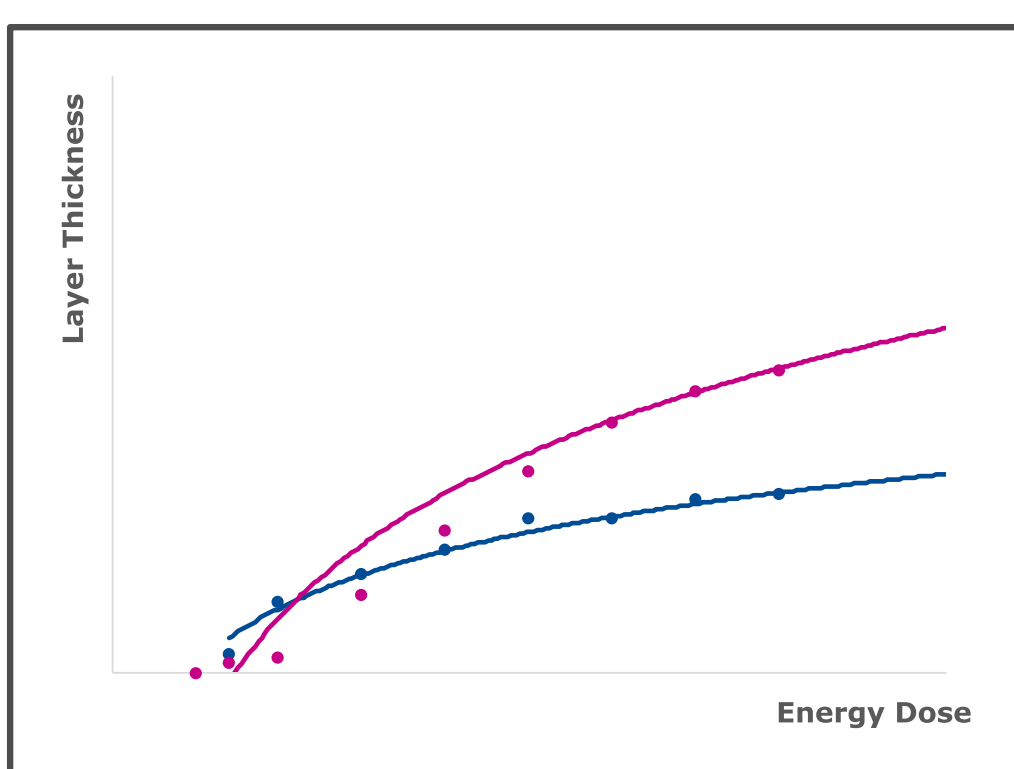


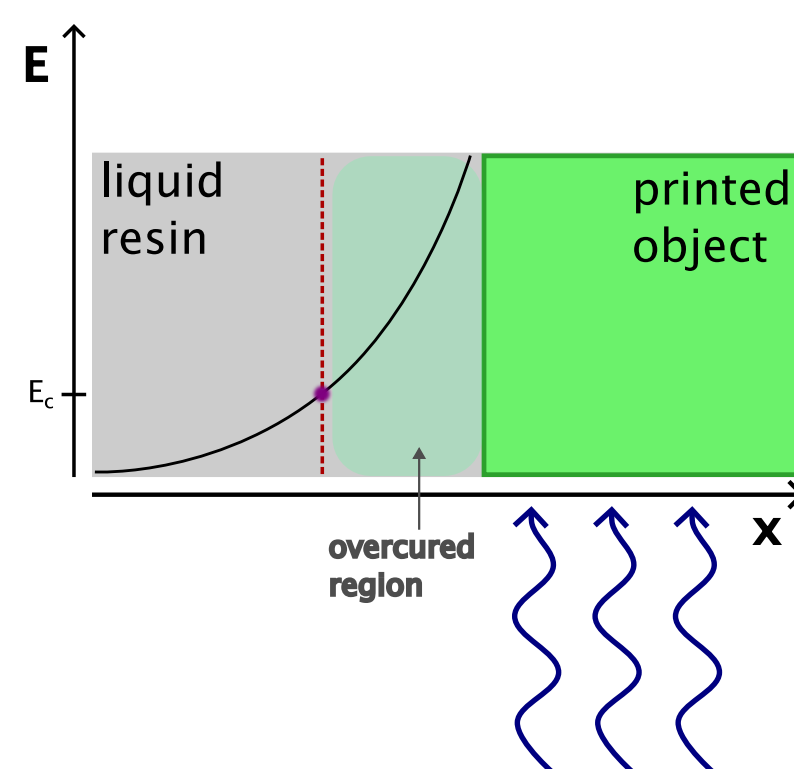
## Introduction

Vat photopolymerization (VPP) 3D-printing of UV-curable photo resins enables the production of narrow channels and cavities with transparent and biocompatible materials. Therefore, it is, among other applications, useful for microfluidics. However, in the past, smaller or larger deviations in the 3D printing result with photopolymers always had to be expected. A root cause for inaccuracies of the prints are overcuring phenomena, which occur particularly with clear materials and can represent a significant deviation, especially when realizing exact inner structures and cavities. A deliberate tuning of the photochemical behaviour of the material when exposed to the 3D printer's light source is