BioBots: Fabrication and Characterization

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BioBots: Fabrication and characterization

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Light Robotics

Light Robotics combines the latest trends in micro- and nanofabrication with intelligent light sculpting. 3D-printed microtools with well-defined shapes and surface chemistry can be tailored to a multitude of applications for biomedical research purposes and actuated using sculpted laser beams.

Figure 1 shows some examples of 3D-printed Light Robotics microtools: fluorescently-functionalized tool (A), nut-and-screw construct assembled using optical manipulation (B), surface scanning probe (C), syringe-like tool for targeted material delivery (D) and a tool for indirect optical manipulation of living cells (E).

In addition to such 3D-printed microtools, Light Robotics encompasses microobjects based on light-responsive materials (e.g. light-sensitive polymers or liquid crystal elastomers).

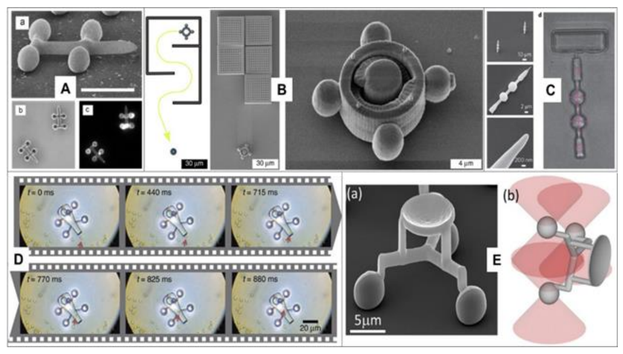

Figure 1: Examples of Light Robotics microtools from different research groups around the world

BioBots

The Light Robotics microtools shown above perform well in water or simple aqueous solutions. To maximize their potential, these microrobots need to perform well in biological samples or simplified models. This represents a significant challenge due to the optical properties of these complex samples and interactions between the tools and their environment.

To overcome this, we are combining two approaches: i) adaptive optics and ii) surface functionalization. Dynamic wavefront correction can help improve light focusing in the biological media and therefore increase the optical trapping forces, while surface functionalization can help reduce the interaction forces between the microrobots and the biological media that they are in. We expect that combining these two approaches will allow us to precisely manipulate the microtools in biological samples and make progress towards microrobotic surgeons (concept shown in Figure 2).

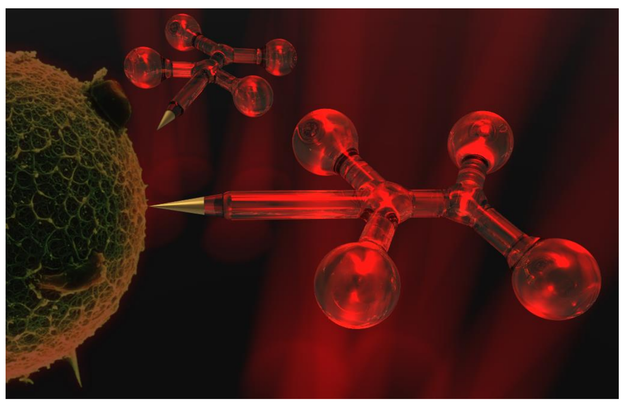

Figure 2: Conceptual drawing of a light-controllable microrobot performing microsurgery on a living cell.

Fabrication

We use two-photon polymerization, the highest resolution available 3D-printing method available, for direct laser writing of our microtools with a feature size of ~200 nm (Figure 3). We print on a Nanoscribe Photonic Professional GT using the IP-L 780 acrylic photoresist.

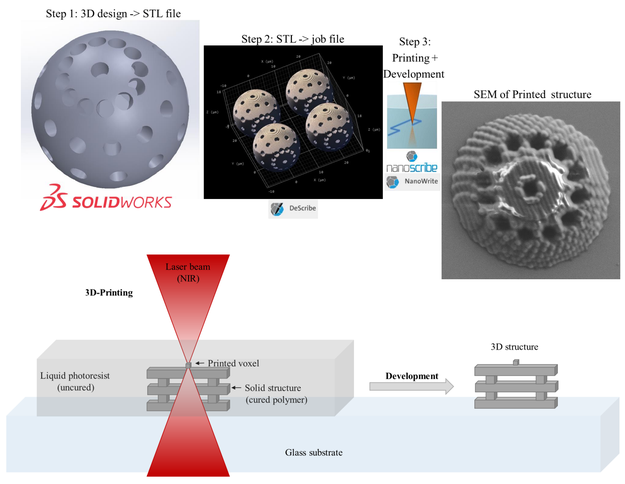

Figure 3: Top: Steps in the 3D-printing process: 1: 3D design; 2: slicing, hatching and array generation; 3: printing and development. Bottom: Schematic representation of the two-photon polymerization 3D-printing process.

