Design of Porous Substrates for Enhanced Development of Microfluidic Devices

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Primary CNF Tools Used: NanoScribe Photonic Professional GT2

Abstract:

Production of micro-scale devices, particularly for microfluidic applications, commonly require high aspect-ratio channels. The sub-micron resolution of the NanoScribe Photonic Professional GT2 allows arbitrarily complex channel designs to be fabricated with relative ease. However, these complex microfluidic channels present significant challenge in terms of post-print part development due to transport limitations of the developer. In this work, custom substrates were designed to increase developer transport, minimizing overall development time and increasing part quality due to decreased exposure to development chemicals. Additionally, through selection of compatible substrate materials it is possible to print directly to a matching material, resulting in a solid bond between the part and substrate.

Summary of Research:

Devices printed on the NanoScribe Photonic Professional GT2 require, at times, a lengthy development process consisting of soaking parts in propylene glycol methyl ether acetate (PGMEA) and isopropyl alcohol (IPA). In this process, PGMEA dissolves the bulk of the uncured acrylate resin left by the printing process, followed by a wash with IPA which removes the remaining PGMEA and resin. In high aspect ratio channels, this process is transport limited due in large part to the high viscosity of the liquid resin (>13,000 mPas at ambient temperature), which flows very slowly and mixes poorly with PGMEA without agitation. Increasing transport therefore will have a significant impact on decreasing development time. This will also help maintain the structural integrity of printed parts by minimizing swelling and ensuring overdevelopment does not occur.

Device design plays a large part in ensuring proper development; minimizing channel length and other bottlenecks in the design is critical. However, altering the substrate from the conventional silicon or borosilicate glass can yield significant dividends. Printing a device atop an open pore in the substrate offers a direct path for PGMEA development, of particular use for certain part orientations and designs. This can also reduce print time, as supports may no longer be required to raise a print from the surface or orient the part on its side. Figure 1 illustrates one such design, where a microfluidic structure is raised to allow for PGMEA transport via a set of supports which are later removed. By printing directly on a pore, this support structure is obviated and removes flow restrictions from below the structure.

A 25 mm × 25 mm × 4 mm substrate with integrated 1 mm diameter pore and microfluidic connector mount was designed, shown in Figures 2 and 3. The design for this substrate is available on the NanoScribe GT2 tool wiki, hosted by CNF under the section "Printing on Porous Substrates" [1]. Substrates were printed on three different resin-based printing systems: an Elegoo Mars 2 Pro with Elegoo Standard Transparent Resin, a low cost stereolithography (SLA) printer; a FormLabs Form 3 SLA printer with FormLabs Clear Resin, and a Carbon digital light synthesis (DLS) printer with Loctite 3D IND405 Clear Resin. In all cases, an acrylate resin was used to ensure compatibility with the printing process and subsequent development as the swelling may cause cracks to form in the substrate and device after the developers have evaporated. Additionally, the same 3D model was utilized, with print orientation varied based on the requirements of the printer.

Figure 1: Original microfluidic device with standoffs for enhanced transport.

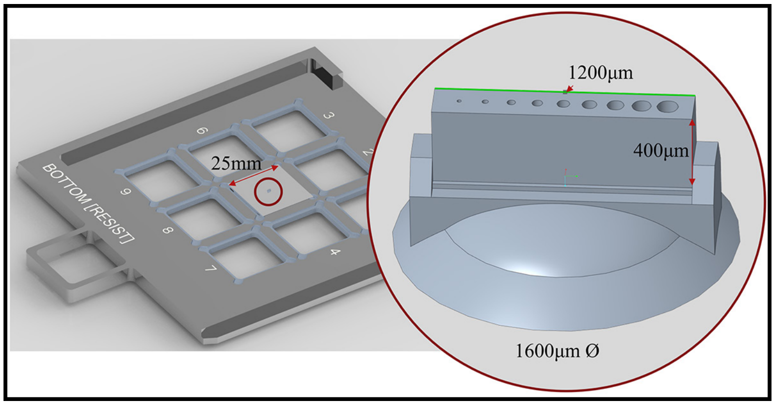

Figure 2: Model of substrate with 1 mm pore.

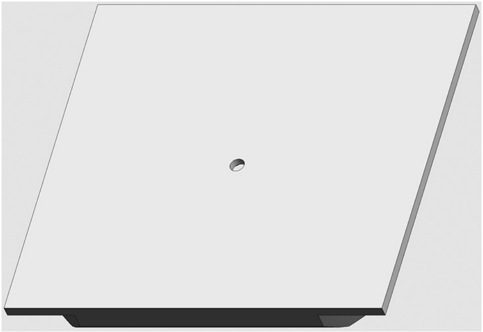

Figure 3: Model of printed microfluidic design on custom substrate.

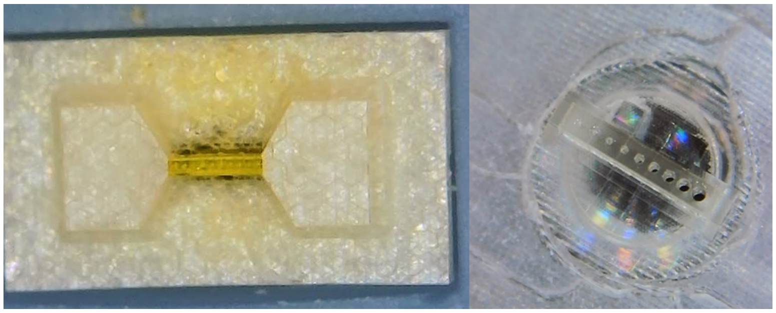

Figure 4: Two prints of a similar channel design illustrating overdevelopment of the old design (left) versus the well-developed porous substrate design.

After printing, the substrates were polished to a 3 µm surface finish then sonicated in IPA before use in the NanoScribe printer. The Elegoo Standard Transparent Resin had experienced minimal swelling and produced no defects due to the development process. The FormLabs Clear Resin swelled little and was acceptable for this process. The Loctite resin exhibited the most swelling during development with notable warping and is not suitable for fine parts, particularly if there are other printing options available.

Samples were printed with the 25x Medium Feature objective and IP-S resin. A microfluidic sample was developed in its standard configuration, then a modified version was reprinted on the porous substrate.

The standard sample required nearly 48 hours of development in PGMEA to attain clear channels, while experiencing massive structural issues due to PGMEA infiltration and swelling of the structure. The white, pillowy texture is characteristic of overdevelopment as the supporting shell-and-scaffold structure experienced significant PGMEA intrusion. The reprint on porous substrate was developed in one hour in PGMEA and 15 minutes in IPA. Due to this significantly shorter development time, device structure did not noticeably swell or overdevelop. A comparison of the two prints shows significant improvements in part quality, as seen in Figure 4. Further, this modification reduced print time from between 6 and 10 hours to just two hours since supports were no longer necessary and the part required less supporting structure for the same strength. Devices were subsequently pressure tested with both deionized water and 99% IPA with pressures of up to 345 mBar without leakage in the new design. Additional details regarding the use of these substrates is available to all users on the CNF User Wiki for Two-Photon Lithography.

References:

[1] "Two-photon Lithography - CNF User Wiki - Dashboard." https://confluence.cornell.edu/display/CNFUserWiki/Two-photon+Lithography.