crucial. The material's working curve correlates the thickness of a formed layer of cured material with the light energy per unit area deposited in the material. Key parameters of the photopolymerization process are the critical energy  $E_c$  to initiate solidification due to polymerization and the penetration depth  $D_p$  of the curing light. The CDB (cure depth barrier) technology suppresses overcuring, which is an undesired effect, to a very minimum level. The technology allows, for example, the precise fabrication of capillaries with an inner diameter of about 1 mm and a wall thickness of only 100-200 microns. 3D prints were performed with MOIIN Tech Clear on an Asiga Max UV printer.

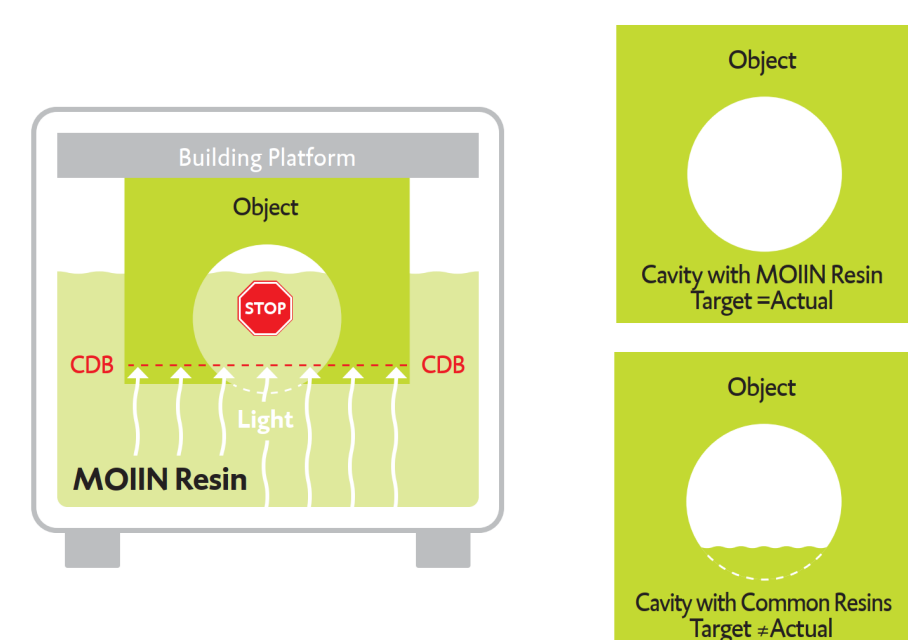
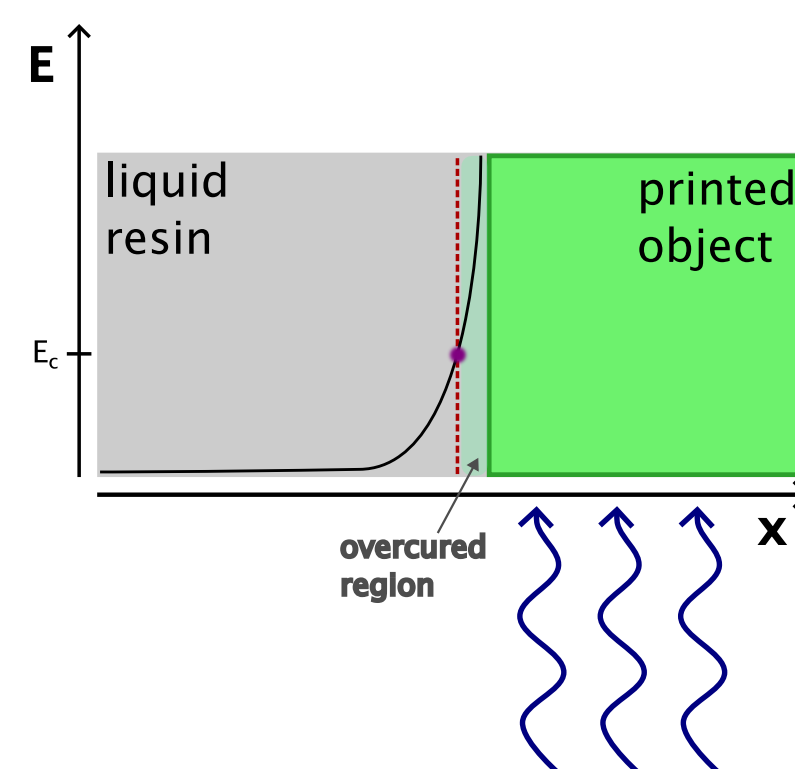
## CDB Technology



