Long Term Stability of Suprasil Line Scales and Gauge Blocks

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Abstract

Quartz is a common material for line scales and lithography photo masks. Compared to ultra low dilatation material like Zerodur, quartz has the advantage of a high transparency and exhibits a better long term stability. For an international line scale comparison, the so-called "Nano3" comparison [1], the Dr. Johannes Heidenhain GmbH manufactured in the year 1999 a number of line scales with 280 mm graduation length from a high quality quartz disc made of Suprasil [2]. From the same disc two gauge blocks of the same length were manufactured for the determination of the coefficient of thermal expansion and the compressibility. During the last years these line scales and gauge blocks have been repeatedly measured at PTB.

The length of the gauge blocks has been determined using the PTB "Precision Interferometer", a Twyman Green interferometer in a highly temperature stabilized vacuum chamber. Using phase shifting interferometry a measurement uncertainty of 0.5 nm can be achieved [3]. The length of the gauge block was repeatedly measured since about eight years. The line scales have been measured with the PTB "Nanometer Comparator" [4] involving a Jamin type interferometer operating in vacuum. After optimization of the microscope three years ago for the change of the scale length an uncertainty well below 2 nm could be achieved.

While for both line scales no length change could be observed, the gauge blocks shrinked with different rates over the last three years.

1 High accuracy measurement of material aging using end gauges

On samples with end faces of optical quality and parallel to each other better than 50 µrad, the long term dimensional stability can be measured in the “Precision Interferometer” which is based on a Twyman-Green Interferometer, operated within a thermally stabilized vacuum chamber [3]. The sample is wrung to a flat reference plate made from the same material as the gauge itself. The interferograms are recorded by a 16bit CCD-camera. Phase stepping interferometry involving 10 shifted interferograms is used to obtain the phase topographies of the sample including the end plate. This approach is done separately for the three different wavelengths available from highly stabilized lasers. The center position of the samples front faces with respect to the camera pixel coordinates is assigned at each measurement using a “Mask Method” [5]. The principle of the measurement setup is shown in figure 1.

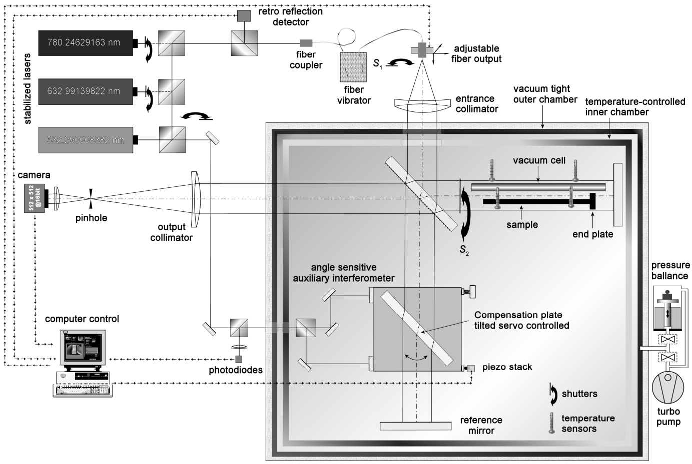

Figure 1: Scheme of the Precision Interferometer.

2 Line scale measurements using the Nanometer Comparator

The base of the comparator is a stiff granite block. A slide that moves on air bearings supports the line scale. The translation of the slide is measured by a interferometer, whose beams pass through an evacuated metal bellow and metal pipes. In this way the interferometer is completely located in vacuum, although the calibration objects can be mounted under atmospheric conditions [4]. The interferometer is based on the Michelson type where the reference beam is connected to the optical microscope. A second Michelson interferometer compensates for angular movements of the optical microscope. In addition only stable mechanical parts of minimal extension in the measurement direction made out of material with low thermal expansion are used within the measurement frame of the comparator.

3 Measurement results

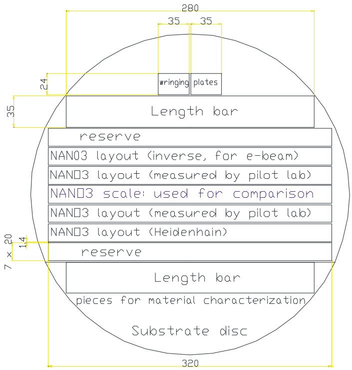

Figure 2: Cutting diagram of the Suprasil samples.

