Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 120 (2015) 744 – 747

Procedia Engineering

www.elsevier.com/locate/procedia

EUROSENSORS 2015

Design and elaboration of 1D photonic crystal cavity based on highly flexible elastomer thin layer for sensors applications

Cecile GHOUILA-HOURI[1], Jean-Claude GERBEDOEN[1], Romain VIARD[1,3], Abdelkrim TALBI[1], Alain. MERLEN[1,2], Philippe PERNOD[1]

Joint International Laboratory LIA LICS/LEMAC [1,2] :

1- IEMN UMR CNRS 8520, Univ. Lille, Centrale Lille, Cité Scientifique, 59651 Villeneuve d'Ascq, France.
2- ONERA, Chemin de la hunière 91123, Palaiseau, France.
3- Fluiditech, Thurmelec, 68840 Pulversheim France

Abstract

We report a new design for realizing a 1D Photonic crystal cavity based on highly flexible thin elastomer that enables a tuning of its resonance frequency by applying pressure, mechanical or thermal stress. The design consists of a Solaris thin film elastomer layer sandwiched between two Bragg reflectors composed of six bilayers (SiOx/SiNx). The structure exhibits a cavity resonance in wavelength band [500nm-1µm]. The wavelength can be reversible tuned over 2nm/Bar and 4000ppm/°C. These reconfigurable structure could find potential applications for integrated photonics mechanical sensors.

Peer-review under responsibility of the organizing committee of EUROSENSORS 2015

Keywords: photonic crystal, MEMS sensors, cavity resonance

Corresponding authors: abdelkrim.talbi@ec-lille.fr

Peer-review under responsibility of the organizing committee of EUROSENSORS 2015
doi:10.1016/j.proeng.2015.08.792

1. Introduction

Controlling intravascular pressure, checking vacuum quality or measuring velocity of an airplane flow, these are all applications for MEMS pressure sensors. Optical pressure sensors have several advantages especially for use in harsh environment where electronics and wiring cannot be used. Several design have been elaborated using different optical concepts. Dessalegn et al. [1] present a simulated cantilever with double ring resonator in which the resonance wavelength shifts when pressure is applied on the cantilever. Lu and Lal [2] developed in 2011 a photonic crystal pressure sensor based on vertical silicon nanowires. With this device, light is selectively trapped or diffracted and when pressure applied, the membrane color change is acquired with a camera to calculate pressure. Photonic crystal structures have also been used by Olyaee and Dehghani in 2012 [3] to perform simulations of a nano-pressure sensor and by Yang et al in 2012 to perform simulated stress sensors [4].

This paper will relate our work on an original 1D photonic cavity based on flexible elastomer thin layer and Bragg reflectors that can be used for sensor applications especially pressure and temperature sensors. We developed in this paper the principle used, simulations achieved and the first experimental results obtained.

2. 1-D Photonic crystal principle

The concept consists in introducing a default inside a Bragg reflector network in order to create an optical cavity as shown on Figure 1. We chose an elastomeric component to form the cavity for its flexibility and sensitivity to external conditions such as being deformed under pressure. The Bragg reflectors considered during the simulation are composed of 6 bilayers of SiNx/SiOx and the elastomer considered has a refractive index of 1.41. In order to achieve the Bragg reflector, we chose nitride thickness of about 80nm and oxide thickness of about 120nm. We considered the elastomer thickness of about 500nm. These values are the ones considered in the simulation study.

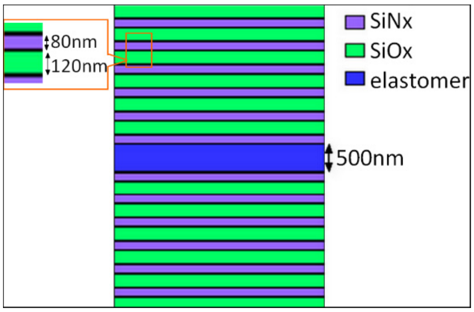


Fig. 1: Schematic design of 1D photonic crystal [5]

Optically, the presence of the elastomer thin layer between the two Bragg reflectors implies the appearance of a resonance inside the mirror bandwidth as shown on Figure 2.

