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Fabrication and characterization of micro fluidic based fiber optic refractive index sensor

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ABSTRACT

A refractive index sensor was proposed by using 3 dimension (3D) grayscale lithography technique. Optical fiber with taper diameter of 12 μm was embedded in a closed microfluidic channel. Taper area of optical fiber is in floating condition at the center of micro channel. Grayscale variation range used for this sensor was 70%–74% and thickness variation 430 μm–694 μm was achieved. The dimension of the sensor was 7.5 cm in length and 2 cm in width. Fabricated sensor was characterized with air condition and solution concentration from 0.1 M to 1 M. A sensitivity of 1457 nm/RIU is achieved. The measured results show a good repeatability and low temperature cross-sensitivity.

1. Introduction

Optical sensing has been broadly studied to measure many parameters such as temperature, refractive index (RI), strain, displacement, humidity, pressure, stress and curvature. It has benefit for many applications for example chemical industry, biochemical analysis, medical diagnostics and environment and contamination assessment. Refractive index and temperature are the most important parameters in these applications especially biochemical analysis for monitoring molecular bindings or biochemical reactions [1]. Numerous designs of RI sensor utilize the tapered optical fiber in an open channel. In recent study, a remote optical measurement was successfully done without any contact between the optical components and the liquid in glass capillary [2]. Despite the less complicated optical setup for measurement, the sensor achieved a low sensitivity of 250 nm/RIU and the glass capillary need specific adapters and connectors for interfacing the capillaries with macro-fluidic devices. In another reported design, a stripped fiber is placed inside an open microchannel on a silicon chip and later is filled with sugar solution for RI measurement. It achieved a low sensitivity of 665.90 nm/RIU [3]. More RI sensors utilizing an open channel with optical fiber submerged in RI liquid in a container [4], a chamber [1], a reservoir [5], a U-shaped groove [6] and a liquid carrying tubing [7]. In other work, the microfiber is surrounded by a few droplets of salt solution on a flat surface [8,9]. Although the described works report a well-designed RI sensor, they have low sensitivity and the liquid handling need an improvement because during each measurement it is crucial to ensure that the liquid is removed completely from the optical fiber. With multiple measurement, it is difficult to handle the tapered optical fiber due to its delicate structure where it can reach down to 4 μm waist diameter [8]. Furthermore, the geometrical structure of tapered optical fiber is nonuniform within the sensing region. This creates a challenge for researchers to design an optimized three-dimensional (3D) microchannel to minimize the volume of tested solutions. In this paper, a high sensitivity RI sensor with a closed 3D microchannel is proposed for easy handling of tapered optical fiber where the liquid samples can be conveniently delivered into and out of the channel for high sensitivity RI measurement. For this 3D microchannel, the variation of its depth can be achieved using grayscale lithography technique. The exposure image of the UV light defines the shape of the 3D microstructures, while the height is determined by the percentage of grayscale concentration [10–14].

2. Design and operating principle

2.1. Microchannel

The geometric dimension of the microchannel for RI sensor is schematically shown in Fig. 1(a). A straight microchannel is connected to one inlet well and one outlet well. A tapered optical fiber is embedded inside the microchannel for sensing purpose. Fluid is injected through the inlet well and flows inside the microchannel towards outlet well.

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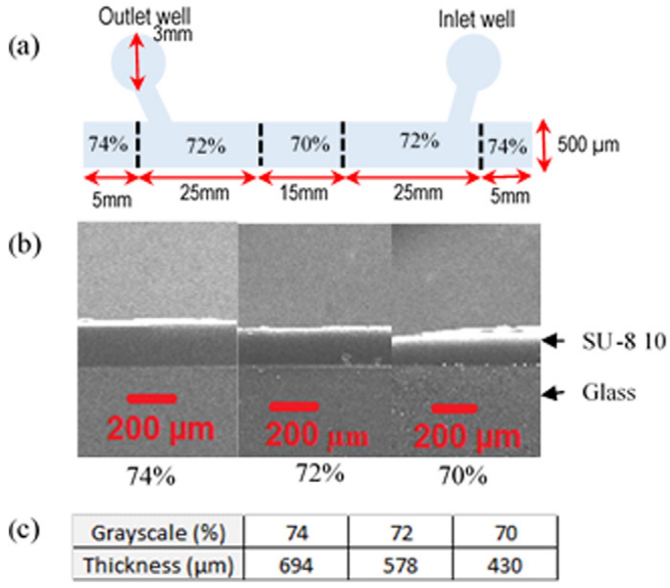

Grayscale (%)	74	72	70
Thickness (µm)	694	578	430

Fig. 1. Grayscale lithography in thick negative photoresist SU-8 10: (a) geometric dimension with grayscale concentration design along microchannel, (b) SEM micrographs of photoresist structures fabricated using grayscale mask, (c) resist thickness at different grayscale concentration design along microchannel.