Exemplary working curves show different characteristics. Depending where the desired layer thickness is located on the working curve the local slope is different. **Material 1** can be more robust to variations in deposited energy and therefore variabilities of the equipment compared to **material 2**.

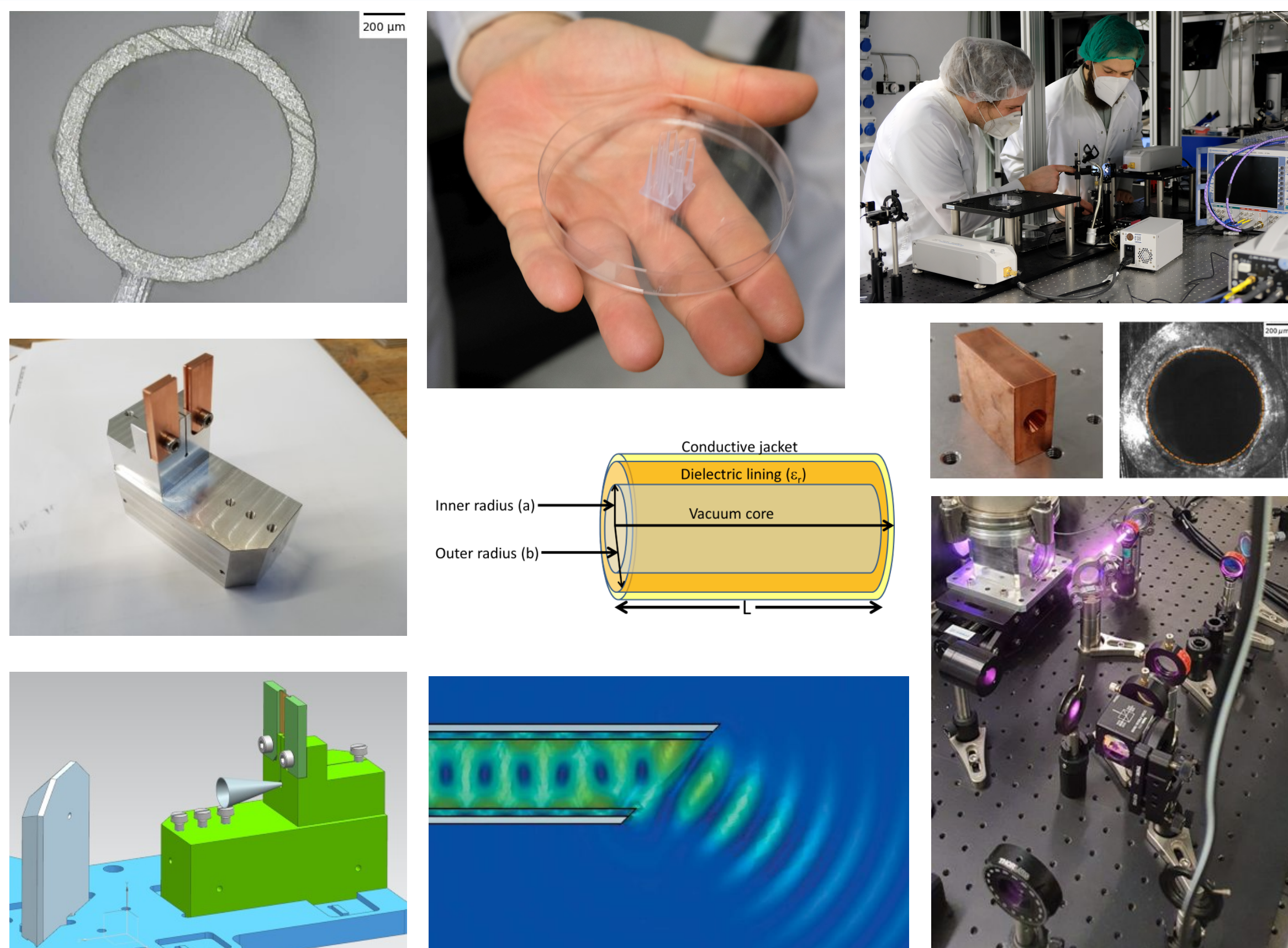


Tailoring of the 3D printing resin in terms of  $E_c$  and  $D_p$  is key to achieve accurate objects. In a high  $D_p$  and lower  $E_c$  situation, as shown on the left image, the area of overcured material is larger. This leads to inaccurate object dimensions. In the case of small scale hollow structures these might be blocked by overcured material. On the right image a material with its working curve optimized by CDB technology is shown. Overcuring effects are minimized leading to very low to almost no overcuring effect in the x/y plane.

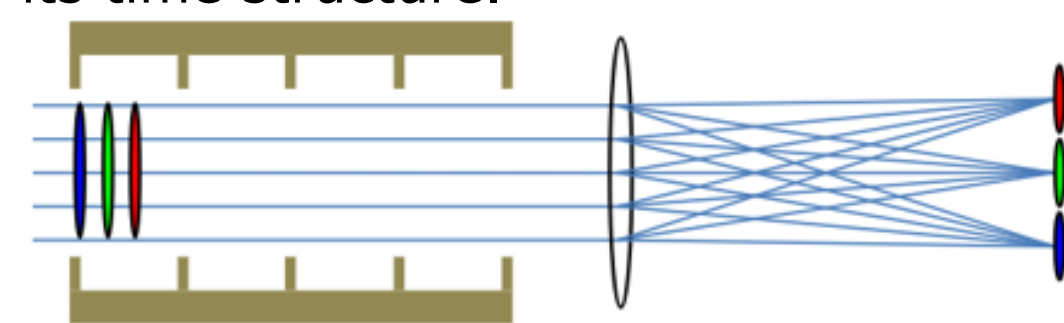


Polymerization shall not take place beyond the layer addressed by the 3D printer. CDB technology helps to prevent undesired overcuring along the z-direction for the formation of a spatially resolved polymer network.

## Use Case



The objective at DESY is to print dielectric-lined waveguides with well known thicknesses to couple to relativistic electron beams. Here we use laser-based approaches to excite THz modes in these 3D printed structures. One example is to streak the electron beam to measure its time structure.



Structures have been designed, 3D printed, coated, and tested in house. Currently iterating for final structure based on phase velocity measurements to reduce phase slippage in the structure. THz source works well and is well characterized (EOS) and supports a range of operation from 288-284 GHz (50 cycle pulses). It has therefore been shown, that effective waveguides could be printed with CDB technology material. The 3D printed structure has a free inner diameter of approximately 1 mm and a wall thickness below 200  $\mu\text{m}$ . Sections cut through the waveguide are assessed by