Waveguide structures based on a low-cost silica–titania optical platform for sensing applications

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1. INTRODUCTION

Photonic integrated circuits (PIC) are widely used as sensors. However, the fabrication of photonic integrated circuits is still very expensive, and the fabrication of precise waveguide structures requires big financial effort and advanced technological background. A possibility of fabricating low-cost waveguide structures for integrated photonics would open new possibilities for a wide range of applications of PICs. The "Hybrid sensor platforms of integrated photonic systems based on ceramic and polymer materials." (HYPHa) project is currently working on establishing a new low-cost technological platform for photonic integrated circuits based on silica-titania (SiO_2:TiO_2) [1]. Some conceivable waveguide structures numerically investigated on this platform for refractive index sensing have been researched and show promising possibilities.

2. MATERIALS AND FABRICATION

The fabrication process of a SiO_2:TiO_2 platform compared to the conventional fabrication of PICs is much cheaper and easier. It doesn't require complex technologies and advanced technological facilities. The fabrication of the platform takes place by the sol-gel dip-coating method shown in Fig. 1. This method allows to precisely control the thickness and refractive index of SiO_2:TiO_2 by adjusting the parameters of the process. SiO_2:TiO_2 is a material that has a wide field of possibilities because its refractive index can vary between 1.6-2.2 and its spectral range is from visible to NIR. [2]

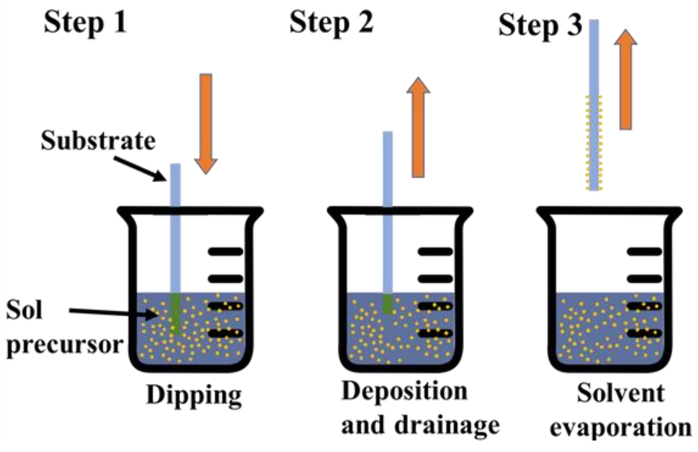

Fig. 1. Fabrication process of SiO2:TiO2 platform via sol-gel dip-coating.

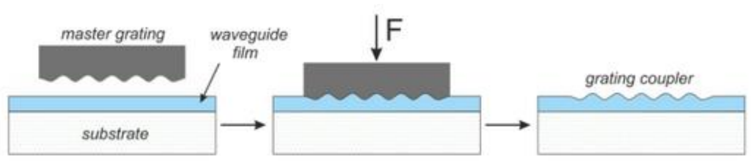

Fig. 2. Fabrication of a grating coupler on SiO_2:TiO_2 [3]

This method of fabricating a SiO_2:TiO_2 layer allows to manufacture waveguide structures in the material before hardening by direct nano-imprint lithography (NIL) as shown in fig. 2. This solution can lead to easier and cheaper mass production of waveguide structures. [3]

3. RING RESONATORS

A ring resonator (RR) is one of the most basic refractive index sensing waveguide structures. The main design parameters of a RR are: W_B - bus WG width, W_R - ring width, G_{RB} - coupling distance, R - ring radius, shown in fig.3. By adjusting those parameters, the sensing properties (sensitivity S, figure of merit FOM and Q-factor) of the RR are changed.

The wavelength transmission spectra of a single RR realized in SiO_2:TiO_2 for three different ambient refractive indices is shown in fig. 4 and the shift of resonance peaks can be easily observed. The designed RR of R=10μm shows relatively high sensitivity of S=125 nm/RIU.