The microchannel functions as channel features for both fiber groove and fluid flow. The work begins with the preparation of grayscale software mask to form the 3D pattern of the microchannel design. Different grayscale concentration levels are designed using CorelDraw software with black at the weakest light intensity and white at the strongest. The shape of the microchannel is defined by the exposure image of the UV light, while the height is determined by grayscale levels. The software mask is designed with 70%, 72% and 74% grayscale concentration along the microchannel. Different grayscale concentrations are chosen to obtain different height of microchannel in order to match with the dimension of the embedded fiber optic, so that the fiber optic is nicely fit inside the microchannel.

2.2. The sensing mechanism of tapered optical fiber

A standard single mode optical fiber has two layers known as the core and cladding. The refractive indices of these two layers play a vital role in ensuring the containment and propagation of light within the fiber. A tapered fiber is an optical fiber that has been gently heat pulled to create a thinner region over a certain length. This particular modification of the optical fiber causes a geometrical change to the optical fiber that forces a portion of the contained light to extend outside of the cladding and propagate in parallel to the surface of the fiber. As the tapered region approaches its normal form, light that has extended to the surrounding of the fiber enters the fiber again and couples with the originating light mode within the core. The coupling incident causes the formation of an interferometric fringe pattern in the output

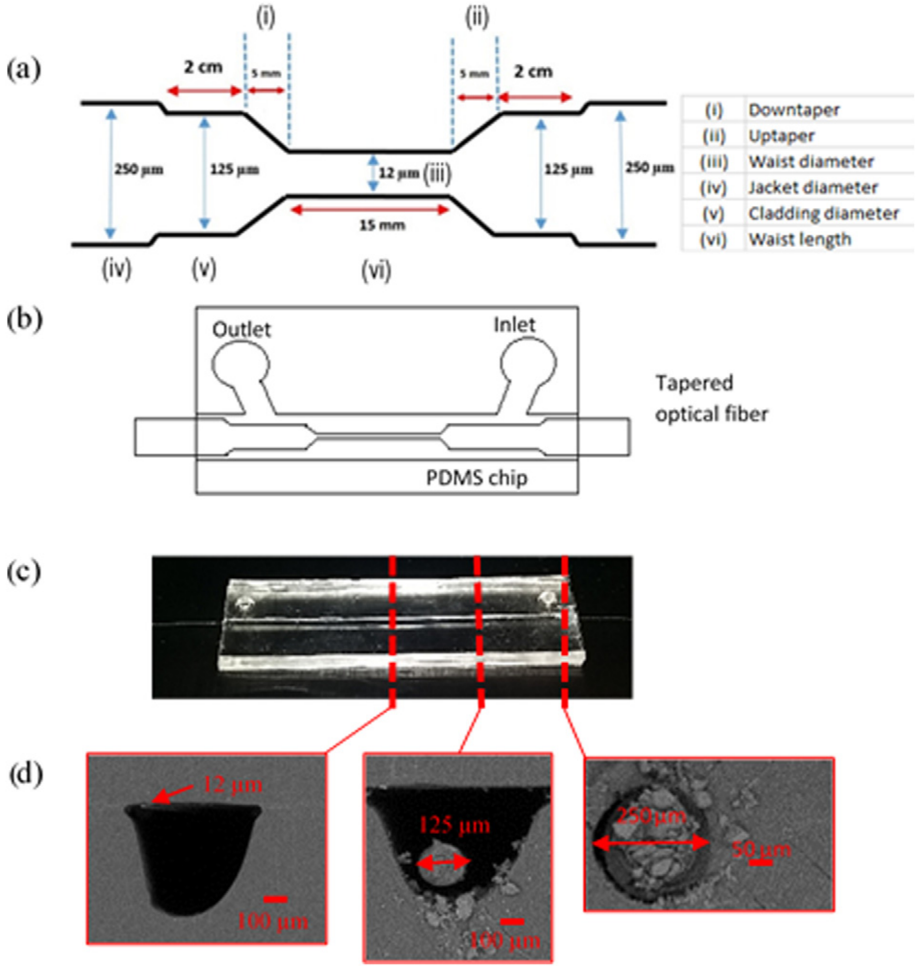

Fig. 2. An optofluidic microchip to implement the RI measurement. (a) A schematic of the tapered fiber optic embedded in microchannel, (b) design and (c) photograph of an optofluidic RI sensor with (d) SEM image of the cross section at (i) tapered region, (ii) cladding and (iii) jacket of the tapered fiber optic in microchannel.