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Process variations in surface nano geometries manufacture on large area substrates

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Abstract

The need of transporting, treating and measuring increasingly smaller biomedical samples has pushed the integration of a far reaching number of nanofeatures over large substrates size in respect to the conventional processes working area windows. Dimensional stability of nano fabrication processes over large area is key to ensure the device functionality. In this research, the process variation of sub-µm lithography processes is evaluated for different positions and features orientations, identified by produced test structures on a 100 mm diameter, 525 µm thick silicon wafer. The deviations from the target designed dimensions are quantified through AFM measurements on the silicon and on the subsequentely electroplated nickel geometries.

1 Introduction

The capability of fabricating at low cost and with high volume deterministic geometries able to carry samples/reagents for biomedical oriented applications has experienced in the last decade a global interest. Moreover the possibility of producing high market potential products on polymeric materials has led to a fast development of polymeric mass fabrication techniques attracting so, even more industrial interests [1-2]. Besides the challenge, in terms of replication fidelity dimensions, represented by the polymer replication techniques to transfer designed master configurations (functional geometries used for different biomedical applications) into the final end user product substrate, nano manufacturing process capability have been quantified. Quality of produced geometries was quantified in terms of height channels variation. Quantitative measurements were performed on both vertical and horizontal gratings, figure 1, on all test structures positions, figure 2. The analysis focused on depth/height variation comparing measurements carried out on symmetric positions on the left and right side of the disk and along its central zone on both silicon and nickel substrates. The designed test structures made the measurements relocation, possible on both substrates.

2 Nickel shim fabrication

The test geometries were produced using the processes parameters used for the fabrication of the functional chip design. The vertical and horizontal gratings, figure 1, composed by identical channels (nominal width = 300 nm and with nominal depth and height = 130 nm) arrays were defined by 100 keV e-beam lithography. Prior to the e-beam lithography the silicon was oxidized. The thickness of this oxide was 105 nm ± 15 nm. The channels defined by e-beam were etched by anisotropic selective reactive ion etching (RIE).

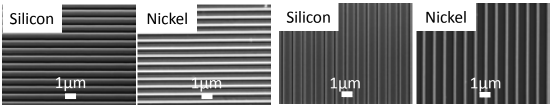

Figure 1: Vertical and horizontal Silicon and Nickel gratings (test structures).

3 Discussion

To evaluate the accuracy of the processes over different positions and channels directions, figure 2, a statistical design of experiment was carried out.

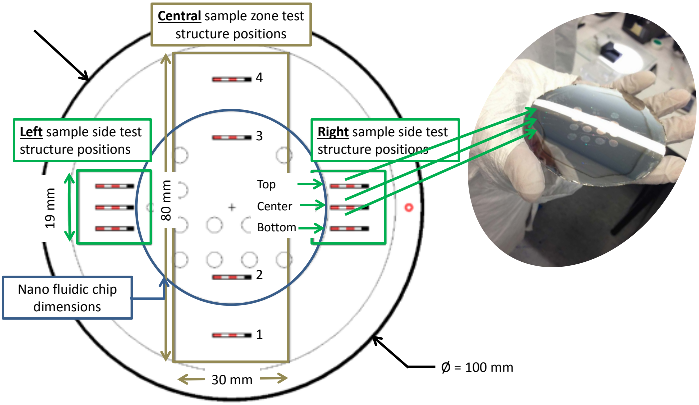

Figure 2: Shim layout with different test structure positions (left); fabricated nickel shim with functional chip design on the central disk area and different test structure position to evaluate processes capabilities (right).

The statistical approach enabled a systematic investigation of the relations between the variables affecting the process and the changes observed in the output response. The experimental results are shown in the format of main effect plot with output channels step height calculated following ISO 5436, figures 3 and 4. In particular, figure 3, shows depth/height variation of channels manufactured on the silicon wafer and the corresponding replicated nickel geometries, dependent by their directions and their positions both on the left and right side of the wafer/nickel substrate. Features significant dimensional variation is dependent on the sample position (left/right) on which test structures were fabricated on both silicon and nickel substrates.

