HIGH RESOLUTION MICROFLUIDIC REFRACTOMETER FOR BIOMEDICAL APPLICATIONS

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ABSTRACT

We present a robust and high resolution refractive index (RI) sensor monolithically integrated to a silicon microfluidic system. The fabrication techniques and challenges are the same as for chip-based liquid chromatography (LC) systems, making the sensor suitable for direct integration to existing LC devices. Measurements of small refractive index variations are performed and yield a resolution of 1.1×10^{-5} RI units (RIU). Such resolution is, to our knowledge, the highest ever reported for a RI sensor performing measurements through the whole diameter of a microfluidic channel (i.e. through tens of micrometers). Therefore the sensor is also an ideal candidate for lab-on-chip characterization of micrometer scale biological specimens such as living cells.

KEY WORDS: Microfluidics, Refractive Index Sensor, Liquid Chromatography, Single-Cell Characterization

INTRODUCTION

Since the first proposal, in 1998 [1], to use perfectly ordered micromachined pillars as the stationary phase of a LC column, a lot of groups have worked toward the realization of on-chip LC systems. While the pillars of the first column were etched in quartz [1], actual devices are frequently fabricated in silicon by deep reactive ion etching (DRIE) [2]. This choice of materiel and fabrication process is mainly motivated by the necessity to obtain high aspect ratio and almost perfectly vertical profiles for the pillars [3]. These requirements are perfectly matching the ones required for the realization of an integrated RI sensor such as the one presented in this work.

By a single DRIE etch step, we fabricate a microfluidic system and an integrated RI sensor. The resolution obtained (1.1×10^{-5} RIU) is the highest ever reported for an integrated microfluidic RI sensor performing measurements through several micrometers of liquid. Therefore the sensor is also an ideal candidate for Lab-on-Chip characterization of micrometer scale biological specimens such as living cells [4].

FABRICATION AND PRINCIPLE OF OPERATION

The sensor is presented in Figure 1. The reservoirs, channels, fiber grooves and refractometer are all patterned by a single photolithography step. Silicon is then etched by deep reactive ion etching (DRIE). The etch depth is 70 μm in order to enable insertion of standard 125 μm diameter single mode optical fibers in the two fiber grooves. The etch process is carefully optimized in order to obtain smooth and vertical optical planes [5].

The two facing mirrors form a Fabry-Perot optical resonator sensible to RI. When the RI of the medium between the two mirrors changes, there is a shift in the resonance wavelength (see Figure 2a) and this shift can be related to the RI of the liquid [6].

RESULTS

The sensor is characterized with certified refractive index oils (Cargille Labs, series AA) and the results are presented in Figure 2. The simulations are performed using the transfer matrix method combined with the Gaussian mode approximation for single mode fibers. As shown in Figure 2b, we obtain a sensitivity of 902 nm/RIU, which is in good agreement with the simulated results. Considering a typical accuracy of 0.01 nm for an optical spectrum analyzer such as the one used for this experiment (Agilent 86142A), we obtain a resolution of 1.1×10^{-5} RIU.

All measurements were performed on the same device with no particular attention paid to cleanliness (quick dip in acetone before changing the liquid sample) and the sensor still works perfectly. This robustness is due to the fact that each of the two multilayered mirrors is made of six silicon-air interfaces, contrarily to only one interface for a metallic mirror. While the interface with the channel gets dirty (or is functionalized for LC), the 5 other remain intact, limiting the impact on the optical response.

CONCLUSION

We fabricated a RI sensor monolithically integrated with a silicon microfluidic system. The obtained resolution (1.1×10^{-5} RIU) is the highest ever reported for an integrated RI sensor performing measurements through several micrometers of liquid. The design of the sensor also makes it intrinsically very robust. From these characteristics, it is expected that our design will be adopted by the lab-on-chip community. In particular, some liquid chromatography chips are fabricated by a very similar process, and on-chip single-cell characterization requires a high resolution sensor to perform measurements through samples having a diameter of several micrometers.