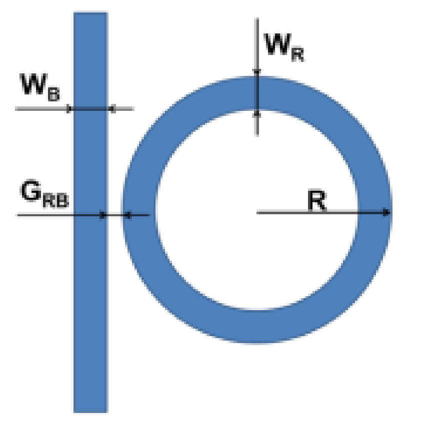

Fig. 3. Basic RR structure and parameters [4]

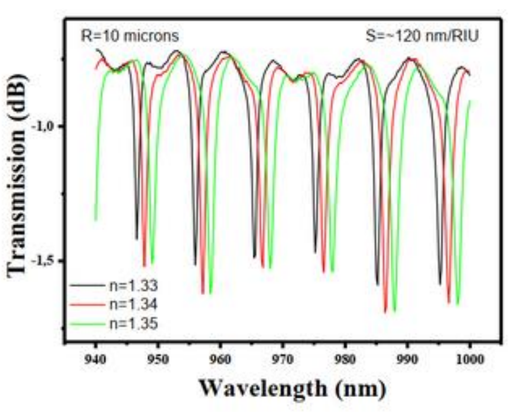

Fig. 4. RR response for different ambient refractive indices [4]

The simulated RR apart from showing high sensitivity also has a relatively wide free spectral range (FSR) which for R=10 μm is equal to 9.6 nm. It allows to connect multiple rings for serial operation. This type of connection opens the possibility of designing a multi-parameter optical sensor which can detect for example different particles. A serial connection is shown in fig. 5.

A great advantage of this connection is that it only needs a single light source with no need of switching or splitting the signal. The simulation results of serial operation of 3 RR with different radii are shown in fig.6. [4]

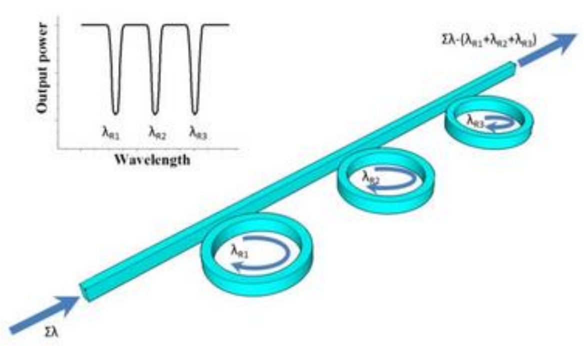

Fig. 5. Three RRs in serial operation [4]

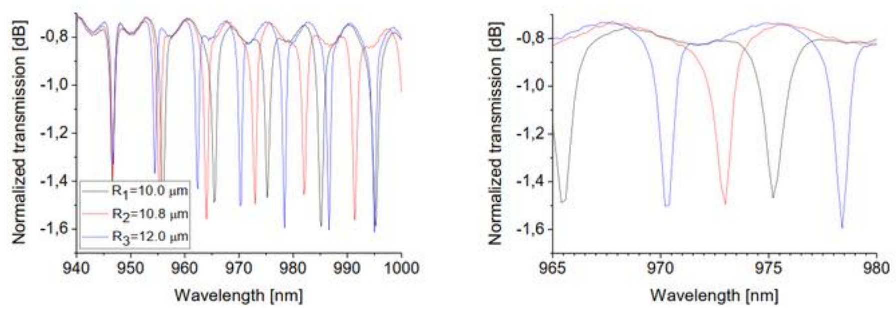

Fig. 6. Response of three RRs with different radii [4]

4. SUBWAVELENGTH GRATING STRUCTURES

Another waveguide structure for refractive index sensing that has been researched is a subwavelength grating (SWG) as in fig. 7 (a,b). A SWG on SiO_2:TiO_2 has been simulated to work as a waveguide NIR filter and also as a FP-sensor.

