Nanoscribe Advanced Patterning Techniques for Two-Photon 2D and 3D Structures

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Primary CNF Tools Used: Nanoscribe GT2, Zeiss Supra SEM, Glen 1000 Resist Strip

Abstract:

The CNF's Nanoscribe GT2 is a laser lithography system capable of printing three-dimensional structures with a resolution down to 200 nm using two-photon polymerization (2PP). Whereas traditional 2D direct writing (DW) tools require 3D structures to be built up one layer at a time, the Nanoscribe allows for complex 3D geometries to be fabricated with multiple levels in a single process step. Moreover, due to its high resolution, extending this tool to the fabrication of 2D structures provides researchers with enhanced flexibility for their process flows. In this work, we explore the Nanoscribe's capabilities in various configurations, with an emphasis placed on process development for spin-coated resists. An alignment strategy is demonstrated, enabling structures to be printed with overlay accuracy of approximately one micron using pre-existing fiducial markers. By investigating the capabilities of this tool, we also gauge its ability to aid in processes such as lift-off and microfluidic mold fabrication, potentially enabling the realization of devices that would be difficult to create using other methods.

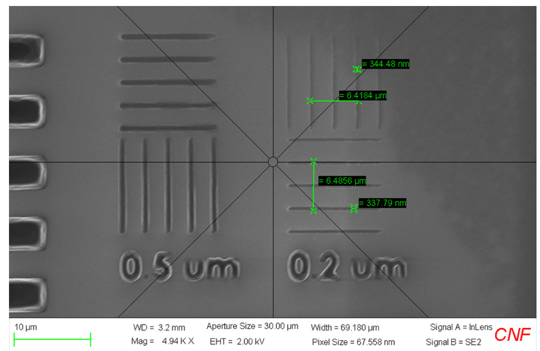

Figure 1: SEM of an S1813 oil immersion resolution test at a 1000 µm/s write speed and 10% laser power.

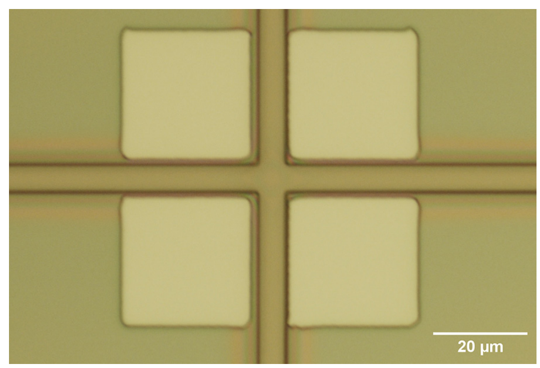

Figure 2: Optical microscopy image of an aligned print conducted using the 10x objective on S1813.

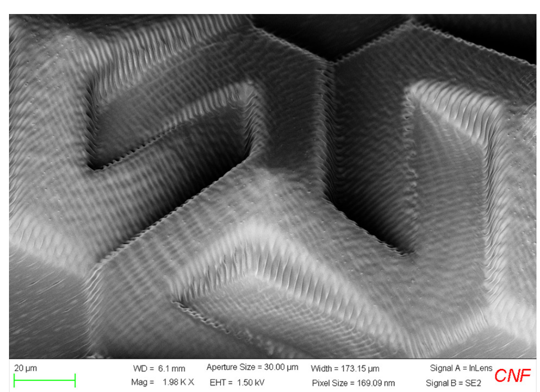

Figure 3: SEM of grayscale print conducted using the 10x objective with IP-Q and slicing distance of 1 µm.

Summary of Research:

To test the resolution capabilities of this tool, oil immersion was used due to oil having a higher index of refraction compared to air, increasing the objective's numerical aperture. Resolution tests were conducted on S1813 and SU-8, using computer-aided design (CAD) with both horizontal and vertical lines of widths ranging from 0.2 to 4 μm. Line widths under 340 nm were observed for the 200 nm nominal CAD on S1813 at a scan speed of 1000 μm/s and a laser power of 10% (Figure 1). Larger line widths of ~ 700 nm were observed for SU-8 at a scan speed of 500 μm/s and a laser power of 60%. We believe this was due to the higher dose required to ensure adhesion between the print and substrate post-development. Focusing was also an issue when working with non-standard materials, as Nanoscribe's automatic interface finding procedure was not possible in certain configurations.

