Microfabrication Using the Deep x-ray Lithography: A Contribution to Process Control

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Abstract

Deep X-ray Lithography (DXRL) allows the production of high aspect ratio 2.5 dimensional polymer structures with quasi perfect side-wall verticality and optical quality roughness. These structures can then be used as templates for mass production of metals or ceramic microparts. We will shed a new light on the process by focusing on its control. We will report metrological study using a coordinate measurement machine (CMM) equipped with a fiber probe (3D measurements) [1]. The results in terms of process capability Cp (Six Sigma) for a small series production will be presented; the microstructures we measured are gears.

1 Introduction

The direct deep x-ray LIGA technique combines lithography using synchrotron light and electroplating. In the past years the demand for microproducts made by deep X-ray LIGA has increased steadily. This is mainly due to the fact that the LIGA products' qualities are still unique with respect to the verticality and low roughness of the sidewalls, the high structural precision in the sub-micron range, the high aspect ratios with heights > 1 mm, and the use of a wide range of metals.

We report on a metrology study concerning the precision and accuracy of the process and its reproducibility using a coordinate measurement machine equipped with a fiber probe.

1.1 Measurement

The process of measuring the parts consists of a number of important tasks; the quality inspection of the substrate/parts during the process is necessary to minimize the scrap costs and to insure that at the end the quality requirement is achieved. The deviation from a reference value can only be made after the development of the resist and at the end of the process (metal). The equipment used is surrounded by a clean room environment (class 10000). The temperature is fixed 20°C (+/-1°C/hour).

Three methods are used to measure our parts: an optical microscope (reflexion, transmission, x 800) with an XY not motorised stage, a CMM with only an optical imaging system and a CCD camera, a CMM with a fiber probe (CMM "Video Check IP-400" from the society WERTH); the CMM-fiber-probe combination delivers the better results even if its accuracy is not satisfying yet. De facto, we concentrate on the comparison of the parts under study to an artefact standard well calibrated by ourselves. The selected artefact is identical to the part under study, the ambient conditions for measurement are kept identical. The summary of all influences on uncertainty and their superposition during measurement are characterised. In this case, the CMM will be used as comparator.

1.1.1 Repeatability and reproducibility of the CMM -

The machine capability Cg [2] ($c_g = \frac{0.2 \cdot T}{6 \cdot \sigma}$;T: tolerance: σ standard deviation) has been determined and is equal to 1.11 for a tolerance of 1µm (+/-0.5µm). To determine the long-term behaviour of the measurement system, a reference structure in both, PMMA and metal per design and height was selected; this "internal reference part" was measured at irregular intervals over a period of several months to years. The borehole of two gears was measured 3 times. As the structure in the resist is the negative of the final part, a PMMA column was measured. A strong linear correlation coefficient was observed between the measurement value for PMMA and the air humidity in the measurement chamber. Figure 2a shows temperature, air humidity and the mean value of the column diameters. In Figure 2b, the mean value with and without correction are plotted versus air humidity. To confirm the influence of the humidity on the results concerning the PMMA, measurements using two Au gears were made; the results are shown in Figure 3. Based on these results and using a level of confidence >99% (student t-test), we can discriminate diameters that differ by only 0.5µm.

1.1 Process capability

In table 1, the results concerning, the production of 30 wafers with 200µm thick PMMA irradiated at the same beam line Lito2 at ANKA, and the production of 23 wafers irradiated at different beam-lines are presented.

	Cp [2] for a tolerance of +/-1µm	Cp [2] for a tolerance of +/-0.5µm
Production of 30 wafers using a beryllium mask and irradiated at the same beam-line	1.85	0.987
Production of 23 wafers using a beryllium mask and irradiated at different beam-lines (Bonn, Bessy, Anka)	0.67	0.33

Table 1: Process capability Cp for two production examples.

