Fabrication of Monolithic Optofluidic Evanescent Probing Device for Sensing Applications

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Micromachining with femtosecond (fs) laser can be exploited to monolithically integrate optical components and microfluidic channels in pure fused silica substrates, due to internal modification of the glass properties that are induced by the laser beam. In this paper, the optimization of the fabrication of microfluidic channels, was conducted by examining etch rate and surface roughness as a function of the irradiation conditions, namely scanning speed, scanning depth, pulse energy, beam polarisation and scan lines separation. Moreover, careful positioning of an optical layer relative to the microchannel was performed by analysing in real-time the channel etching reaction. This latter feature enables precise control of the optical interaction between the two structures, which can be of use in optofluidic devices for sensing applications.

When a fs-laser beam is focused in fused silica, several changes can occur within the material, which include increase of the refractive index (RI) with high spatial resolution and generation of etching selectivity [1]. The former can be employed to form optical waveguides among other more complex devices such as first order Bragg gratings, while the latter is used to produce hollow structures after etching the sample in hydrofluoric acid (HF). This approach has the benefit of monolithic integration of optical and fluidic components and three-dimensional (3D) fabrication, which are of significant interest in the production of on-chip optofluidic devices [2].

To enable coupling with minimal optical losses, the channel must present smooth sidewalls, as depicted in Fig. 1a. Such characteristics were obtained by 3D stacking multiple laser passes with the following optimal exposure conditions: scanning speed of 500 µm/s, pulse energy between 60 nJ and 80 nJ, scanning depth between 50 µm and 150 µm, beam polarisation perpendicular to the scanning direction and scan separation along Y of 1 µm and along Z of 2 µm (according to the axial system of Fig. 1a). The fabrication of buried structures is possible, as shown in Fig. 1b, where the HF flows through laser written vertical holes that connect the buried channel to the silica surface.

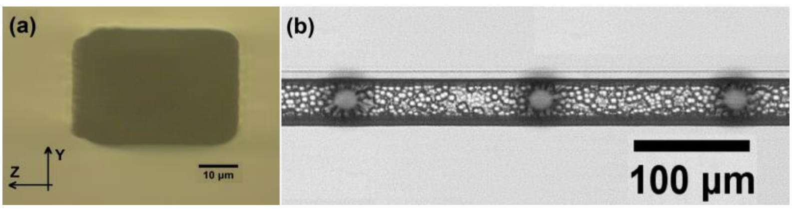

Figure 1: (a) optical microscopy image of the channel cross-section, (b) top view image of a microfluidic channel adjacent to a Bragg grating waveguide.

Optical sensing can be accomplished by writing a waveguide, containing a Bragg grating (BGW), adjacent to the channel. Efficient optical evanescent interaction with the fluids requires a distance to the channel of less than a couple of microns, which is tough to accomplish as the etchant may diffuse into the channel, thereby damaging the device. Therefore, the etching reaction needs to be closely monitored in order to control the distance between both structures. Figure 2 shows the optical reflection spectra obtained during the etching reaction of a microfluidic channel placed parallel to a BGW, together with a reference grating placed in another region of the waveguide. Analysis of the obtained spectra yielded the following conclusions: (i) as the HF acid fills the channel and the gap channel-BGW decreases, the resonant wavelength increases, indicating a higher interaction; (ii) when the etchant starts carving into the BGW, the reflected peak strength decreases and the reaction has to be stopped. It should be noticed that the sensing Bragg grating has two functions: during fabrication it serves as an etching monitoring sensor and after as a coarse fluid refractometer (high resolution RI sensor can be accomplished if the set is fabricated in the arms of a Mach-Zehnder interferometer, for example).

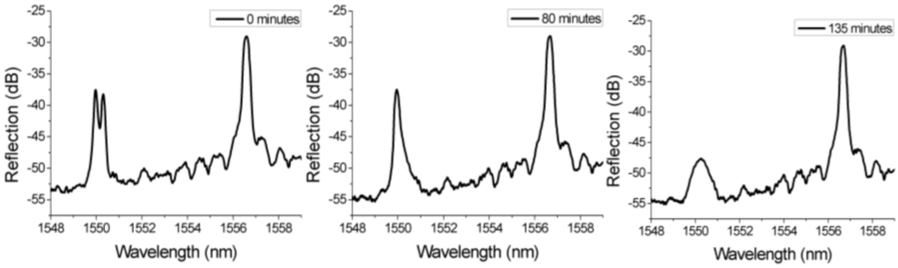

Figure 2: spectrum of the two BGWs (sensing at 1550nm and parallel to the channel, and reference grating at 1558nm) during etching at 0, 80 and 135 minutes. (left to right)

The resonant behaviour of the BGW depends on the fluid RI inserted on the channel, as demonstrated by the calibration results shown in Fig. 3, where a maximum sensitivity of 38 nm/RIU at 1.456 at 1550 nm was obtained for the device shown in Fig. 1b. Improvements on the device configuration can still be made, namely by fabricating multiple channels surrounding the BGW to further increase coupling between the evanescent field and the fluid. Nevertheless, the presented etching monitoring methodology reveals itself as a new opportunity for the precise fabrication of optofluidic devices.

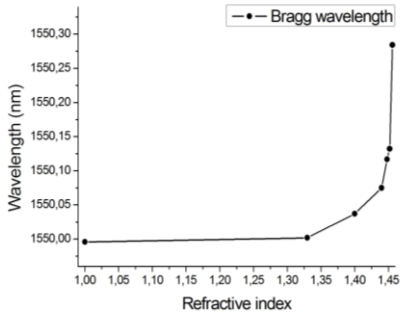

Figure 3: Bragg wavelength as a function of the fluid refractive index.

Acknowlegments

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