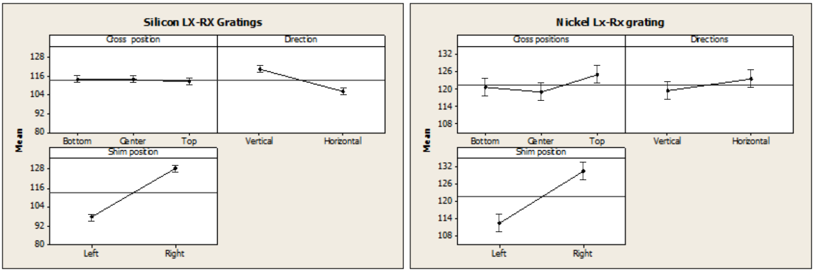

Figure 3: Main effect plot for fabricated geometries. Error bars indicate experimental expanded uncertainty ($Uexp_{Si} = \pm 1{,}9$ nm; $Uexp_{Ni} = \pm 3{,}2$ nm).

The analysis, figure 4, performed measuring the different test structures along the central part of sacrificial silicon wafer and on the replicated nickel disk, figure 2, shows on the upper part the main effects of test structure position and geometries directions affecting the parts quality compliance with target product specification (depth and height = 130nm) . It is possible to observe on both nickel and silicon substrates the same trend that divide the produced gratings in two sub-groups position 1-2 and position 3-4 on which the variation between features dimension are within 5 nm. On the bottom part of figure 4, the features reproducibility at different positions inside each grating is presented.

3 Conclusion

The process variation in manufacturing nano geometries on large area substrates for nanofluidic polymer based applications has been characterized. Specifically the study identifies the reduced process repeatability whenever the designed test structures are produced at more than 35 mm from each other. Maximum average channels depth deviations of 30 nm between the right and left sample sides are measured. Deviations within approximately 14 nm between position 1-2 and 3-4 along the central test structures have been measured. On the nickel substrate, test structure positions in the substrate have a significant effect on the dimensional deviation from the channels target height, whereas different channel directions have almost no effect. Nano fabrication technologies characterized by process variation in the nanometer range for the integration of high accuracy surface structures on increasingly large areas allows for further device performance optimization within biomedical nano-fluidic chip applications.

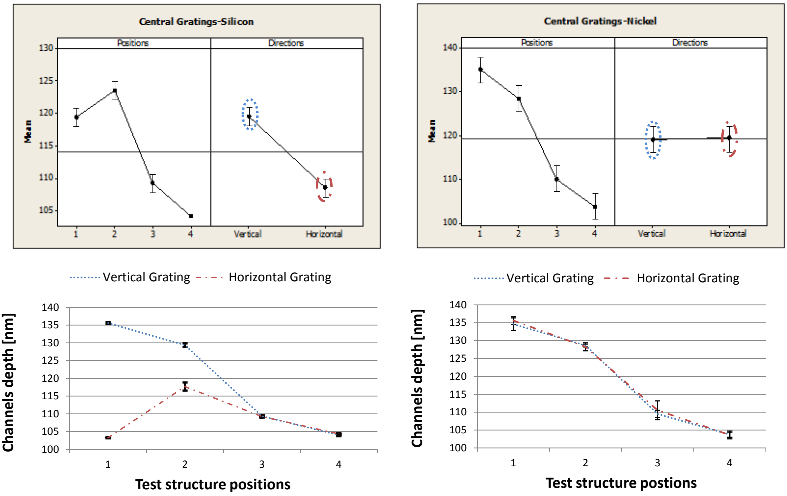

Figure 4: Main effect plot for fabricated geometries. Error bars indicate experimental expanded uncertainty ($Uexp_{Si}$ = ± 1,9 nm; $Uexp_{Ni}$ = ± 3,2 nm).

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