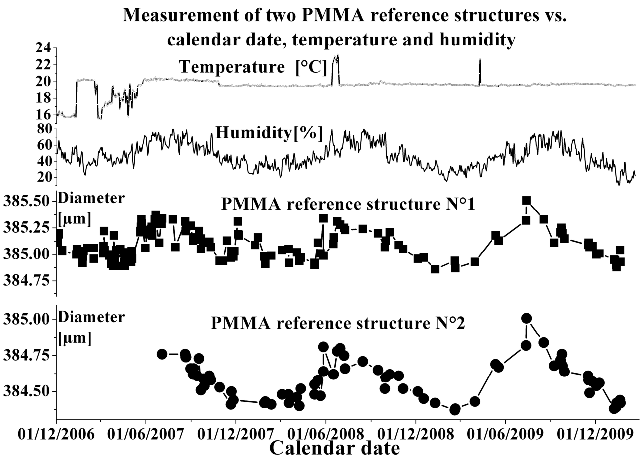

Figure 2 a: Results of the measurement of two PMMA reference structures (square and circle points) on the same wafer over the time, and as a function of the temperature and humidity. Thickness: 200µm.

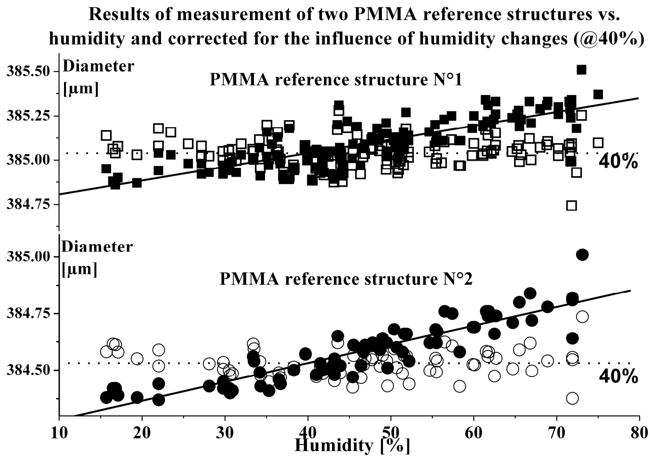

Figure 2 b: Results of the measurement of two PMMA reference structures on the same wafer as a function of the humidity. Colored points: results corresponding to Fig. 2a. Uncolored points: results corrected for the influence of humidity changes (humidity=40%).

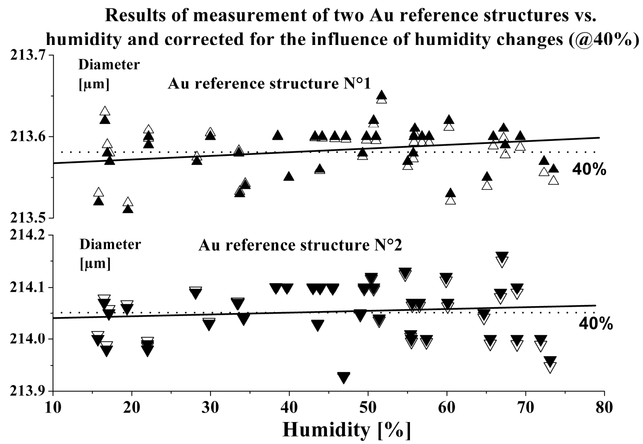

Figure 3 : Results of the measurement of two Au reference structures (borehole of a gear) on the same wafer as a function of the humidity. Colored points: uncorrected results. Uncolored points: results corrected for the influence of humidity changes (humidity=40%). Thickness: 180µm.

In the best case, the reproducibility of the process for tolerances of about +/-0.8µm gives a Cp ($c_p = \frac{T}{6 \cdot \sigma}$) equal at 1.33, indicating that the LIGA process is capable in the 6 sigma formulation for the mentioned tolerance band.

2 Conclusion

Using the CMM with fiber probe, the capability index Cp of the LIGA process was evaluated in the case of the fabrication of 200µm thick gears. Furthermore the parameter's influence on the dimension of the parts (difference should be > 0.5µm) could be evaluated. The limitation of the method is the dimension of the structures (they must be larger than the fiber probe, which in our case means, it must be larger than 85µm). To meet accuracy it will be important to determine the exact dimension of the selected artefact.

References:

[1] Pascal Meyer, Olaf Mäder, Volker Saile and Joachim Schulz "Comparison of measurement methods for microsystem components: application to microstructures made by the deep x-ray lithography process (x-ray LIGA)", Meas. Sci. Technol. 20 (2009) 084024 (5pp)

[2] Ford G M, Chrysler 1995 Measurement System Analyses Reference Manual, Automotive Industry Action Group, AIAG, Detroit, Michigan