Integrating 3D photonics and microfluidics using ultrashort laser pulses

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Femtosecond laser direct writing can form both 3D optical and fluidic microstructures buried in photoetchable glass, enabling integrated photonic fluidic devices.

The integration of photonics and microfluidics can benefit both information technology and sensor technology. On the one hand, optical devices that incorporate liquid elements can be modified by changing or modifying the fluid, which could eventually revolutionize the optical communications industry. On the other hand, optical methods, such as fluorescence detection and photoabsorption spectroscopy, have been popularly used in chemical and biological sensors. Compared with complex and expensive external bulk optical elements, incorporating micro-optical components into the sensors offers substantial benefits for creating compact and cost-effective devices.

At present, fabrication of microfluidic devices integrated with optical elements relies heavily on planar technologies, such as soft lithography. The main drawback of these methods is the difficulty involved in making 3D structures. Multistack bonding is often needed, which results in many process steps and, consequently, increased complexity and cost. To get around this problem, we have been working on a new approach using femtosecond laser direct writing in a photoetchable glass called Foturan. Both microfluidic and micro-optical structures can be formed and three-dimensionally deployed in a single glass chip by one continuous process.

Microstructuring photoetchable glass with UV light can be traced back to the mid-20th century. Since UV-light modification of Foturan glass is performed by a single-photon process, it inherently occurs at the surface of the glass. For this reason, we turned to a multiphoton-based approach that can be realized using a femtosecond laser operating at a near-IR wavelength. Figure 1 illustrates our fabrication approach, which consists of four main steps: forming a latent image in the glass by scanning a focused femtosecond laser beam; transforming the latent image into an etchable phase via postannealing; removing the modified areas by chemical etching; and smoothing the internal surfaces with additional postannealing.

As a first step toward integrating photonics and microfluidics in Foturan glass in true 3D configurations, we constructed a microchemical reactor composed of microfluidic channels and reservoirs inside the glass. Moreover, we showed that freely moving micromechanical elements can be directly fabricated within a hollow chamber. These structures served as microvalves for switch-Continued on next page
Figure 2. (a) An optical micrograph shows the top view of a microfluidic laser. (b) The side view makes evident how the channel passes through the chamber. (c) Light circulates in the microfluidic laser. The measured reflection loss was only 0.24dB at the communication wavelength of 1550nm. Furthermore, we used this technique to generate nonplanar optical structures such as freestanding optical fibers and micro-optical lenses.\(^9\)

Integrating micro-optical and fluidic structures in Foturan glass thus becomes straightforward. Figure 2 shows a microfluidic dye laser that consists of a buried microchamber and through channels arranged at the core of the optical ring cavity.\(^1\)

All the microstructures were created in one scanning step. We filled the microfluidic chamber with various kinds of laser dyes and pumped them with a pulsed neodymium-doped yttrium-aluminum-garnet (Nd:YAG) laser, and observed the laser spectra with a full width at half-maximum of \(\sim\)5nm.

Three-dimensional integration of photonics and microfluidics in Foturan glass is still in its infancy. Further refinement of this technique could eventually create high-performance optical elements such as single-mode optical fibers or micro-optical lenses that can produce nearly diffraction limited focal spots. Such optical components incorporated into a fluidic chip could enable a series of state-of-the-art information-processing optical functions such as switching and routing, as well as biophotonic functions such as optical trapping and multiphoton fluorescence excitation.

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Continued on next page


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