After 3D-printing and development, the microtools are selectively modified by:

- Physical vapor deposition (PVD) of metals, such as gold for laser-assisted thermoplasmonic heating; we use e-beam evaporation for PVD (Figure 4).
- Chemical functionalization, which allows further coupling of a wide range of (bio)molecules.

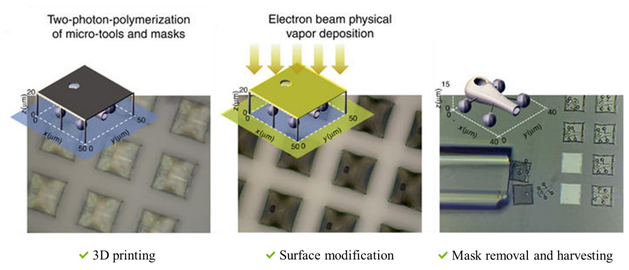

Figure 4: Schematic fabrication of hollow-body syringe microrobots: two-photon polymerization, selective metal coating of the internal feature and harvesting from the glass slide.

To introduce reactive groups on polymer surfaces, we use plasma treatment or an anthraquinone amine photolinker. For further functionalizing gold, we employ thiols. Figure 5 shows a schematic representation of a combination of plasma treatment and chemical reactions used to selectively modify patterned polymer/gold surfaces.

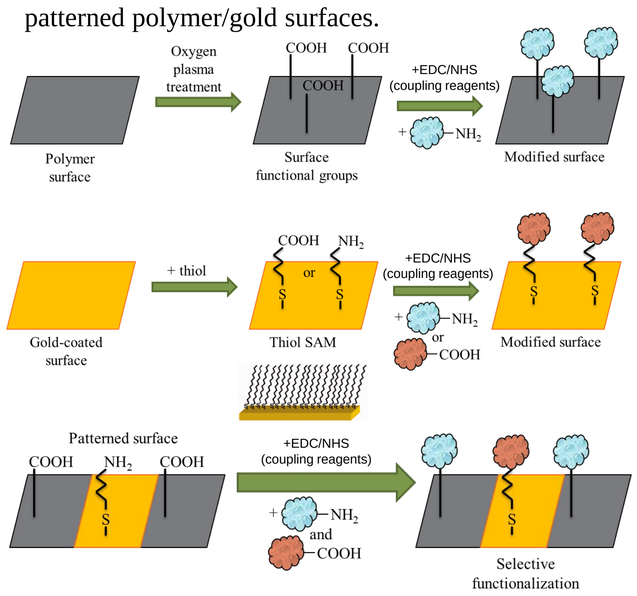

Figure 5: Top: Surface functionalization of plain polymer surfaces and gold-coated surfaces. On patterned gold/polymer surfaces, selective chemical functionalization with biomolecules can be obtained by combining different reagents and techniques.

Characterization

We use optical microscopy and scanning electron microscopy (SEM) to check the topology of our printed microtools. For estimating the printing resolution, we use high magnification SEM images. Figures 6 and 7 show examples of microtools we have developed for biomedical applications.

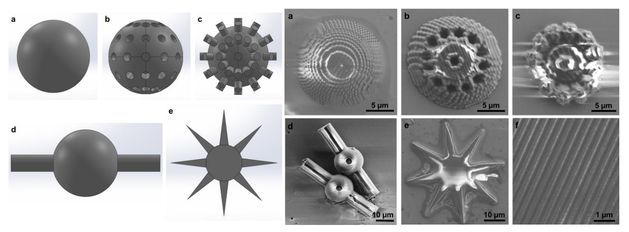

Figure 6: Microtools with different shapes and one trapping handle developed for investigating mucus biobarriers: 3D design (left) and SEM images after fabrication and development (right).