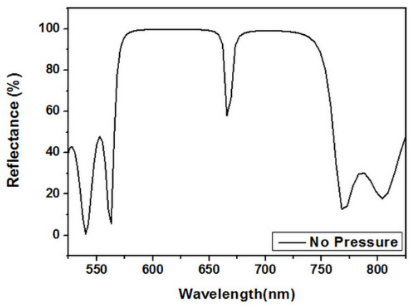


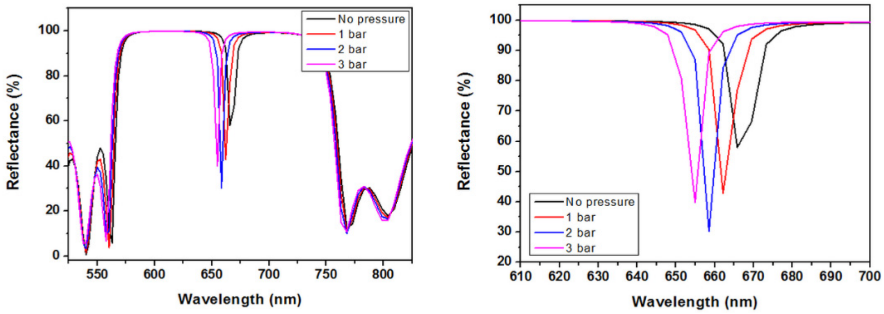
Fig.2: Reflectance of the structure calculated for 500nm-thick elastomer layer.

3. Application for sensors

The first aim of the designed optical cavity is pressure sensor applications. When pressure is applied on the device surface, the elastomer layer is deformed and to the elastomer thickness decrease as function of applied pressure. As a consequence the resonance wavelength shifts. However, other physical sensors can be designed using this structure such as strain or temperature sensors, based on the refractive index change due to stress or temperature dependence.

The study has been made on COMSOL Multiphysics and was divided into two parts. As the resonance wavelength is directly dependent from the cavity size, the first study was a mechanical one and aimed at determining the elastomer thickness change when pressure is applied. We consider a homogeneous pressure applied on the device. The obtained results show that the elastomer thickness varies of around 6nm/bar.

The value was introduced into the photonic crystal model and optical simulations have been made to determine the resonance shift under pressure. The sensor structure is defined in COMSOL Ray Optics by the different layers and each layer is defined by its refractive index and its thickness. The simulated device was defined as the schema presented in figure 1. Figure 3 (a) and (b) illustrate the simulated reflectance device for pressure from 0 to 3 bar. The simulated sensitivity is around 3.7nm/bar.

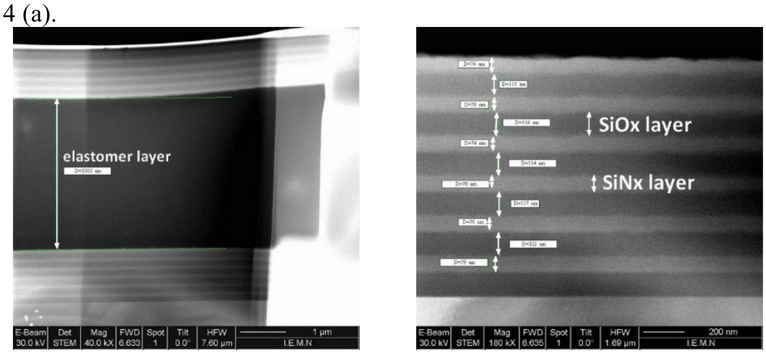


(a) (b)

Fig. 3: (a) Photonic crystal cavity resonance shift versus applied pressure obtained by simulations (b) Zoom on the wavelength shift

4. Experimental results

Experimentally, we successfully elaborate a first prototype. However, the targeted value for the elastomer thickness is around 500nm and the obtained value is much higher with a 3µm-thick elastomer, as shown on the SEM picture presented on Figure 4 (a).



