Integration of Three Dimensional Photonic Crystals For Refractive Index Sensing in Microfluidics

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Abstract: We present the concept of a refractive index sensor based on integration of a three dimensional photonic crystal with a microchannel by femtosecond laser fabrication. The sensor performance was characterized by FTIR spectroscopy.

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Introduction

Microfluidics is a multi-disciplinary field that involves the characterization, manipulation and modelling of fluid flows at the micrometer scale and the development of relevant devices. The advancement in microfluidics is underpinning an explosion in many fields due to the fact that conventional biological, chemical and physical experiments can be performed on a much smaller microfluidic platform. The integration of sensing elements into microfluidics is significant for applications such as clinical analysis, biochemical synthesis or pharmaceutical drug delivery.

Among various methods of realizing the sensing function, the introduction of photonic crystal (PC) for sensing is regarded as one of the most competitive candidates. Photonic crystals are periodic structures that possess bandgaps to forbid certain wavelength of light to pass through, or to say, they can confine photons of certain wavelengths. Due to the exceptional photon confine ability, photonic crystals seem to be ideal for highly localized sensing application in a microfluidic environment. Great efforts have been put into development of microfluidic PCs sensors [1,2]. However to date most of the research on PC microfluidic sensors have been limited to one dimensional (1D) or two dimensional (2D) PC sensors [3]. The only three dimensional (3D) PCs used for biosensing to date were fabricated by self-assembly [4]. 3D woodpile PCs have been intensively researched due to its great flexibility in tuning the photonic band gap effect and the potential to open up a complete bandgap. Femtosecond laser writing has proved to be an effective way to fabricate 3D woodpile PCs in polymer substrate [5].

In our work a 3D woodpile PC were fabricated by femtosecond laser writing and were integrated with a microfluidic channel to form a refractive index sensor. To our knowledge it is the first 3D microfluidic PC refractive index sensor by direct laser fabrication.

Experiment

Fig. 1. Schematic illustration of the experiment system for fabrication of the three dimensional photonic crystals

The fabrication of the 3-D microfluidic refractive index sensor can be divided into two processes: (A) Fabrication of the 3-D PC and (B) Fabrication of the microfluidic channel. (A) The laser beam (810 nm) from a femtosecond laser pumped an OPO operating at 580 nm. The beam from the OPO (32 mW) was then expanded and collimated to uniformly illuminate the back aperture of a 1.4 NA objective and then focused into the procured NOA 63 polymer substrate. A 24-layer woodpile PC (in plane spacing δx= 1.3 µm, layer spacing δz= 1.5 µm) was fabricated at a scanning speed of 450 µm/ s. (B) The microfluidic channel was fabricated by focusing an amplified femtosecond laser beam (800 nm, 1 kHz, 110 fs, 15 µJ) through a 0.25 NA objective, the microfluidic channel was fabricated at a scanning speed of 1500 µm/s.
A schematic of the sensor structure is shown in Fig. 2 (a). The channel was sealed by a layer of polydimethylsiloxane (PDMS) polymer. An SEM image of the etched microfluidic channel is shown in Fig. 2 (b).

Result

Different refractive index fluids were introduced into the microfluidic channel in order to study the sensing ability of the photonic crystal. The response of the integrated photonic crystal sensor was characterized by Fourier Transform Infrared (FTIR) spectroscopy. As the index of the fluid increased, the measured position of the bandgap in the FTIR spectra of the integrated PC sensor shifted towards longer wavelength and showed a linear relationship to the fluidic refractive index (Fig. 3).

Summary

We present the concept of a refractive index sensor based on integration of 3D photonic crystals with a microchannel by femtosecond laser fabrication. The sensor performance was demonstrated by FTIR spectroscopy. After the femtosecond direct laser fabrication, the 3D photonic crystal and microfluidic channel were integrated as a refractive index sensor. Sensing was demonstrated that a change in the refractive index of the liquid in the microfluidic channel shifted the photonic band gap position in their FTIR spectra.

References