The alignment capabilities of this tool were also investigated. Our proposed alignment strategy consists of two main components: a coordinate transformation followed by offset compensation.

First, a coordinate transformation is performed by the user with alignment to pre-existing marks. This enables stage movement to known locations on the substrate.

Second, offset compensation is required to account for the offset between the camera and laser system. This is done by opening the laser shutter until visible polymerization occurs, manually measuring the observed offset, and adjusting the system's stage position accordingly. It is important to note that this position varies depending on the objective being used. Following this procedure, we were able to demonstrate aligned prints with an accuracy of ~ 1 μm (Figure 2).

After investigating these capabilities, we explored potential applications of the Nanoscribe. Notable difficulties were encountered when exploring the direct fabrication of microfluidic devices on spin-coated resists. Experiments were conducted using both negative (SU-8) and positive (AZ4903) resists. Unfortunately, Nanoscribe's recommended AZ resins are no longer available. Using these resists, we saw incomplete channel development and long print times due to the slow write speeds required for exposure. Moving forward, alternative resins should be explored to address this problem.

We were able to successfully demonstrate the 3D capabilities of this tool through the creation of grayscale structures. Tests were conducted using both the 63x objective with S1827 and the 10x objective with Nanoscribe's IP-Q resin. Using the latter configuration, we observed adhesion issues when printing on bare silicon. This was resolved using plasma etching followed by the addition of a thin SU-8 adhesion layer. The effect of different print parameters was also investigated. We found that increasing the *FindInterfaceAt* value and dose delivered to the resin also helped to improve adhesion. Moreover, by decreasing the slicing distance parameter, we were able to demonstrate the ability of this tool to create 3D structures with relatively smooth surface profiles (Figure 3).

Additionally, we demonstrated the Nanoscribe's ability to be used in lift-off processes. Tests were conducted using the 10x objective on S1813 on LOR, with lift-off successfully occurring following the evaporation of gold and chromium on our sample. This process was performed in conjunction with our aforementioned alignment procedure.

We also conducted aligned prints on ultra-small pieces, approximately 1 mm^2 in dimension. These pieces were secured to a silicon substrate using polymethyl methacrylate (PMMA) before being immersed in IP-Q resin. From here, prints were aligned to the center of pre-existing circles and conducted using the 10x objective.

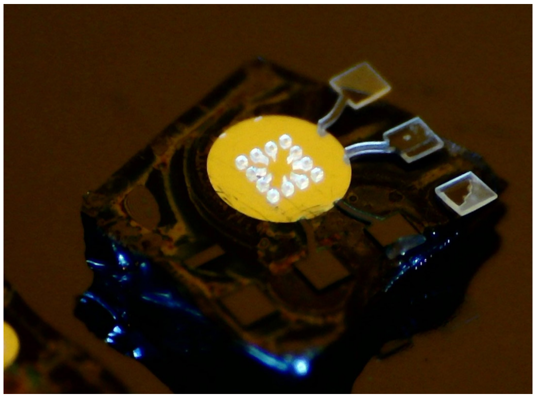

Figure 4: Image of an aligned print conducted using the 10x objective with IP-Q on a ~ 1 mm^2 piece.

The structures printed were 40 μm tall, and show the potential for this tool to create suspended geometries (Figure 4).

Conclusions and Future Steps:

Overall, this work demonstrates that Nanoscribe GT2 is a competitive tool for DW. Although larger than the 200 nm theoretical limit, the resolution results of this work remain non-trivial in showing this tool's capabilities. The linewidths observed are smaller than what is achievable with other DW methods at the CNF and could likely be decreased with additional parameter optimization. Moreover, in combination with its alignment capabilities, this tool has the potential to be used in a variety of applications from grayscale images, to lift-off, to direct fabrication on CMOS chiplets.

More process development is required regarding the Nanoscribe's ability to be used with other spin-coated resists. This, in combination with further parameter optimization, could further push the resolution limit of this tool. Additionally, quantitative characterization of this tool's alignment is still needed.

Acknowledgements:

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References:

[1] NanoGuide Professional Photonic Series. (n.d.). Retrieved June 20, 2023, from https://support.nanoscribe.com/hc/en-gb/categories/201695349