Room temperature imprint and extrusion based printing of water-based microparticle inks towards glass microfluidic devices

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Polymer microfluidic devices have been widely used for diagnostic purposes, and the process chains have been established to mold them by casting, hot embossing and injection molding. However, for many applications, glass devices would be favored, because of their higher chemical stability, their compatibility with other microfabrication processes that would allow for integration of different functionalities and the possibility to develop devices that could be easily reused. In contrast to polymer molding, glass molding is much more difficult to employ, mostly because of the thermal process temperature around 600°C, the difficulties to generate durable molds with good antiadhesion properties, and the high thermal expansion mismatch between mold and glass. To overcome this, thermoplastic molding using hybrid (composite) glass materials are used to combine the advantages of low temperature processing and subsequent sintering at high temperatures, similar to the materials for ceramic injection molding [1,2].

Recently, novel low-temperature glasses based on phosphate glass that are suitable for 3D printing have been developed and used via extrusion printing to realize fully-integrated functional microfluidic systems [3]. Typically, these suspensions ("glass-inks") are made from a mix of glass powders, and a few percent of an organic binder, here methyl cellulose, that can be used in standard additive manufacturing processes. Since the material is water-based, its solidification is purely based on the evaporation of the water during extrusion through a nozzle onto a hot bed. We have used this material for room temperature imprinting using PDMS (polydimethylsiloxane) molds and hot embossing using hard stamp (Figure 1). Similarly to extrusion, the material solidifies upon drying. In both processes, a heating process was employed that first removes the binder from the green body, and then facilitates sintering together at higher temperature. For simple microfluidic devices with 100-200 µm wide channels, the shape is fully retained during demolding and annealing and the shrinkage is almost isotropic (lateral 27% and vertical 24%). We sealed the open channel by extrusion based printing before sintering and SEM cross-sectional image is confirming the perfect sealing (Figure 2). For more delicate structures, and auxiliary sacrificial material such as PLA (polylactic acid) could be used as a supporting mold material that does not need to be demolded and melts away at 280°C. The annealing showed that an average roughness, R_a of below 1 µm could be achieved, which is lower than the maximum particle size. This suggests that the glass particles are merged but not melted in the annealing step. In contrast to this, using molding at 600°C, sub-µm roughness could be achieved (Figure 3). The current process has higher resolution than previously reported extrusion processes. These hybrid processing schemes are promising because they enable the use of higher resolution molding processes in conjunction with other additives processes to facilitate multi-material printing for preparing integrated functional structures as preparing electrodes on the microfluidic channel before the final device is annealed in a batch process.

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[2] J. Luo, H. Pan, E.C. Kinzel, Additive manufacturing of glass, J. Manufactur. Sci. Eng., Dec. 2014, Vol. 136 / 061024 (6pp.).
[3] B. Mazinani and V. Subramanian, Synthesis and characterization of highly durable P_2O_5-ZnO-Na_2O/CaO-Fe_2O_3 glasses for low-temperature sealing applications, E-MRS 2023 Spring Meeting, Strasbourg, May 28 – June 2, 2023.

