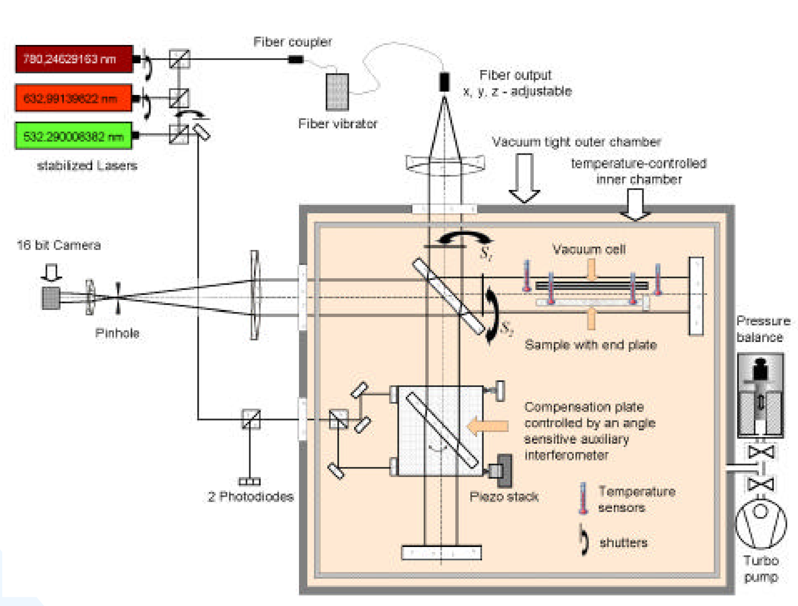

Figure 3: Interferometer at PTB

With the interferometer at PTB additionally a measure for the homogeneity of CTE can be extracted from the interference data array. The orientation of the sample front face with respect to the end plate would change if the rod bends due to inhomogeneous length change upon heating. Fig. 4 shows measurements in vacuum of a 280 mm Zerodur® sample at two different temperatures (A, B). Although total length changes of ≈100 nm occur the surface topography and orientation remains unchanged (C within 0.5 nm rms). Consequently, the homogeneity of the Zerodur ® sample geometry is excellent.