The samples are cut out of a circular substrate as shown in figure 2. The end gauges were manufactured separately. The first measurement of the SuprasilX end gauge was produced and first measured in 2001, so that for this sample a length history of eight years exist as visible in figure 3, while the SuprasilXX sample was first measured in 2003. Please note, that the SuprasilX sample was exposed to increased temperatures during end gauge polishing.

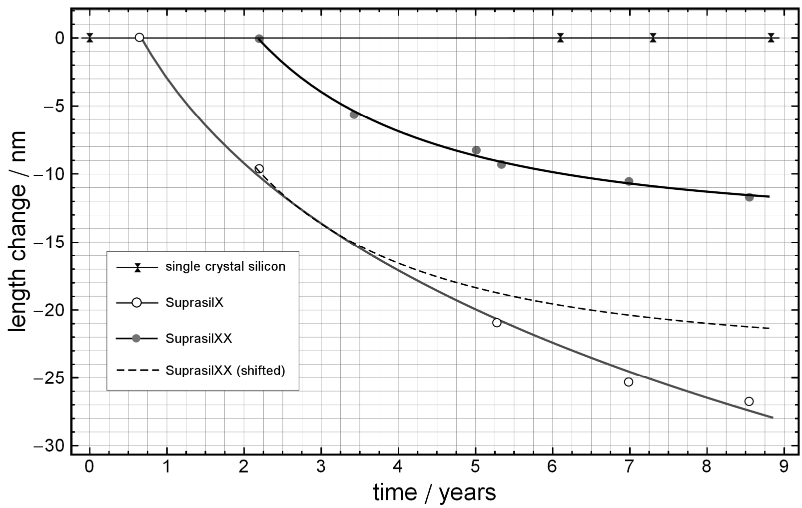

Figure 3: Long time stability of the two end gauges.

The line scales carry a graduation of 280 mm length consisting of 4 µm wide Cr line every mm. All lines have been measured and the total length of the scales given in figure 4 is calculated using a linear fit over all line positions. While the line scales were also measured starting in 2001, until 2006 the measurement uncertainty was too large to allow reasonable conclusions.

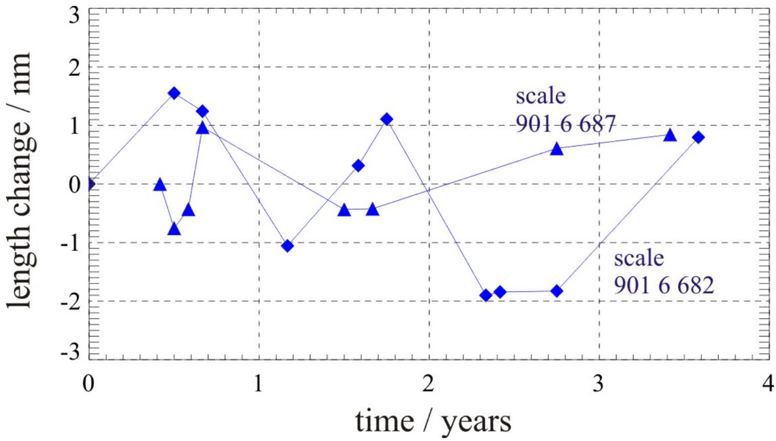

Figure 4: Long time stability of the two line scales.

4 Conclusion

While for both quartz line scales no length change could be observed within a range of ± 1 nm, resp. ± 2 nm, the gauge blocks shrinked by 2.5 nm resp. 5.8 nm over the last three years. It is possible, that the different thermal treatments during the manufacturing processes causes differences in the dimensional stability of the scales and gauge blocks although they were produced from the same block of material.

References:

[1] H. Bosse, W. Häßler-Grohne, J. Flügge, R. Köning: *Final report on CCL-S3 supplementary line scale comparison Nano3*, Metrologia 40 (Technical Supplement 2003)

[2] Suprasil is a registered trademark of Heraeus Quarzglas GmbH & Co. KG, Quarzstrasse 8, 63450 Hanau, Germany.

[3] R. Schödel, Ultra high accuracy thermal expansion measurements with PTB's Precision Interferometer, Meas. Sci. Technol. 19 (2008).

[4] J. Flügge, R. Köning, H. Bosse: High precision line scale calibrations with the PTB nanometer comparator; Proceedings of the 7th international conference, EUSPEN, Vol. 2, Bremen, 20-24. May, 2007

[5] R. Schödel, J.E. Decker, Methods to recognize the sample position for most precise interferometric length measurements, Proceedings of SPIE Vol. 5532, 237-247 (2004).