With the advance of the nano-imprint fabrication technology, the mass production of SWGs on PICs could be achieved at low-cost with high resolution. In fig. 8 the simulation results for a NIR filter and a FP-sensor are shown. [5]

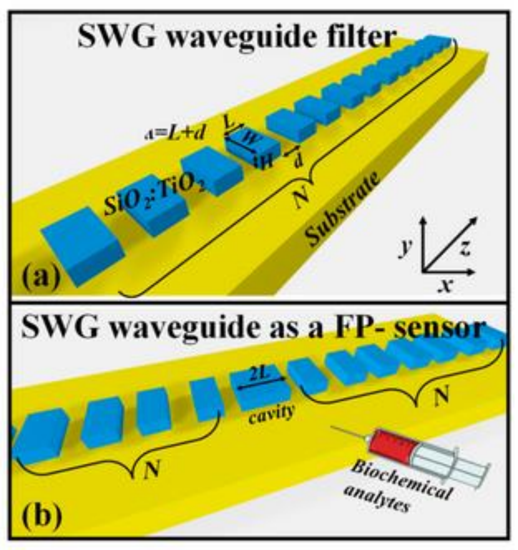

Fig. 7 SWG structure for sensing applications [5]

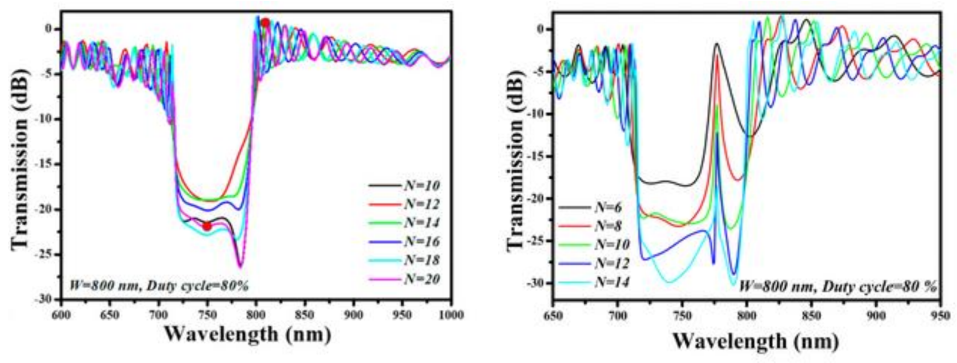

Fig. 8. SWG NIR filter (left), SWG FP-sensor (right) [5]

5. 1D-PHOTONIC CRYSTALS

1D photonic crystals (1D-PhC) are a different waveguide structure for sensing. They work on a similar principle of operation as SWGs but instead of having a periodic change of refractive index, they have air holes distributed along the waveguide. A scheme of a 1D-PhC is shown in fig.9.

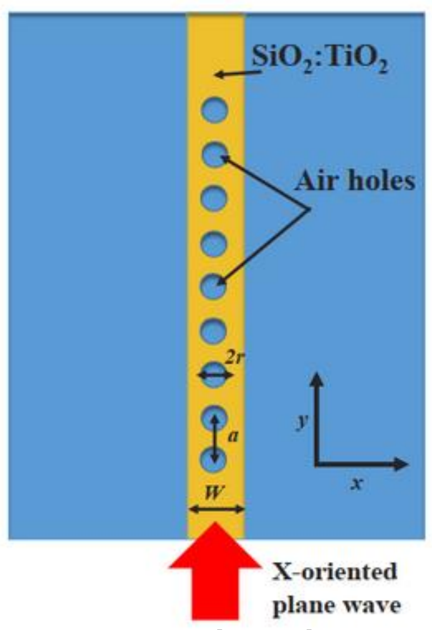

Fig. 9 1D-PhC scheme with basic parameters [6]

In fig. 10 the numerical simulation for a 1D-PhC waveguide FP-sensor is displayed. The sensitivity of the sensor can be manipulated by changing the width of the waveguide. For W=1000nm the sensitivity is S=75 nm/RIU and it can be increased up to S=175 nm/RIU by decreasing the width of the waveguide. [6]

