3D molding processes based on two-photon microfabrication

Shoji Maruo

Combining precision micromachining with novel polymer or ceramic molding techniques addresses some of the challenges associated with mass producing 3D microdevices.

For over a decade, two-photon microfabrication using femtosecond pulsed laser beams has been attracting increasing attention as a 3D laser-fabrication technique. Unlike single-photon microfabrication (microstereolithography), which builds structures layer by layer in the 100μm–1cm size range, the two-photon approach offers sub-100nm resolution and structures with flexible parts. Moreover, it is amenable to a wide variety of materials, including photopolymers, biopolymers, and metals.1–6 Consequently, two-photon microfabrication has enjoyed wide use in metamaterials, photonic crystals, and lab-on-a-chip and medical microdevices.3–6 However, the method is based on laser direct writing—i.e., structures are produced by scanning the laser focus inside a material—which means that throughput is relatively low compared with other micro- and nanofabrication processes, such as lithography and nanoimprinting. Recently, a promising, ultra-high-speed 3D printing method using two-photon lithography was reported.7 Yet, mass production of functional 3D microdevices will depend on improving both throughput and the types of materials that can be used.

One popular technique for large-scale production of micro- and nanopatterns is soft lithography using a polydimethylsiloxane (PDMS) stamp. In an advanced application of the method, the group of John Fourkas replicated 3D microstructures, such as an overhanging trench and bridge, by means of so-called membrane-assisted transfer molding.8 Their approach inspired our own work in replicating movable microstructures.

We have developed a soft-molding process that employs a 3D polymeric template (PDMS mold) produced by two-photon microfabrication.9 We replicate complicated 3D microstructures simply by injecting a photopolymer into the mold and then curing it by exposure to UV light. Using membrane-assisted molding,8 we can reproduce even freely movable microstructures, such as microgears and microtweezers (see Figure 1). We have also shown that replicated microtweezers can be operated using an optical manipulation technique.

Another challenge of two-photon microfabrication is how to expand the range of materials beyond merely those sensitive to light, such as photopolymers and photoresists. To this end, we developed a 3D ceramic molding process based on both single- and two-photon microfabrication. In the two-photon approach, we begin by filling a polymeric mold produced by laser direct writing with a high-concentration slurry containing ceramic nanoparticles. After drying the slurry, we thermally decompose the polymeric mold, which produces a a green body (i.e., an unsintered form) with the inverted shape of the

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original master mold. Finally, we sinter the green body to obtain a 3D ceramic microstructure. Since this technique can use various kinds of ceramic nanoparticles, it has a much broader range of applications than conventional approaches, including not only MEMS (microelectromechanical systems) but also photonics and biomedicine. We have shown that transparent 3D microchannels can be made with a slurry composed of silica nanoparticles: see Figure 2(a) and (b).

Starting with a master polymeric model made using microstereolithography, we also constructed a complicated scaffold with high-precision microscopic pores using a slurry consisting of beta-tricalcium phosphate microparticles: see Figure 3(a) and (b). The desirable characteristics of ceramics—including high mechanical strength, high heat resistance, and biocompatibility—make this molding technique appropriate for practical microdevices.

In summary, our soft-molding process makes it possible to reproduce 3D movable micromachines easily and at low cost. Such devices will find application in optically driven micromachines, lab-on-a-chip devices, and microtools for biological study. The ceramic molding process provides various kinds of practical devices and elements, including 3D ceramic micromechanical parts with high strength and high heat resistance, 3D microactuators and energy harvesters using piezoelectric ceramics, 3D microfluidic devices using transparent glasses, and 3D bioscaffolds using bioceramics. In the near future, we would like to combine soft molding with ceramic-based molding to mass-produce practical ceramic elements such as piezoelectric energy harvesters and bioscaffolds.

Figure 3. Fabrication of a bioceramic scaffold. (a) Master polymeric model made by single-photon microfabrication. (b) Bioceramic scaffold. Scale bar is 1mm. (© 2011 The Japan Society of Applied Physics.)

References