(a) (b)

Fig. 4: (a) SEM picture of the 1-D photonic crystal cavity showing the two Bragg reflectors and the elastomer cavity (b) SEM picture of the Bragg mirror with SiOx/SiNx bilayers

Due to the large elastomer thickness (3um) and as predicted by simulations, several peaks of resonance appear in the mirror bandwidth as shown on Figure 5. Obtaining the right elastomer thickness (500nm) is a real issue for the moment.

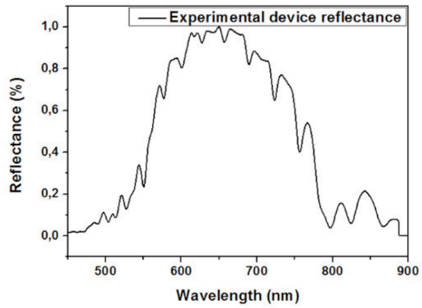


Fig. 5: Reflectance as function of wavelength

Measurements under temperature were performed showing the shift of the wavelength peak resonance with an experimental sensitivity close to 4000ppm/°C. Figure 6 (a) and (b) show experimental results under temperature variations. The wavelength resonance increases with temperature. Tests under pressure and strain are in progress.

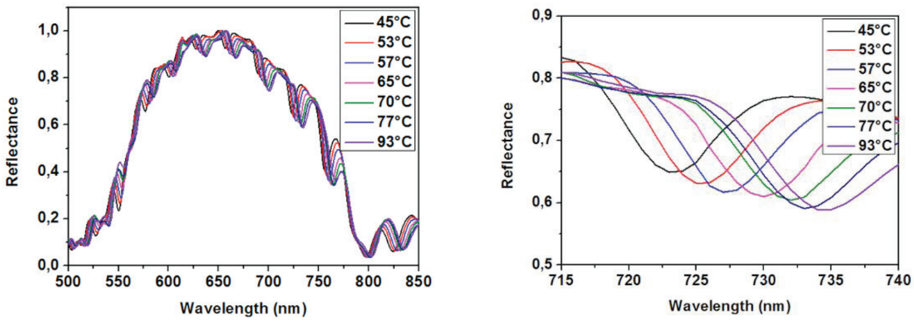


Fig. 6: (a) Experimental device reflectance with temperature variation (b) Zoom on a wavelength resonance

5. Conclusion

A 1-D photonic crystal cavity has been designed and simulated revealing results useful for sensors application. Designed with a flexible elastomer thin layer, the optical cavity is sensible to elastomer thickness and refractive index variations. Experimental results have confirmed the device concepts and are promising for designing pressure, strain and temperature sensors.

References

[1] H. Dessalegn, T. Srinivas, "Optical MEMS Pressure Sensor based on Double Ring Resonator", IEEE Int.Conf. on Microwave and Photonics, p.1-4, 2013

[2] Y.Lu, A. Lal "Photonic crystal based all-optical pressure sensor", IEEE International Conference on MEMS, p. 621-624, 2011

[3] S. Olyaee, A. Dehghani, "Nano-Pressure Sensor using High Quality Photonic Crystal Cavity Resonator" IEEE 8th International Symposium on Communication Systems, p.1-4, 2012

[4] Y. Yang, D. Yang, H. Tian, Y. Ji, "Photonic crystal stress sensor with high sensitivity in double directions based on shoulder-coupled aslant nanocavity", Sensor and Actuators A: Physical, Vol 193, p. 149-154, 2013

[5] R. Viard "Dispositifs fluidiques de contrôle actif d'écoulement à base de MMEMS", Thèse IEMN Ecole Centrale de Lille, 2010