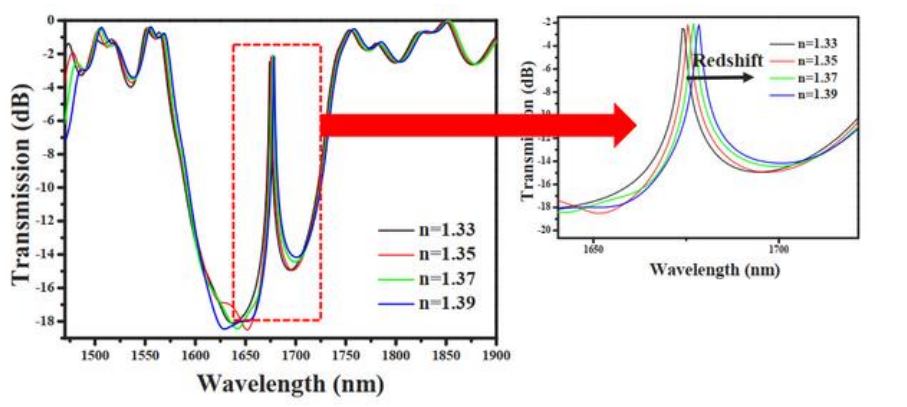

Fig. 10. 1D-PhC response for different ambient refractive indices [6]

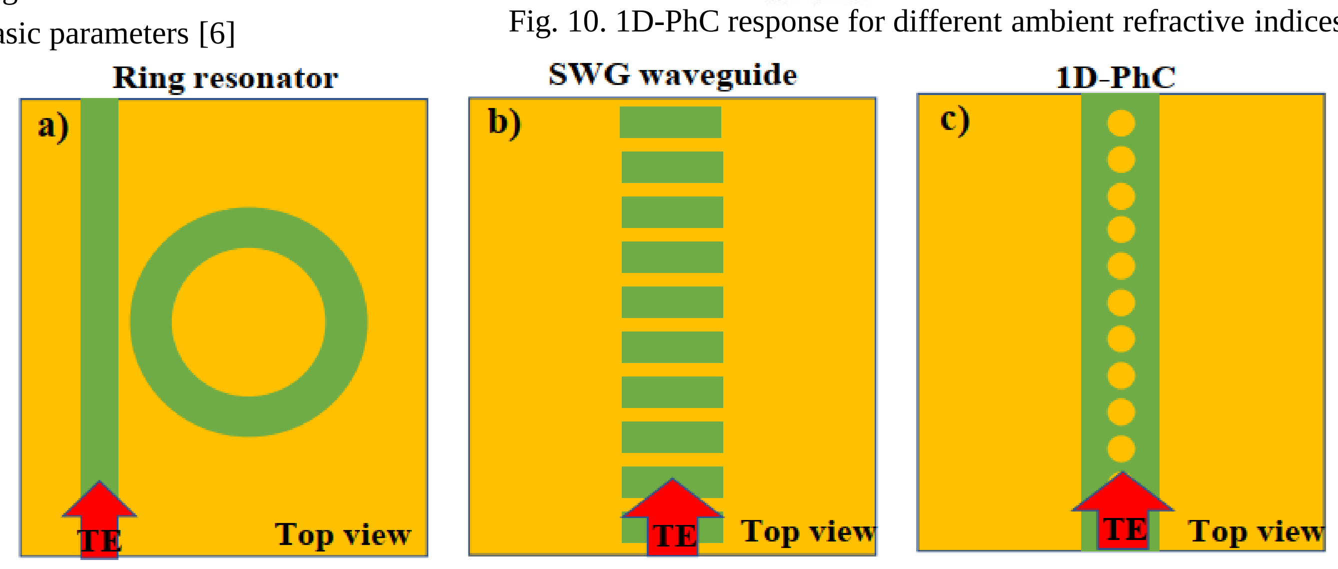

Fig. 11. Schematic representation of different refractive index sensing waveguide structures: a) ring resonator, b) subwavelength grating, c) 1D photonic crystal [1]

6. CONCLUSION:

The presented low-cost technological platform for PICs based on SiO_2:TiO_2 if properly researched and investigated could have a significant impact on the market of photonic integrated sensors and in general on the whole industry. The possibility of producing a low - cost PIC would speed up the development of integrated photonics and find new applications for integrated circuits. Refractive sensing applications for SiO_2:TiO_2 were investigated, and the material shows good properties for sensing. The combination of good sensing properties and cheap fabrication could be a game changer. Three waveguide structures for refractive index sensing have been presented: RR, SWG and 1D-PhC. Each of them shows different sensing properties and could be applied in different sensing devices.

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