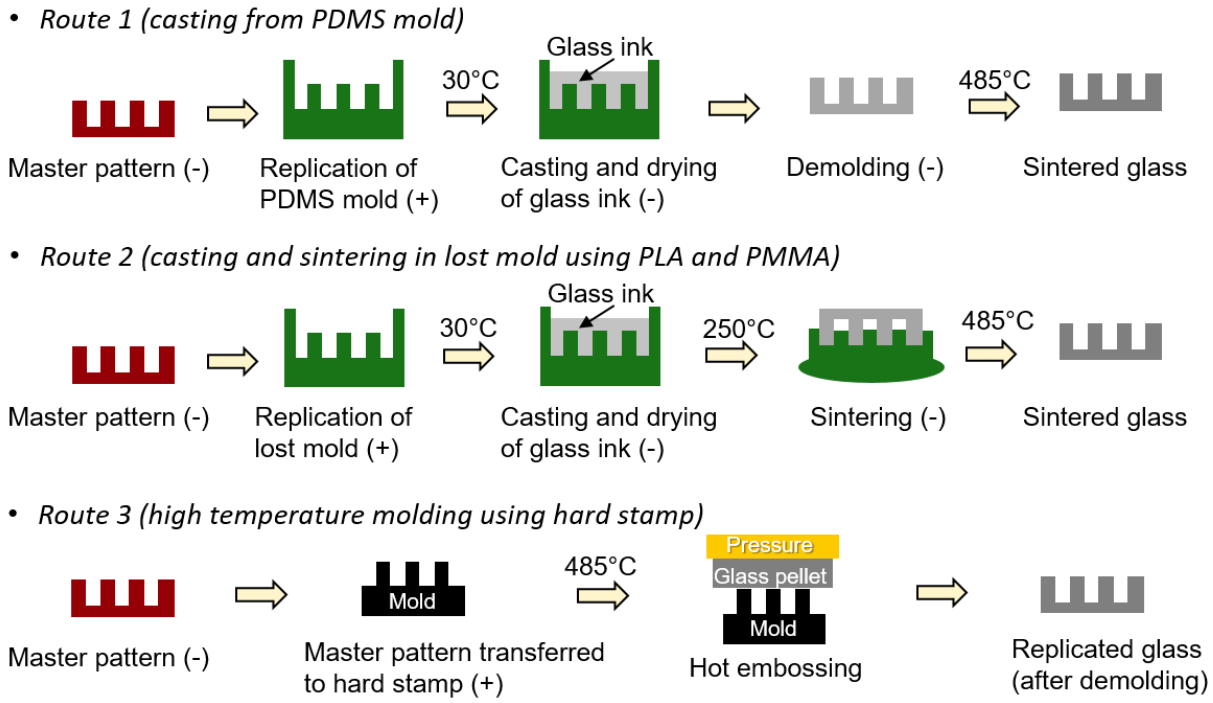

Figure 1. Schematics of the different molding routes to fabricate phosphate glass based open microfluidic channel using hybrid glass materials.

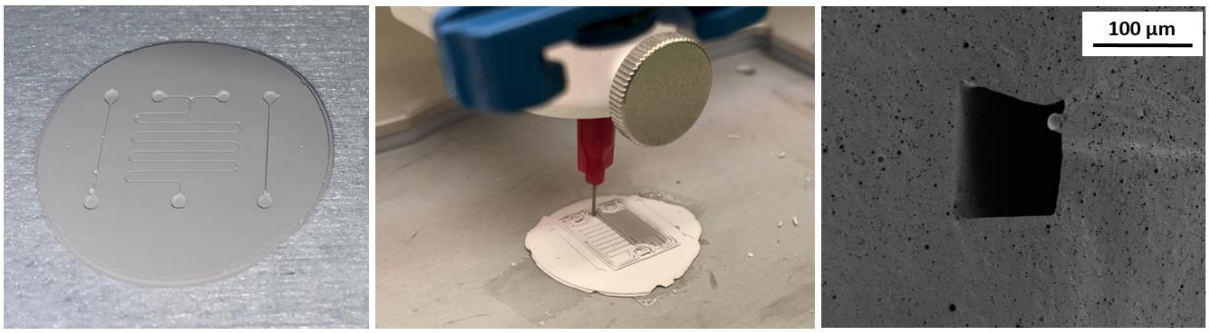

Figure 2. Photograph of the imprinted green body of microfluidic channel before sintering (left), sealing the channel by extrusion based printing onto demolded green body (center) and SEM cross-sectional micrographs of the microfluidic device after sintering (right).

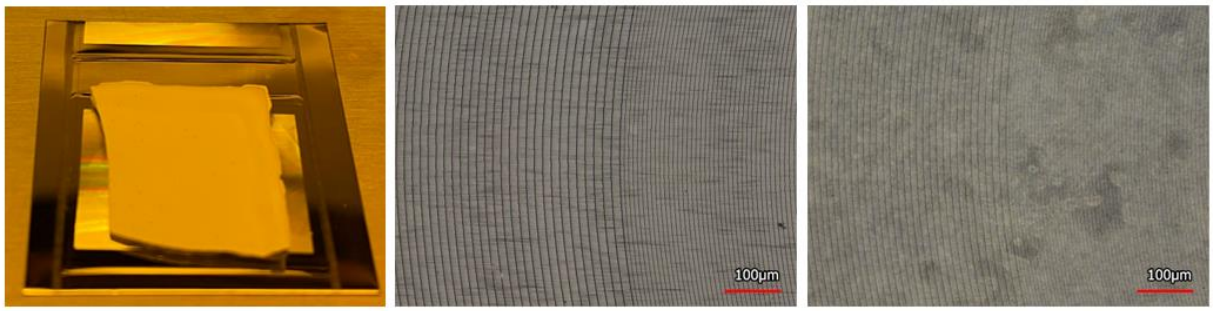

Figure 3. Photograph of green body molding setup on nickel stamp (left) with 0.5 µm 3D surface structures (Fresnel lens) performed at 600 °C. Comparison of replication quality between mold (center) and molded glass (right) with sub-µm roughness.