Characterization of Additively Manufactured High Aspect Ratio Microchannels via Two-Photon Polymerization

CNF Fellowship

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Primary CNF Tools Used: NanoScribe Photonic Professional GT2

Abstract:

Two-photon polymerization and its application to additive manufacturing represents an unprecedented ability to develop nanometer scale 3D and 2D designs. Such microchannels have a variety of research applications, including creating high aspect ratio microchannels for microfluidic devices [1] and making architected gas diffusion layers [2] among a host of other applications. The NanoScribe Photonic Professional GT2 was utilized to develop high aspect ratio microchannels and better characterize the printing and developing process.

Summary of Research:

Two-photon polymerization offers the ability to create structures with delicate features, in the range of hundreds of nanometers. In the case of the NanoScribe Photonic Professional GT2, the manufacturer reported minimum feature size is on the order of 160 nm [3]. Given these capabilities, this 3D printer has a number of applications, among which are the development of microfluidic channels. The printing process itself relies on selectively polymerizing portions of a resin bubble, bonding the print to a substrate, typically glass or silicon. As part of this process, unpolymerized resin remains in the printed object and must be removed during a process called development, wherein a solvent is used to remove this excess resin.

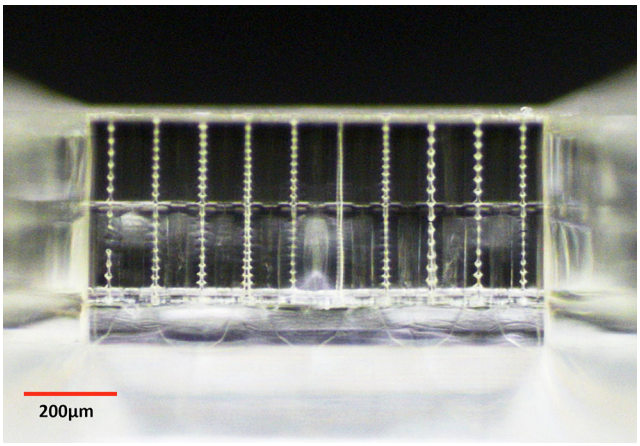

Figure 1: Fully developed microchannels, 400 µm in height, with varying channel diameter.

High aspect ratio microchannels, of up to 100:1 (length: diameter) were printed and sampled for appropriate development. As this is a transport limited process, various methods such as sonication, stirring, and long duration development were attempted. Additionally, the age of the resin and storage method were examined with IP-S resin, a type suited to medium size features (at 200 nm layer height).

In the first case, samples were developed using the suggested 20 minutes of development with propylene glycol methyl ether acetate (PGMEA) to dissolve uncured resin and a subsequent bath of isopropyl alcohol for five minutes to remove the PGMEA. After this, samples were optically characterized using the Nikon Wild light microscope to determine channel development. At this point no samples displayed complete development, requiring modifications to the development procedure. Further, it was determined that the light from the microscope was causing some degree of polymerization of the undeveloped resin. In effect, this prevents further development by clogging channels, meaning it was not possible to optically characterize the samples with unfiltered light.

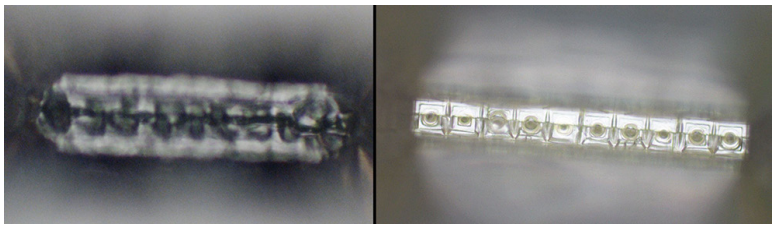

Figure 2: Underside of the microchannels. At left, resin that has been partially cured by a light microscope, inhibiting channel development. At right, fully developed channels from the sample in Figure 1 after 48 hours in PGMEA.

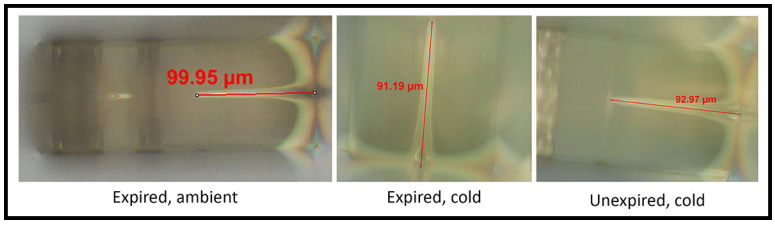

Figure 3: IP-S development performance for the three resin types examined; all showed similar results.

Therefore, it is recommended that for applications where there is not a suitable light source, samples should be tested for an appropriate development cycle with articles not meant for production.

Figure 2 is illustrative of the impact of a light microscope on inhibiting channel development. Partial curing of the resin created a block of material which could not be cleared via extended development (>72 hours) and sonication.

Additionally, the build method, such as creating a totally solid versus shell and scaffold design must be considered for extended development. Long duration development (>24 hours) will produce vacancies in the shell and scaffold designs as the PGMEA develop creates small holes in the shell and dissolves resin within the scaffold. For critical sections, a solid development method must be used, as seen in Figure 1. Here the surrounding structure is shell and scaffold, reducing printing time, while the area surrounding the microchannels is solid.

Another set of tests examined the impact of age and storage conditions of IP-S resin. Resins used in the GT2 printer have short shelf lives and are recommended to be stored cold. Prior to use, the resin should be brought to room temperature. Print quality and development time were explored with expired, cold resin (stored just above 0°C), expired, warm resin (stored at ambient), and unexpired, cold resin (stored in similar conditions to the expired, cold resin). A variety of geometries were printed, demonstrating micron-scale walls, overhangs, and microchannels via the 25X objective lens. All samples were developed for the NanoScribe-recommended 20 minutes in PGMEA and five minutes in isopropanol. Per the previous study, this time was known to be inadequate for complete channel development, however this could be accentuated with the different resins, as there is the possibility that some self-polymerization could occur within the expired materials.

Ultimately the results of testing showed that all resins with the suggested development procedure produced similar results. In fact, in this small sample, the expired, ambient temperature resin exhibited the greatest channel development. This seems to indicate that there is not a significant drawback for using this older resin for short development cycles. Longer development times were not trialed, and these results should not be extrapolated to out beyond short development cycles (<1 hour).

References:

[1] A. C. Lamont, A. T. Alsharhan, and R. D. Sochol, "Geometric Determinants of *In situ* Direct Laser Writing," Sci. Rep., vol. 9, no. 1, p. 394, Jan. 2019, doi: 10.1038/s41598-018-36727-z.

[2] J. Wicks, et al., "3D-Printable Fluoropolymer Gas Diffusion Layers for CO_2 Electroreduction," Adv. Mater., vol. 33, no. 7, p. 2003855, 2021, doi: 10.1002/adma.202003855.

[3] "Photonic Professional GT2: World's highest resolution 3D printer." https://www.nanoscribe.com/en/products/photonic-professional-gt2 (accessed Jul. 16, 2021).