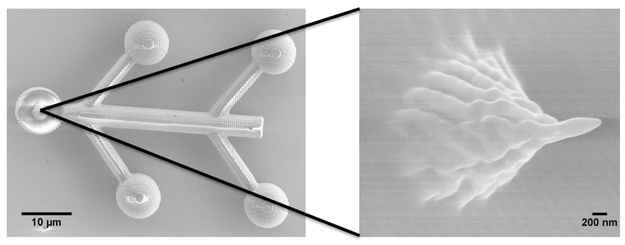

Figure 7: SEM image of a disk-tip microtool with four trapping handles and zoom-in on the tip feature, showing the print lines.

We use different techniques to characterize functionalized surfaces, among which X-ray photoelectron spectroscopy (XPS), Fourier transform infrared spectroscopy (FT-IR) in attenuated total reflection (ATR) mode, bright field and confocal microscopy. Figures 8 and 9 show examples of XPS and FT-IR spectra that we employ to characterize surface modification of the IP-L 780-derived polymer with the anthraquinone amine photolinker.

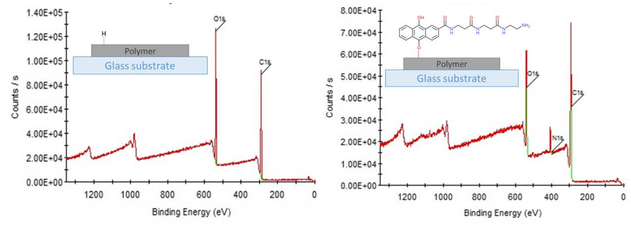

Figure 8: XPS survey spectra of IP-L 780- derived polymer after 3D-printing and development (left) and after subsequent functionalization with anthraquinone amine photolinker (right). The presence of nitrogen confirms photolinker grafting on the polymer surface.

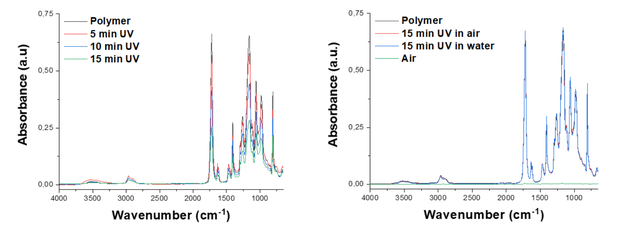

Figure 9: ATR-FT-IR absorbance spectra of IP-L 780-derived polymer and polymer modified with anthraquinone amine using different UV exposure times (left) and reference samples: air, crosslinked polymer, polymer exposed to 15 min UV in air, and polymer exposed to 15 min UV in water (right).

Figure 10 shows a thermoplasmonic disk microtool used to generate a natural convection flow in a microfluidic channel. We used particle tracking in a bright field image series to investigate this behavior.

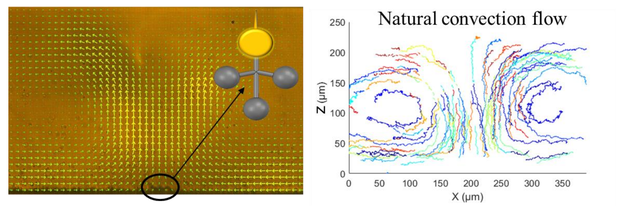

Figure 10: Particle tracking in a series of brightfield images reveals a natural convection flow induced by a thermoplasmonic disk microtool in a microfluidic channel. Inset shows tool design.

References

Bunea, A.-I. & Glückstad, J. Strategies for optical trapping in biological samples: Aiming at microrobotic surgeons. *Laser Photon. Rev.* **13** (2019)

Bunea, A.-I, Jakobsen, M. H, Engay, E., Bañas, A. & Glückstad, J. Optimization of 3D-printed microstructures for investigating the properties of the mucus biobarrier. *Micro Nano Eng.* **2** (2019)

Engay, E., Bunea, A.-I., Chouliara, M., Bañas, A. & Glückstad, J., Natural convection induced by an optically fabricated and actuated microtool with a thermoplasmonic disk *Opt. Lett.* **43** (2018).

Villangca, M. J., Palima, D., Bañas, A. R. & Glückstad, J. Light-driven micro-tool equipped with a syringe function. *Light Sci. Appl.* **5** (2016).

Acknowledgments

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