

Customization of microfluidic devices using femtosecond laser micromachining

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We use tightly-focused femtosecond laser pulses to add an integrated microcapillary to a microfluidic device fabricated in poly(dimethylsiloxane) (PDMS). Femtosecond laser micromachining together with debris removal by a wetting fluid complements standard soft lithography techniques for microfluidics fabrication in PDMS, allowing the addition of three-dimensional and micrometer-diameter channels to devices.

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Microfluidic devices offer great potential for performing biological and chemical assays under carefully controlled conditions, and soft lithography in PDMS has become the method of choice for fabricating microchannel arrangements [1]. While versatile and simple, this technique is inherently limited to two-dimensional channel structures and to feature sizes of about 10 μm or larger. Here we show that femtosecond laser micromachining combined with debris removal using a wetting fluid can be used to modify microfluidic devices that are prefabricated in PDMS using standard photo- and soft lithography techniques. As a demonstration, we add a 2- μm diameter integrated microcapillary to a PDMS microfluidic device.

When a high-intensity femtosecond laser pulse is focused in a transparent material, energy is deposited in the focal volume through nonlinear absorption, leading to vaporization of the material in the focal volume, and allowing three-dimensional micromachining [2]. In order to drill a high aspect ratio hole, however, debris must be efficiently removed from the hole to avoid clogging. It was recently shown that allowing a fluid to wet into the hole while it is being machined solves this debris removal problem [3].

In our experiments, 120-fs laser pulses were focused into a PDMS microfluidic device with a 1.4 NA objective. Starting from inside prefabricated channels, we drilled holes into the PDMS by alternately irradiating with 10 pulse bursts and translating the sample perpendicular to the incident direction of the laser in steps of 0.1 to 1 μm . The prefabricated channels were filled with 10 mM fluorescein in ethanol both to provide a wetting fluid for debris removal and to allow real-time visualization of the machining process using *in situ* two-photon fluorescence microscopy.

Figure 1a shows cross-sectional views of channels micromachined with different laser energies. At high energy, the machining threshold is exceeded above the laser focus, resulting in a cone-shaped structure. At lower energy, an elliptical channel less than 1- μm wide and 2- μm tall is formed.

As a demonstration of the capability of femtosecond micromachining for customization of microfluidics, we fabricated the device shown in Fig. 1b. A U-shaped channel is connected to a T-shaped channel via a 2- μm diameter hole that is micromachined using femtosecond laser pulses (see Fig. 1c). The hole serves as a microcapillary, accessed by the U-shaped channel on the left and located at the stagnation point of the T-shaped channel on the right. By applying suction to the U-shaped channel, this microcapillary can be used to pin a cell or other object to the wall of the T-shaped channel while the flow velocity, and thereby the hydrodynamic extensional stress on the object, is varied. Figs. 1c and 1d show two-photon fluorescence microscopy images of the microcapillary.

In conclusion, we have demonstrated the complimentary nature of standard soft lithography and femtosecond laser micromachining for fabricating microfluidic devices in PDMS.

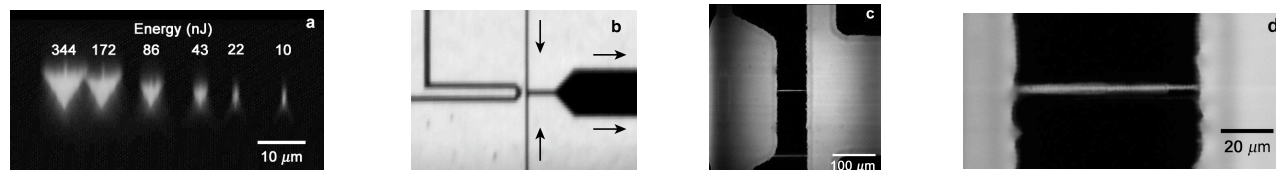


Fig. 1 a) Two-photon fluorescence microscopy cross-sectional image of channels micromachined in PDMS using 120-fs laser pulses of different laser energies. The pulses are focused by a 1.4 NA microscope objective and are incident from the top of the figure. The sample was moved in the direction perpendicular to the plane of the image to machine the channels. b) Photograph of a microfluidic device with an integrated microcapillary. The arrows indicate the flow direction in the T-shaped channel used to produce hydrodynamic stress on an object located at the stagnation point. c) Two-photon fluorescence microscopy image of the central region of the device shown in (b). The microcapillary was drilled from the U-shaped channel on the left to the T-shaped channel on the right using 20-nJ laser pulses and 1 μm steps. d) Close-up view of the microcapillary shown in (b). The laser energy was reduced to 10-nJ about 10 μm before reaching the T-shaped channel to provide a smaller opening.

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