

Back injection molding of polymer films with capillary filled sub-micron silver wires

Sijia Xie¹, Barbara Horváth¹, Jerome Werder², Helmut Schift*¹

Paul Scherrer Institut (PSI)¹, Lab. for Micro- and Nanotechnology, 5232 Villigen PSI, Switzerland
FHNW University of Applied Sciences and Arts Northwestern Switzerland², 5210 Windisch

E-mail: helmut.schift@psi.ch

Monolithic integration of integrated circuits onto macroscopic polymer parts can be done by adding individual electronic elements after the polymer part has been molded or by adding a film with the entire circuit prepared in advance. In the first case, the patterning of non-flat surfaces requires a patterning method with tools that can follow the outline of a 3D topography, in the second case a flexible film that needs to be deformed. This approach has been used for thermoforming and is now also favored for printed electronics [1,2]. This way, fabrication methods for low-cost flexible electronics can be used to prepare the polymer films.

We placed a 175 μm -thick polymeric film into the crowned mold of an injection-molding tool that constitutes a concave cylinder lens with a radius of 30 mm and a depth of 10 mm, with a convex cylinder at the opposite side. The film (PMMA: Evonik Plexiglas film 99524, T_g 113°C) was patterned by thermal nanoimprint (T-NIL) at 180°C and was pressed into this crowned surface by the viscous polymer (Evonik Plexiglas 7N, T_g 110°C) injected onto the backside of the film. The tool temperature (40°C) was low enough that the 260°C hot melt was cooled down to \sim 100°C when it reaches the film upon entering the mold cavity, thus it was able to deform the thermoplastic film without erasing its topography. The resulting back-injected cylinder-like element consists of the film that is covering the top of a 3 mm thick convex polymer body. Two cases were implemented: When the film is patterned towards the mold surface, the resulting cylinder has a surface topography constituted by the film. When it is patterned towards the injecting polymer, the surface structures are embedded. The latter is an interesting alternative if not only surface structures are used, but films that are already processed, e.g., covered with electrodes.

We used both cases for the fabrication of components covered with a metal wire array (Fig. 1). Our process has, in comparison to inkjet printing used for printed electronics, resolutions down to sub- μm and relies on nanoparticle self-confinement in V-grooves [3]. Similarly, films with open microchannels were back-injection molded (Fig. 2). The shape of the 3.1 μm wide V-grooves is slightly flattened by the process, thus enabling capillary filling in an open microfluidic approach [4]. In both cases, the wires are electrically conducting.

Combining nanoimprint lithography and additive patterning techniques may be a viable strategy to create low-cost devices on large areas or even free-form components. Such strategies can be applied to various designs of electrical circuits that enable to build complex devices as planned within the SFA project FOXIP [5]. Applications would be LEDs and sensors embedded in polymer components.

References:

- [1] H. Schift, *J. Appl. Phys.* 121(2) (2015) 415-435
- [2] T. Senn, et al., *Microelectron. Eng.* 88 (2011) 11.
- [3] B. Horváth, et al., *Adv. Mat. Technol.* 4(3) (2019) 1800652.
- [4] B. Horváth, B. Křivová, and H. Schift, *Micro and Nano Eng.* 3 (2019) 22.
- [5] FOXIP Project, <https://www.sfa-am.ch/foxip.html>.

