# Inkjet Printed Optical Waveguides

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*Optical waveguide structures have been inkjet-printed with a special technique relying on the formation of capillary bridges. The optical losses amounted to 0.61 dB/cm on average with the best waveguides performing at 0.2 dB/cm, highlighting the precision with which the features were deposited. Besides waveguide-based applications like sensing or data transfer, the developed printing technique could also easily be adapted to other structures or materials to enable rapid prototyping and actual production alike.*

Additive manufacturing has received a lot of attention recently as it is a material-efficient, low-temperature, and vacuum-free process. Non-contact printing is a highly customizable technology amongst this family of techniques due to the different inks and hence functionalities available. Inkjet printers usually also only require a simple digital blueprint. It is therefore no surprise that huge efforts have been undertaken to apply inkjet printing outside of classical color generation and use it for writing electrical circuits, optical microstructures or microfluidic channels. Unfortunately, basic microscopic geometries such as (high aspect ratio) lines are for example inherently instable and prone to bulging due to the surface tension of the deposited ink. For this reason, smooth and tall lines comparable to photolithographically patterned waveguides have been very difficult to print up to now.

We recently developed an approach that turns the formerly problematic surface energies into the driving forces for structure generation. The technique relies on the deposition of pinning caps, which can subsequently be connected with self-aligning capillary bridges (Figure 1).

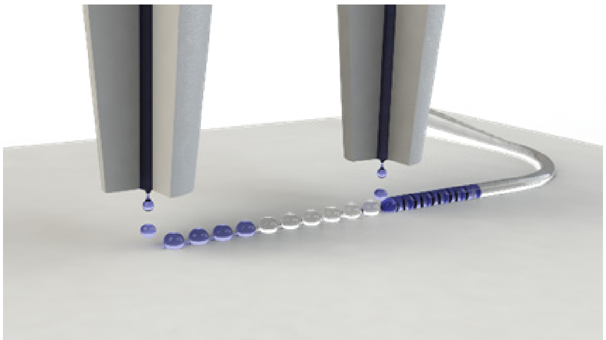

*Figure 1: Sketch of the specially developed printing process.*

This very simple method allowed us to accurately print a variety of continuous structures including curved waveguides or optical splitters (Figure 2). These are examples for features that would be nearly impossible to print through classical droplet deposition, as the cohesive forces in the liquid would force the material into round blobs instead of thin, connected lines.

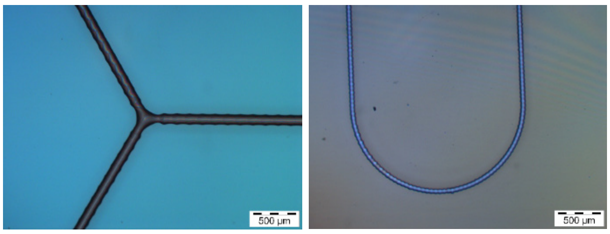


*Figure 2: Printed optical waveguide geometries.*

To compare the performance of the printed structure, a series of tapered, curved waveguides was printed and optical losses were measured with red laser light and a photodiode (Figure 3). Our average loss measurements of 0.61 dB/cm on a batch of waveguides are to our knowledge the first ones to date for inkjet printed waveguides. The best performing waveguides in the batch showed losses down to 0.2 dB/cm, which is comparable to lithographically patterned ones. In this context, we also demonstrated the importance of minimizing any line roughness (and especially preventing bulge formation) in order to achieve such high quality waveguides.

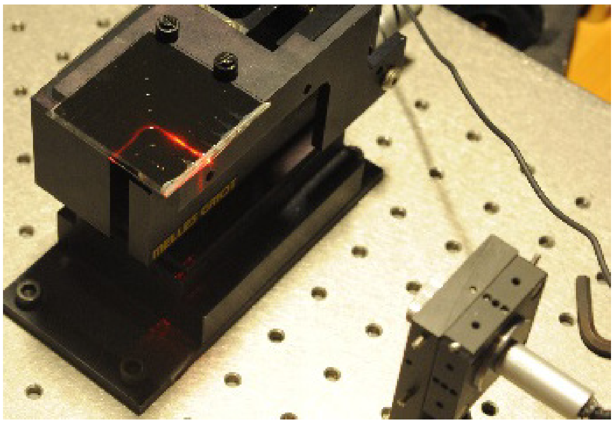

*Figure 3: Optical characterization setup excluding the photodiode.*

In general, the replacement of standard optical components by micro-optical elements has often proven advantageous. Rather frequently though, several elements must be combined and aligned with respect to each other, which is particularly challenging in the context of miniaturization. The use of inkjet printed capillary bridges here also allows for flexible yet simple designs to connect or align waveguides with other components, which is a clear advantage over common photolithographic techniques.

In summary, the capillary-bridge printing technique reported circumvents the severe problems inkjet printing previously experienced in attempts to print linear or complex features on low energy surfaces. Besides rapid prototyping, which traditionally relies on additive manufacturing techniques, the present technique also facilitates industrial fabrication since inkjet printing is a very mature process that can even be included in roll-to-roll lines. It may not only pave the way towards flexible waveguide design, but can also be applied for new solutions in the broader domain known as free-form optics, where removing constraints on symmetry can offer considerable savings both in space and weight. Consequently, lab-scale as well as industrial applications ranging from lab on a chip over optical sensors to lighting can profit from these developments.