microscopy show the high accuracy of the print. Further the material showed a relatively low attenuation, for THz radiation, causing a reduction of absorption losses of the radiation in the printed object. Important factors are also the strength of the material to ensure a reasonable stiffness of the capillary. Another important factor is a minimum release of volatile substances from the material to enable its use in high vacuum.

F. Lemery, K. Floettmann, T. Vinatier, R. Assmann, "A transverse deflection structure with dielectric-lined waveguides in the sub-THz regime," Proc. IPAC19 (MOPAB052)

M. Kellermeier, F. Lemery, K. Floettmann, W. Hillert, and R. Aßmann, "Self-calibration technique for characterization of integrated THz waveguides", Phys. Rev. Accel. Beams 24, 122001 – Published 6 December 2021

## Conclusion

Delicate capillary structures were successfully printed of a highly transparent material using the VPP technology DLP 3D printing. Structures have been designed, 3D printed, coated, and tested by DESY. First tests of such structures as THz radiation waveguides were successful. Dielectric-lined waveguides (DLW) lead to a wide variety of beam-related applications. This is not limited to THz generation but can include more acceleration and beam manipulation tasks like de-chirping, microbunching or streaking.

It has been shown, that the material enables the production of narrow channels and cavities with transparent and biocompatible materials. Even though first results obtained were promising there are needs for further development. Further goals are to improve the coupling efficiency with new hardware and improving the THz source. Development of the 3D printing material is going to reduce the damping of THz radiation paving the way to even more efficient 3D printed waveguides.

The results obtained here support the conclusion, that clear 3D printing materials employing CDB technology could be useful in many applications, especially where fine capillary structures are needed like in microfluidics applications.