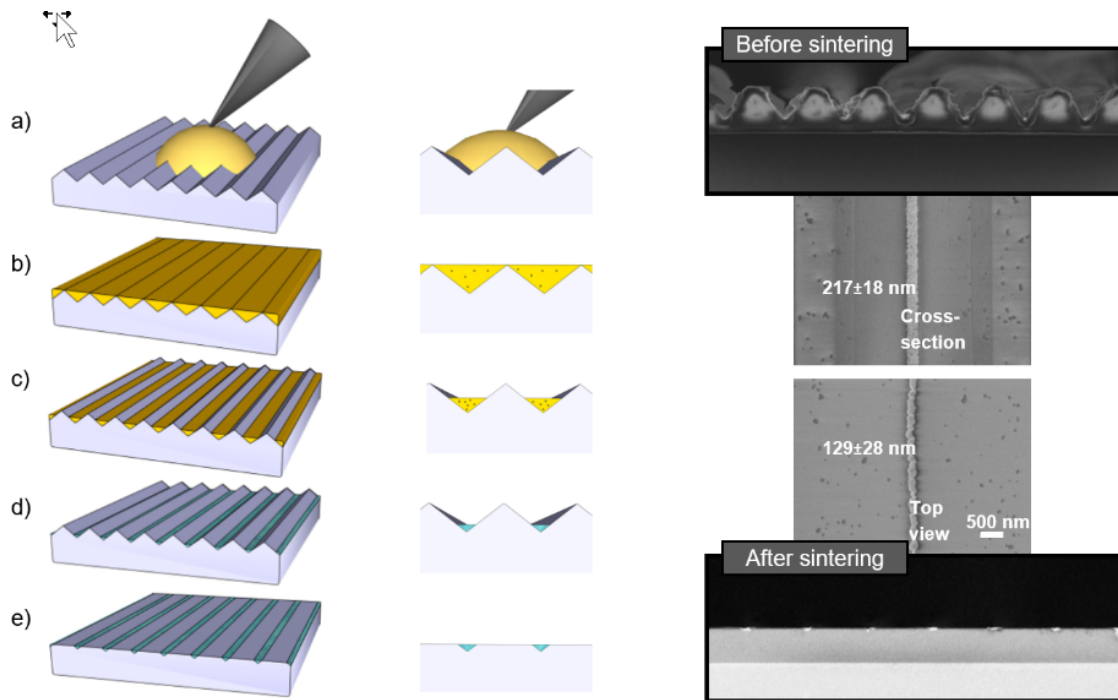


Figure 1. Fabrication of films with self-confined metal line pattern. Left side: Schematics of process (a) Dispensing of silver ink, (b) solvent evaporation, (c) drying, (d) densification, (e) simultaneous sintering of metal lines and thermal reflow of substrate. Right side: SEM micrograph of V-grooves cross-section with particles (substrate: spincoated PMMA on Si-wafer) [3].

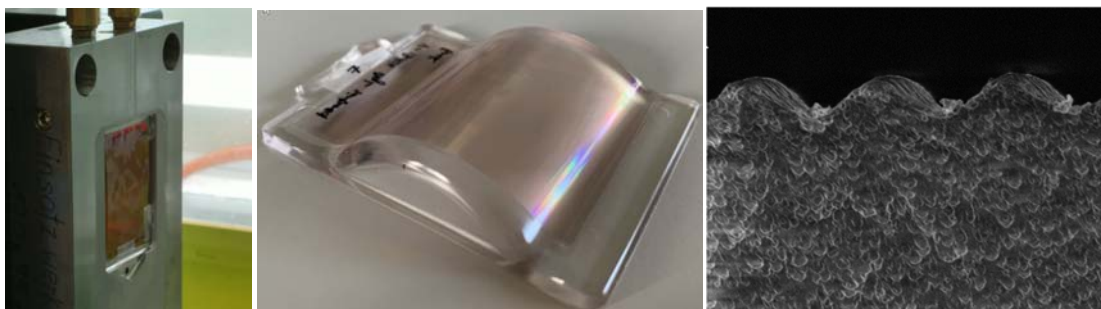


Figure 2. Back-injection molded film on polymer cylinder component. Left side: A patterned PMMA film (175µm) is placed into the crowned side of an injection molding tool. Center: Cylinder element with surface silver wires. Right side: SEM micrograph with 4-µm period V-grooves in PMMA film (original: groove width/depth 3.1/2.2 µm, depth after sintering and back injection molding: 1.2 µm), with Ag wires in the vertices (light grey). In comparison to Fig. 1, V-grooves did not reflow due to a low sintering temperature, and not because of the back-injection molding process, too.