Integration of femtosecond laser written waveguides for optical detection in microfluidic chips

R. Martínez -Vázquez[1], D. Nolli[1], R. Osellame[1], C. Dongre[2], M. Pollnau[2], G. Cerullo[1], R. Ramponi[1]

[1]IFN-CNR, Dipartimento di Fisica, Politecnico di Milano, Piazza Leonardo da Vinci, 32 20133 Milano, Italy
[2] Integrated Optical MicroSystems, MESA+ Institute for Nanotechnology, University of Twente, PO Box 217, 7500 AE Enschede, The Netherlands

email: rebeca.martinez@polimi.it

Summary

Optical waveguides have been fabricated focusing femtosecond laser pulses into a commercial microfluidic chip. The waveguides intersect the channels and are used to optically excite their content. Fluorescence from the optically addressed volume is efficiently collected by a fiber, resulting in an highly compact and portable setup.

Introduction

Lab-on-chips (LOCs) are microsystems aiming at the miniaturization onto a single substrate of several functionalities that typically require an entire biological laboratory [1]. Through a network of microfluidic channels very small volumes (micro- to nanoliters) of biological samples can be transported, mixed, separated, and analyzed with significant advantages in terms of high sensitivity, speed of analysis, low sample and reagent consumption, and measurement automation and standardization.

While many different fluidic functions have already been implemented on LOCs, a key unsolved problem is the development of an integrated on-chip detection system [2]. Optical waveguides allow one to confine and transport light in the chip, directing it to a small volume of the microfluidic channel and collecting the emitted/transmitted radiation. However, the fabrication of optical waveguides or more complex photonic components integrated with the microfluidic channels is not a straightforward process, since it requires a localized increase of the refractive index of the substrate.

Recently, a novel technique has emerged for the direct writing of waveguides and photonic circuits in transparent glass substrates, exploiting refractive index modifications induced by focused femtosecond pulses [3, 4]. When a femtosecond pulse is tightly focused in a transparent material, a nonlinear absorption mechanism, combining multiphoton and avalanche ionization, allows one to deposit energy in a small volume around the focus, where the intensity is highest. By moving the laser focus inside the substrate, one can use the laser beam to define regions of increased index and thus directly produce three-dimensional light-guiding structures. It is a powerful technique enabling single-step, three-dimensional fabrication of optical waveguides in glass, and it appears to be particularly suited for their integration into LOCs.

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Discussion

We have fabricated optical waveguides inside a commercial chip designed for Capillary Electrophoresis (CE) (model D8-LIF from LioniX BV). The chip layout is shown in Figure 1: we have written the optical waveguides perpendicularly to the separation channel towards its end (see red lines in figure 1).

The microfluidic channels are rather small, with a rectangular cross-section measuring 50 µm in width and 12 µm in height, so the positioning of the optical waveguide with respect to the microfluidic channel is quite challenging. Several waveguides have been fabricated, either tangent to the microfluidic channel, for evanescent sensing, or crossing it for direct excitation. Figure 1(b) shows some microscope images of the optical waveguides end-view together with the microfluidic channel.

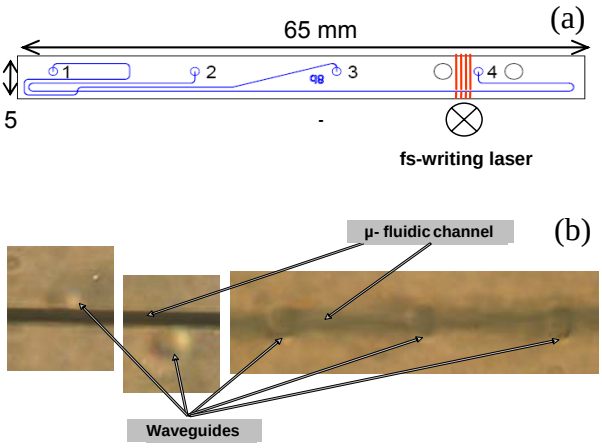

Fig. 1 (a) Layout of the LOC device used for CE, on which the optical waveguides have been inscribed; (b) side views of femtosecond written waveguides at different positions with respect to the microfluidic channel.

The experimental set-up used for the Laser Induced Fluorescence (LIF) experiments is shown in Fig. 2: it combines compactness, portability, high sensitivity and strong background rejection. The fluorescence is collected by an optical fiber pigtailed to the chip in correspondence to the excited portion of the microchannel, in a 90° geometry with respect to the exciting waveguide, thus achieving a strong suppression of the exciting light background. Both the numerical aperture (NA = 0.48) and the diameter of the optical fiber were selected in order to maximize the collected fluorescence and minimize stray light.

The light collected from the fiber is collimated and refocused by aspherical lenses (NA=0.54) on a photon counting photomultiplier (PMT, Hamamatsu, model H6240-01). A notch filter (at 532 nm) and an interference filter (10 nm bandwidth at 560 nm) are placed between the collimation and focusing lenses. The output signals from the PMT are recorded by a 16 bit A/D board and processed using a program written with LabVIEW.

In order to assess the sensitivity of our system, we performed a limit-of-detection measurement. To this purpose the chip was filled with different concentrations of Rhodamine-6G. Our system is capable of detecting very low

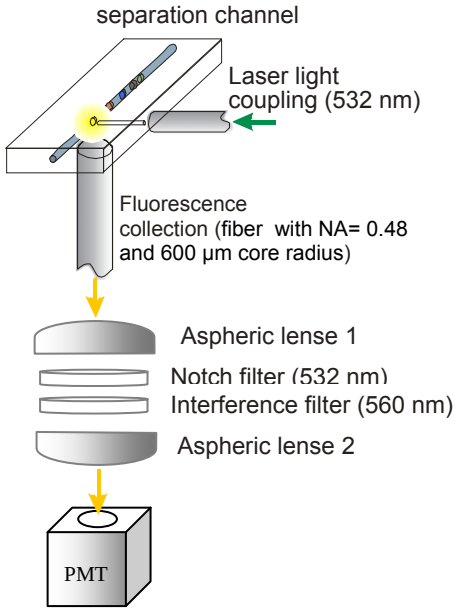

Fig. 2 Scheme of the setup used for the LIF experiments, with two optical fibers for fluorescence excitation and collection.

chromophore concentrations, down to the 40 pM level.

References

[1] G.M Whitesides, *Nature*, 2006, **442**, 368-373

[2] E. Verpoorte, Lab Chip, 2003, 3, 42N-52N.

[3] K. M. Davis, K. Miura, N. Sugimoto, K. Hirao, Opt. Lett., 1996, 21, 1729-1731.

[4] R.R. Gatass and E. Mazur, Nature Photon., 2008, 2, 219-225.