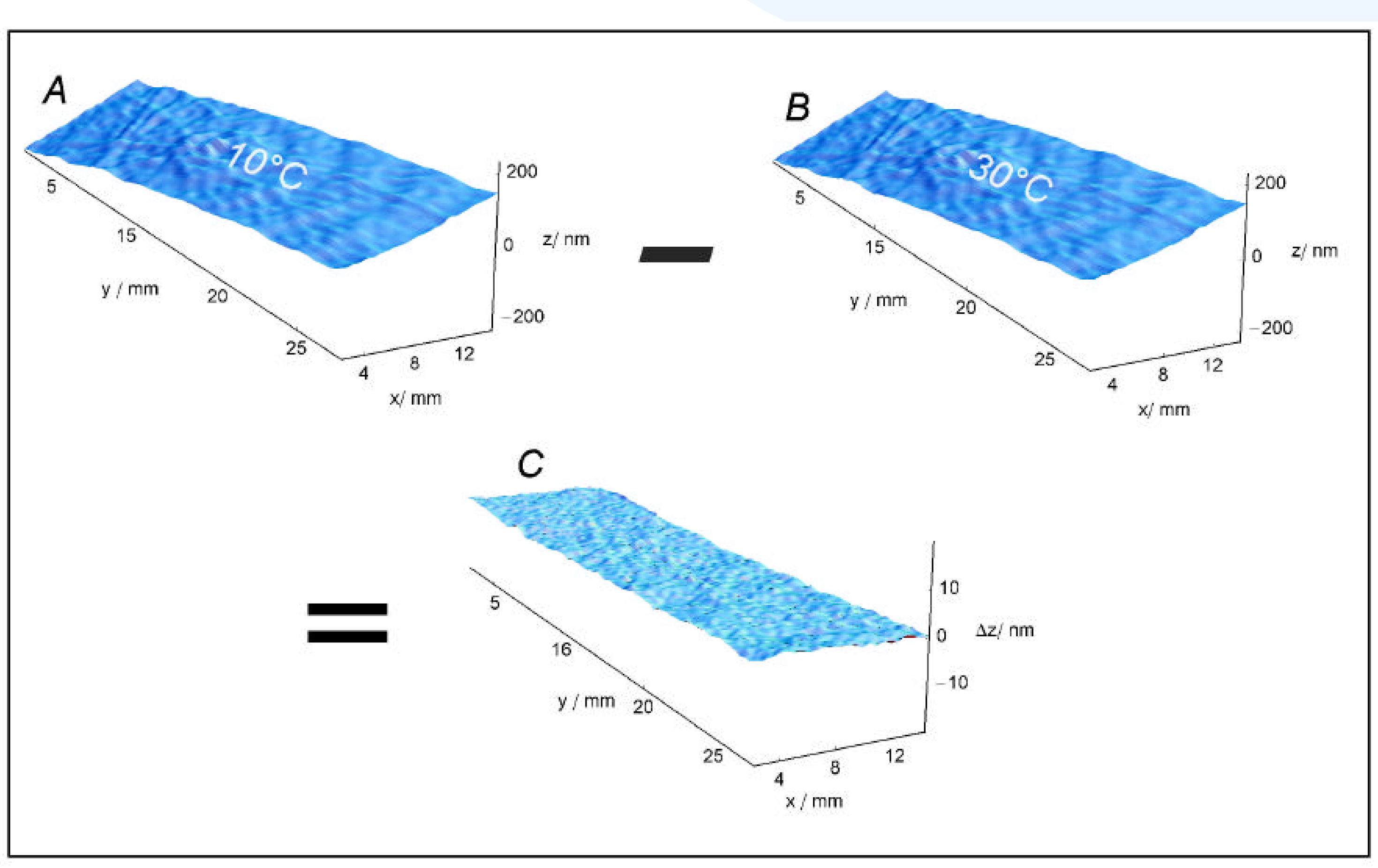

Figure 4: Surface maps of Zerodur® sample at 10°C (A), 30°C (B) and their difference (C)
(no change of orientation/curvature observable proving homogeneity of Zerodur®)

CTE Homogeneity – Surface Interferometry

In cooperation with the University of Erlangen a Fizeau interferometer for the direct detection of surface change upon heating was developed. As a proof of concept a system with small aperture (60 mm) was set up and tested with Zerodur® (fig. 5).

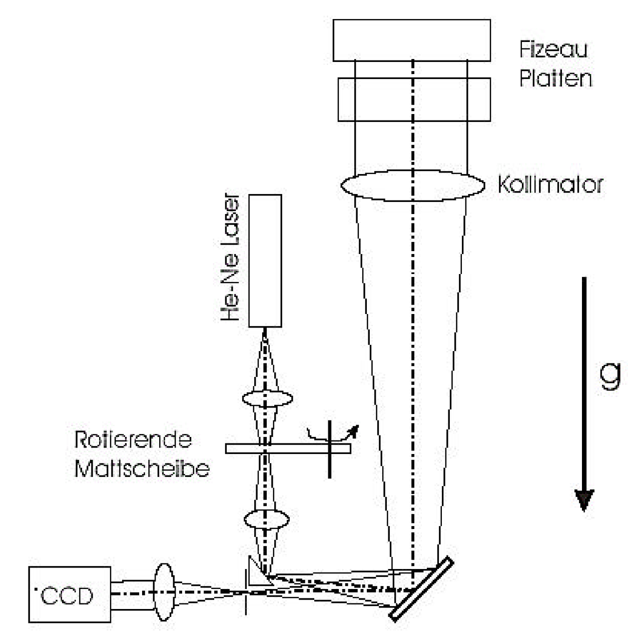

Figure 5: Surface interferometry

The measurement comprises the following steps:

1.Surface map at room temperature (T_1)
2.External heating of the sample to T_2
3.Transferring the sample to the interferometer
4.Surface map at T_2

The cooling of the sample was simulated. The measuring time at elevated temperature was kept short enough to prevent a significant change of the temperature profile of the sample (thickness 100 mm).

The reproducibility of surface deformation was determined to be < 0.3 nm rms at room temperature (including a transfer of sample) and < 0.6 nm rms for the difference map between T_2 = 40°C and T_1 = 20°.

The difference between the surface map at 20°C and at 40°C was 0.32 nm rms without any structures that can be related to the material itself (after subtraction of the 4 most symmetrical Zernicke terms). So the observed change in the surface map is lower than the error of measurement. The surface change of Zerodur® is therefore ≤ 0,3 nm rms if heated up by 20°C.

