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LETTER

How is 3D Printing Revolutionizing the Design and Fabrication of Analytical Microfluidic Devices?

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Microfluidics, the science of the study and manipulation of small volumes of fluids, has played a fundamental role in the miniaturization of analytical devices. As a result, analytical microfluidic devices (AMD) can enhance portability, reduce costs, minimize sample and reagent consumption, increase analysis speed, and integrate and multiplex analytical steps. These features align with the principles of green chemistry and make AMD suitable for point-of-care diagnostics, environmental and remote monitoring, food safety, and many other applications.[1,2]

The development of AMD was boosted in the 1990s, and the first devices were usually fabricated on silicon or glass substrates using photolithography methods. However, these microfabrication techniques were expensive, laborious, and required complex and difficult-to-access facilities. Using polymeric substrates, microfabrication techniques such as micro-milling, embossing, and soft lithography made AMD fabrication more straightforward and affordable. Furthermore, better cost and fabrication simplicity were achieved using paper, thread, and fabric (cloth) as substrates for developing AMD.[3–6]

In the last decade, another revolution in the fabrication of AMD has emerged: the use of three-dimensional (3D) printing.[7] This additive fabrication method has transformed manufacturing in several fields, including analytical chemistry. Figure 1 illustrates the main steps required to 3D print an AMD. Initially, the microfluidic layout of the AMD is designed using computer-assisted design (CAD) software. Subsequently, the model is digitally sliced into layers, converted to a G-code, and sent to a 3D printer that builds the AMD layer by layer. The 3D-printing methods allow fast prototyping of AMD with complex and 3D architectures, which could be challenging to obtain by using the traditional microfabrication methods earlier cited. Thus, 3D printing has brought significant versatility for integrating diverse functionalities in AMD. As 3D printing is based on additive methods, there is less waste of material compared with traditional methods such as subtractive fabrication techniques. The most used 3D-printing techniques for fabricating AMD are the fused deposition model (FDM) and stereolithography (SLA), particularly digital light processing (DLP) and liquid crystal display (LCD) methods. Several review papers have provided a comprehensive overview of the advancements, challenges, applications, and perspectives of AMD fabricated by 3D-printing methods.[8–10]

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Figure 1. Schematic illustration of the 3D-printing fabrication process of an AMD.

The FDM 3D-printing method, based on the extrusion of melted thermoplastic materials, is simple and affordable but shows resolution limitations for manufacturing AMD that contain structures with dimensions below 200 µm. Our group has employed FDM 3D printing to manufacture AMD for nanoparticle synthesis[11,12] and colorimetric detections.[13] Additionally, we have improved this 3D-printing process by optimizing the geometry of the extrusion nozzles and the printing parameters to obtain microchannels with a width of about 70 µm.[14] This achievement has allowed multi-material printing of an AMD to conduct capillary electrophoresis separations with capacitively coupled contactless conductivity detection (C^4D).[15]

DLP and LCD 3D printing are based on layer-by-layer photopolymerization of a photocurable resin using ultraviolet-visible (UV-vis) light. These 3D-printing techniques provide better print finishing and resolution than FDM: They are suitable for fabricating detailed AMD with dimensions below 100 µm. Our research group demonstrated that a DLP 3D printer could fabricate AMD with complex geometries, including devices containing microchannels and spiral electrodes around the separation channel for microchip electrophoresis and C^4D.[16] Additionally, a straightforward adaption of a DLP 3D printer allowed us to perform multi-material printing.[17] There has been a marked decrease in the cost of DLP and LCD printers in recent years, making them affordable for research groups interested in manufacturing customized AMD.

As perspectives, developing new materials for 3D printing with tunable features such as electrical conductivity, porosity, flexibility, and chemical functionality continue to be a hot topic. The constant advancements in the multi-material 3D-printing processes could allow the fabrication of AMD with different materials. These advancements will bring more functionality to AMD and facilitate the integration of sample preparation, separation, detection, and other analytical steps in these devices. The resolution and print speed of commercial 3D printers are constantly being improved, which indicates a promising future for the scalability of the production of AMD.

In summary, 3D printing has fostered a breakthrough in the manufacturing of AMD, allowing fast prototyping of customized, intricate, and multifunctional designs. The trends in developing new functional materials, multi-material printing processes, improved resolution, and faster print speed show much room for creating innovative AMD for several applications, including diagnostic, environmental monitoring, food safety, and more.

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