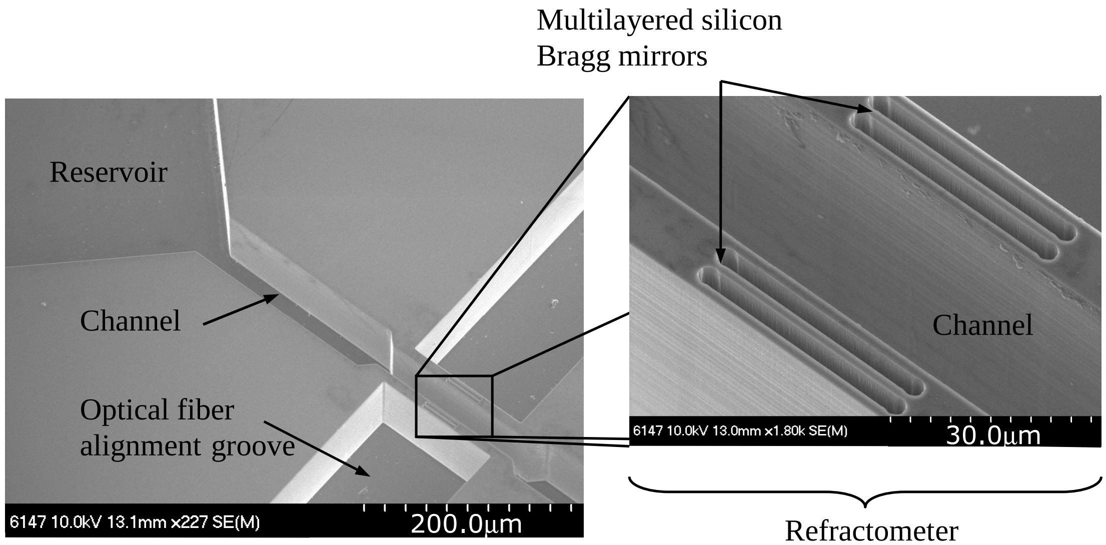

Figure 1: SEM photograph of the refractometer integrated with optical fiber alignment grooves, microfluidic revervoirs and microfluidic channels.

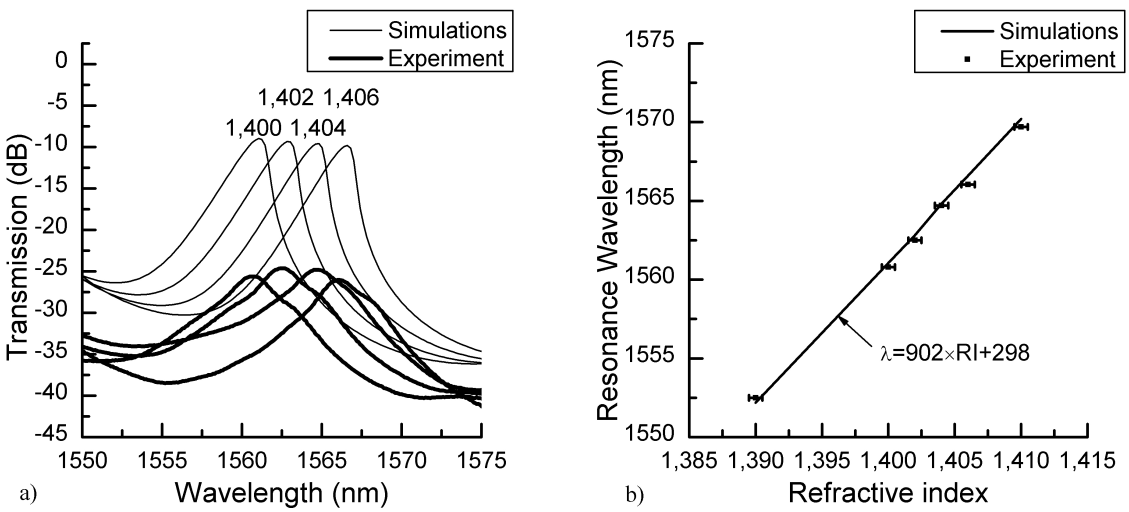

Figure 2: Experimental and simulated response of the refractometer. (a) Resonance peaks for the four different refractive indices labeled on the figure. (b) Resonance wavelength as a function of refractive index.

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