Capillary Filling of Nanoparticle Inks in Open Microchannels

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With the current trend of decreasing feature sizes of electrical interconnects, e.g. on printed circuit boards, the digital fabrication of high-resolution conductive lines is of increasing interest. While inkjet printing of nanoparticle inks allows for feature sizes down to several tens of micrometres, using prepatterned substrates and employing capillary forces even 5 µm conductive channels were achieved [1,2]. In this work, we show the fabrication of micrometre sized nanoparticle tracks with lengths up to several millimetres by inkjet printing nanoparticle silver inks onto nanoimprinted microchannels and subsequent drying and sintering.

The process we are aiming at is depicted in Figure 1. First, the open microchannels are created on the substrate by UV-nanoimprint lithography. Then a liquid reservoir is inkjet printed onto the structured area, which starts the capillary filling. After the microchannels are filled with the liquid, the solvent is evaporated, leaving only the nanoparticles behind. Thus, after sintering the nanoparticles form a high-resolution conductive track inside the microchannels. We are working towards further improving the filling process and increasing the filled length by trying to better understand the behaviour of fluids in open microchannels through experiments, simulations and theoretical considerations. We present experiments using three different patterns: rectangular, lenticular and V-shaped grooves, as shown in Figure 2.

First experiments on V-grooves and rectangular channels imprinted in OrmoComp (micro resist technology) verify the condition on the contact angle for channel filling arising from the minimization of the Gibbs free energy [3]. An example is shown in Figure 3, where two different contact angle inks were deposited on V-shaped grooves and only the one fulfilling the contact angle condition is filling the microstructures. Using these findings as starting point, we present simulation and experimental results on V-shaped, rectangular and lenticular channels filled with various nanoparticle inks and demonstrate the fabrication of high-resolution tracks down to 1 µm width and 5 mm length, as shown in Figure 4 and Figure 5.

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[1] Smith, P.J.; Shin, D.-Y.; Stringer, J.E.; Derby, B.; Reis, N.; "Direct ink-jet printing and low temperature conversion of conductive silver patterns" Journal of Materials Science 2006 41,(13) 4153–4158.
[2] Horváth, B.; Křivová, B.; Schift, H.; "Nanoimprint meets microfluidics: Development of metal wires from nanoparticle ink filled capillaries" Micro and Nano Engineering 2019 3,22–30.
[3] Butt, H.-J.; Graf, K.; Kappl, M.; *Physics and Chemistry of Interfaces*. Wiley, 2006.
[4] Herminghaus, S.; Brinkmann, M.; Seemann, R.; "Wetting and Dewetting of Complex Surface Geometries" Annual Review of Materials Research 2008 38,(1) 101–121.
[5] Brakke, K.A.; "The Surface Evolver" Experimental Mathematics 1992 1,(2) 141–165.

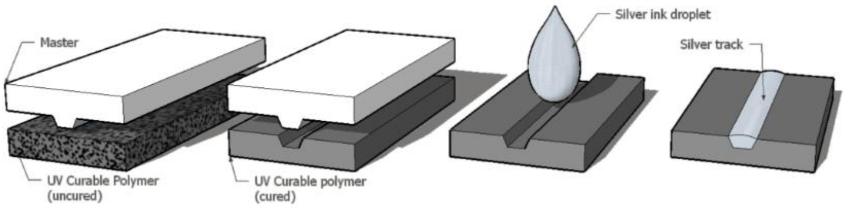

Figure 1. Fabrication process of high-resolution tracks. First, a master structure is pressed into a liquid UV curable polymer, which is hardened by UV light. After separation, the inverse protrusions of the stamp are replicated into the polymer. Placing silver ink onto the structured substrate leads to capillary filling of the channels and creation of high-resolution silver tracks after drying and sintering.

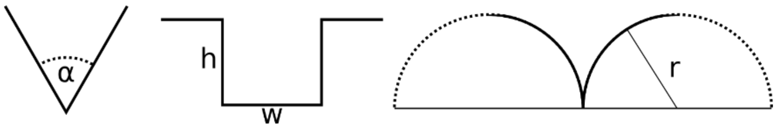

Figure 2. Cross section of the microstructures used for guiding the nanoparticle inks. From left to right: V-shaped, rectangular and lenticular grooves.

Figure 3. Microscope image V-grooves of 31 µm periodicity imprinted in OrmoComp (micro resist technology) with nanoparticle inks (PV Nano Cell) manually deposited on top. The left image shows the resulting conductive lines for an ink that has a low contact angle θ fulfilling the capillary filling condition $\theta < (\pi - \alpha)/2$ [4]. The original deposited droplet vanishes completely and fills the microchannels up to a length of 1 cm. Right: A nanoparticle ink with a higher contact angle deposited on the same structure stays within the deposited region.

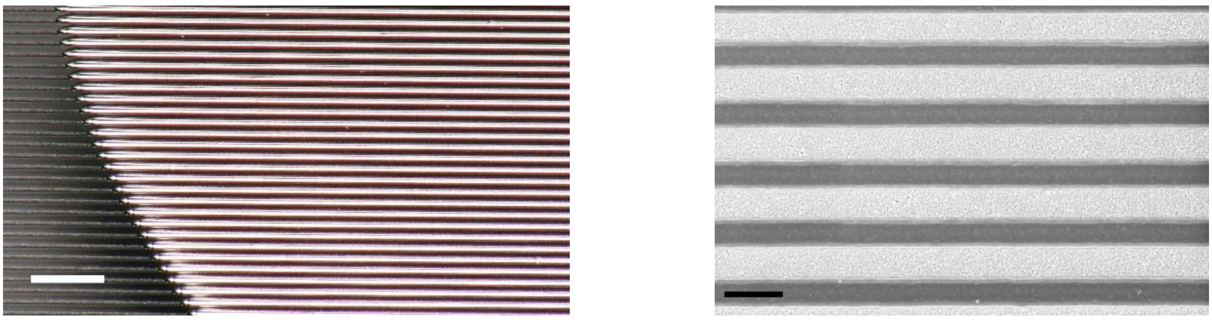

Figure 4. Left: Close up of the microchannels shown in Figure 3 left. Scale bar 200 µm. Right: SEM image of 1 µm wide and 5 mm long nanoparticle lines created by capillary filling of rectangular structures of 1 µm half-pitch and 850 nm height imprinted in OrmoComp (micro resist technology). Scale bar 2 µm.

Figure 5. Simulation results of the minimal energy configuration of a liquid (blue) with contact angle of 50° (left) or 90° (right) on a V-shaped substrate with opening angle of 60°. Note that the 90° result corresponds to a spherical wedge. Simulations performed with “Surface Evolver” [5].