Biosensors based on nanoporous silicon multilayer structures

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Abstract

In a traditional planar photonic sensing structure only its external surface is typically used for sensing purposes. In order to increase its sensitivity, its surface/volume ratio takes relevance. In this respect, porous silicon (PSi) multilayer structures allow to increase this ratio as well as offering the possibility to infiltrate the target analytes directly into the pores. The infiltration produces a variation of the effective refractive index of PSi layers, and a shift of the multilayer spectral response. This shift is much higher if the specific surface area increases. According to Fig. 1, it implies PSi layers with low diameters and high densities (high porosity). Because of that, in this work we present a PSi multilayer structure with a high refractive index contrast and pores with low average diameters.

One effective reflectivity optical sensor based on photonic structures is the Bragg reflector [1]. It consists of a periodic structure made of alternating layers of high (n_H) and low (n_L) refractive index. Their thicknesses, d, must satisfy the relation $n_H \cdot d_H = n_L \cdot d_L = \lambda_B/4$, being the stop band centered at λ_B. Taking into account the characteristics of our measurement setup, we have used ten periods of PSi layers with refractive indices of $n_H \approx 2.5$ and $n_L \approx 1.8$, and thicknesses of $d_H \approx 145$ nm and $d_L \approx 200$ nm respectively. The average pore diameter is lower than 12 nm and 20 nm for the PSi layers with the high and low refractive index respectively. Taking into account the tendencies of the surface/volume ratio presented in Fig. 1, and respect to publications from other researchers [2], the available sensing area is higher in our case. Moreover and for sensing areas with millimeter dimensions, this multilayer structure has a higher mechanical stability than in cases where higher pore diameters are used. The reflectance spectrum of our Bragg reflector is presented in Fig. 2. As the refractive indices of the PSi layers change due to the infiltration of analytes, the bandgap will shift to longer wavelengths.

To carry out our experimental measurements, we have developed a fluidic cell that allows to flow different solutions over the sample and to illuminate perpendicularly the sample at the same time. An optical interrogator is used to analyze the spectrum of the light reflected in real-time. A LabVIEW program has been implemented to examine the evolution of the reflectance spectrum. A highly sensitive photonic sensing interrogation method based on the continuous monitoring of the output power of a range of the reflectance spectrum, obtaining a real-time measurement.

The sensitivity of our sensing structure has been tested by flowing several ethanol concentrations in DIW. The limit of detection (LoD) of our sensor is in the range of 10^{-6} RIU.

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References

[1] Snow et al., J. Appl. Phys., **86**, pp. 1781 – 1784, 1999
[2] Mukherjee et al., Opt. Express, **21,** pp. 17324 – 17339, 2013

Figures

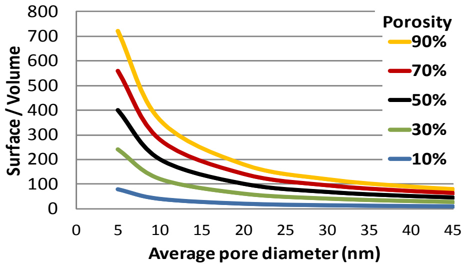

Fig. 1: Surface/Volume ratio of a PSi layer respect to its porosity and its average pore diameter. It has been assumed that pores have cylindrical shapes.

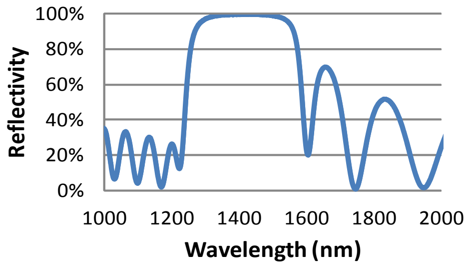

Fig 2: Reflectance spectrum of the PSi multilayer structure.