A special interaction between lasers and glass enables small, single-material systems that combine optical, mechanical, and fluid-handling functions.

Microsystems carry out sophisticated tasks in miniaturized volumes. Shaping and measuring light signals; mixing, processing, and characterizing chemicals; sensing mechanical signals; analyzing gas; and sequencing biomolecules are all common operations that can be performed by these tiny machines. The potential benefits of miniaturization seem infinite. However, and despite undisputable successes (most notably accelerometers and inkjet-printer heads), the number of microsystem applications that make it out of the laboratory remains limited and well below the perceived potential of the technology. Cost-effectiveness and reliability issues are still a bar to broader acceptance.

To make microsystems easier to fabricate and to increase their performance and reliability, we have focused our research on monolithic integration based on a concept of ‘system material.’ Rather than building up a device by combining materials and fitting them together, this approach turns a single piece of material into a system by tailoring its properties in selected locations. Consequently, the material is no longer just an element of a device but becomes a device on its own. This method has many advantages. It greatly simplifies processing, reduces microsystem-assembly steps (a common source of expense, inaccuracy, and failure), and presents new design opportunities.

We first demonstrated the idea by applying a continuous-wave IR laser to selectively anneal shape-memory alloy objects. In so doing we distributed active and passive functions throughout a piece of material, turning it into an integrated actuator. Femtosecond lasers give a new dimension to the concept of system material applied to dielectrics (such as glass). They broaden the choice of material modifications that can be selectively introduced (increase in refractive index, subwavelength patterns, voids, and changes in thermal properties, to name just a few examples that have been reported for fused silica). Also, thanks to the nonlinear nature of the laser-matter interaction, femtosecond lasers can transform structure not only at the material surface but anywhere in the bulk where the light is focused. Scanning the laser through the specimen volume enables one to distribute, combine, and organize these material modifications to form complex patterns. The structure and function are directly ‘printed’ into the material.

We focus low-energy pulses (a few tens of nanojoules with an average power <250mW) to write the microdevice contour in the bulk, along with optical functions (consisting of waveguides). At this level of energy, no ablation occurs. Instead,
Figure 2. Biochips for observing algae. The glass biochip (a) consists of a single channel and a curved waveguide. Algae flowing inside the channel are shown in (b). The inlet and outlet are made of polydimethylsiloxane and bonded to the glass chip. A four-quadrant detector is used to analyze the shadowed image of objects flowing through the channel (c) and passing in front of the point source defined by the waveguide.

the material properties undergo subtle changes characterized by a higher refractive index and a significant increase in the hydrofluoric-acid (HF) etching rate. Following laser exposure, the device contour is revealed by etching in a low-concentration HF bath.

To illustrate this monolithic integration scheme we designed a sensor that measures microdisplacements (see Figure 1). The device is made entirely from a single piece of fused silica and has optical and mechanical functions embedded within it. A double-compound flexure precisely guides the motion of the probe, while an array of waveguides is used to encode the displacement of the mobile platform. This provides an accurate optical measurement of the motion.

Figure 2 shows an additional example of system material in glass: a biochip for examining algae. Here we have employed the laser to create a fluidic channel and a curved waveguide that are both written into the substrate. The waveguide is used as a point source to illuminate a small portion of the channel. The shadow of algae flowing through the channel and passing in front of the waveguide is projected and analyzed using a four-quadrant photodetector.

Novel microfabrication paradigms and design principles are needed to reduce the complexity of microsystems and enhance their reliability. The approach we have described, based on system materials, is a first step in that direction. Using femtosecond lasers we have achieved the simultaneous introduction of optics, micromechanics, and fluidics in a common platform. Our next step will be to further evolve this concept and to integrate active functions, both optical (higher-harmonic generations in waveguides, for instance) and mechanical (actuators), in fused silica. We also plan to extend our approach to other materials of potential interest for microsystems.

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References