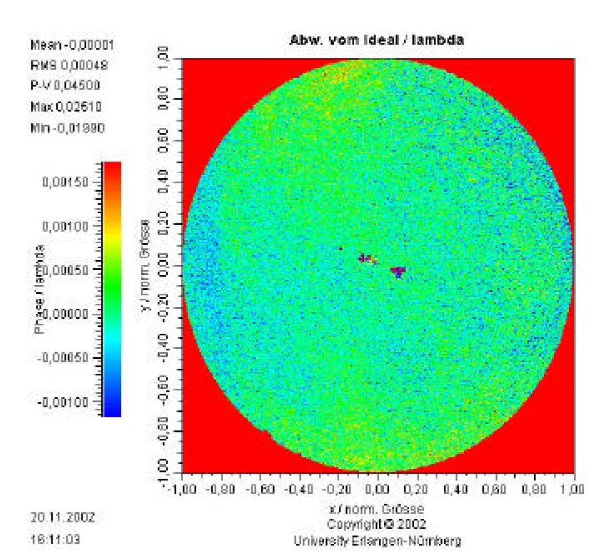

Figure 6: Reproducibility of surface map at room temperature

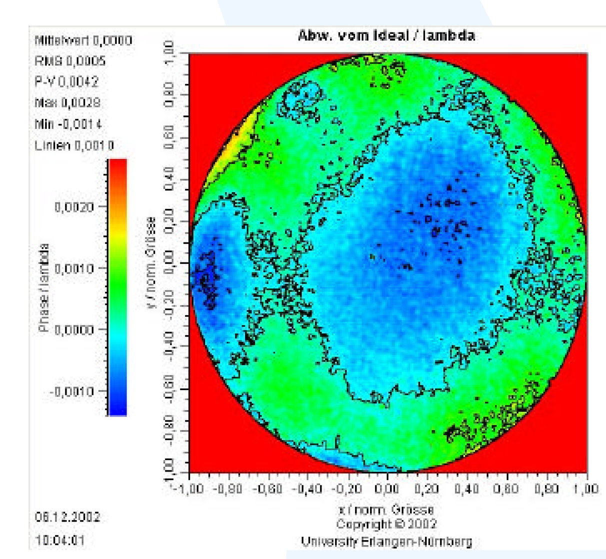

Figure 7: Difference between the surface map at 20°C and at 40°C

Correlation between CTE inhomogeneity and surface deformation

Surface deformation depends on the size, shape and amount of a corresponding CTE inhomogeneity. The effect of different model distributions were calculated by FEM simulations.

As an example the above mentioned surface change of 0.3 nm rms corresponds to a CTE change of < 1 ppb/K for the alternating structure of figure 8 (period 10 mm).

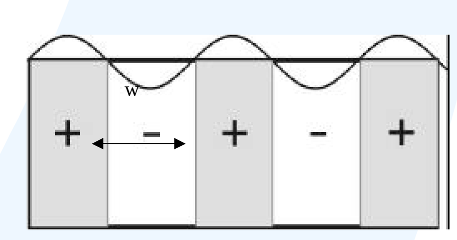

Figure 8:
Model distribution of possible inhomogeneities

The CTE homogeneity of Zerodur was therefore demonstrated to be < 1 ppb/K which is in agreement with dilatometry.

Summary

The improvement of our dilatometer led to an accuracy and reproducibility sufficient to measure EUV substrate materials. The technique allows for fast measurement of small and easy to prepare samples.

A direct measure of the surface change due to heating has been developed. Schott in cooperation with the University of Erlangen-Nürnberg set up a test stand and proved the suitability of the concept. Measurement of Zerodur® samples showed a reproducibility of 0.3 nm rms for the room temperature surface roughness as well as for the difference map between room temperature and heating to 40°C. So no significant change was observed upon heating.

The correlation between CTE deviations inside a substrate and surface deformation was estimated using models for the distribution, shape and size of possible inhomogeneities. The observed surface roughness correlates with a homogeneity of CTE better than 1 ppb/K. This number is limited by the reproducibility of the measurement and not by the material itself.

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References

[1] Alkemper et al., 1st Int. EUVL Symposium, Dallas (TX), 2002
[2] Schoedel et al., Proc. of the 3rd Euspen International Conference, Eindhoven, The Netherlands, May 26th –30th, 2002