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3D printed microrobots controlled by light – Towards environmental and biomedical applications

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Abstract

Microrobots are rapidly developing as a valuable solution for performing microscale tasks, among which they seem particularly promising for biomedical and environmental applications. Two-photon polymerization enables the fabrication of microstructures with complex shapes, while focused laser beams allow for precise manipulation of such 3D printed objects. Whereas several challenges have yet to be overcome before microrobots can perform in the real world, many interesting laboratory applications have already been demonstrated, while others are being explored.

1. Introduction

Microrobots are raising enormous interest in the scientific community because of their potential for performing various tasks at the microscale. Among their target fields of use, biomedical and environmental applications are likely the most promising. Recently, we reviewed the literature on the use of microrobots for biomedical applications [1], and would like to highlight that, while the use of microrobots in vivo is a noble goal, there are yet numerous related challenges when it comes to e.g. deployment and retrieval strategies, control, or imaging. On the other hand, microrobots could in the near future become valuable tools for laboratory testing, where for example hyperlocalized sensing is particularly interesting for both biomedical and environmental applications.

2. 3D printing by two-photon polymerization

Two-photon polymerization 3D printing is a direct laser writing technique, where the structure is written layer-by-layer and voxel-by-voxel into a suitable negative photoresist using a highly focused femtosecond-pulsed laser beam. We use a Nanoscribe GT+ system for the microfabrication of polyacrylate robots amenable to optical trapping and manipulation. Typically, for producing microstructures with maximum resolution, we use a Plan-APoChromat 63×/1.40 Oil DIC objective and the commercial photoresists IP-L 780 or IP-Dip. With optimal parameters, the resolution of the system is 100-200 nm in the XY plane and, because the laser focal spot is ellipsoidal rather than spherical, around 1.5-3.5 lower on the Z-axis [2,3]. An example of a 3D printed polyacrylate microrobot is shown in Fig. 1.

3. Light-controlled micromanipulation

Among the many different approaches to microrobot propulsion and control, light offers unique opportunities in terms of precision, as highly focused near-infrared laser beams can be employed for simultaneous micromanipulation of multiple microrobotic components [2]. Furthermore, the use of light-responsive materials which deform when exposed to ultraviolet or visible light also offers interesting perspectives for introducing additional functionality (Fig. 2).

In our group, we employ a custom-made optical trapping setup called the Biophotonics WorkStation (BWS) for precise microrobot manipulation with six degrees of freedom (Fig. 3). The setup allows for visualizing the microrobots in motion both from the top and from the side.
micromanipulation of such objects. Implementing state-of-the-art solutions to improve light focusing in complex media while simultaneously tailoring the surface chemistry of the microrobots should foster applications in complex media, which is extremely relevant for many envisioned environmental and biomedical applications. Light-controlled microrobots with the ability to sense target analytes, deliver therapeutic agents, or neutralize toxic chemicals should soon become the go-to solution for laboratory experiments where such tasks need to be performed on the microscale with extreme precision. Ultimately, we envision that more complex microrobots will be able to perform microscale tasks in the real world, for example in lakes, rivers, or the human body.

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