Impact of the Absorption in Transmittance and Reflectance on Macroporous Silicon Photonic Crystals

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1. Abstract

Photonic Crystals (PC) were introduced almost simultaneously in 1987 by Eli Yablonovitch [1] and Saajeev John [2]. They showed that propagation of certain wavelengths could be inhibited in a Photonic Crystal. Since then, a wide variety of applications have been proposed, in particular, gas detection is of great interest. By introducing a defect in the PC, a reflection dip or a transmission peak can be accurately placed in a desired wavelength, corresponding to an absorption line of the gas to be detected. In addition, irregularities and losses play a key role in PC-based optical applications. In this paper we report the influence of the material losses in the reflection or transmission peaks in order to estimate its maximum acceptable value for gas sensing applications and their effect in the response of the sensors.

2. Motivation of the study

Photonic Crystals allow the inhibition of light propagation at certain frequencies and directions. By modifying its regular structure, i.e. introducing a defect inside it, light can propagate through the crystal in the forbidden band. This phenomenon can be used for gas detection. The basic sensing setup is composed by an emitter [3], a receiver and a volume in where light interacts with the gas to analyze. Within the bandgap, the reflectance of a Photonic Crystal is very high except for the defect wavelength, where there appears a dip in the reflection spectra. In the same way Photonic Crystals can be designed to exhibit a peak in reflection around a given frequency. These peaks and dips will be tuned to a particular wavelength where the target gas has a distinctive absorption feature and, therefore, by analyzing the signal in the receptor, the presence and concentration of the gas can be determined.

The application of Photonic Crystals for gas sensing, allows the fabrication of devices with very fast response times and a high specificity which, added to the low cost of their production, make them good candidates to compete with commercial gas sensors.

The most important element in the gas sensor described above is the Photonic Crystal. Its optical properties will depend on both the periodicity of the structure, and the material's optical properties. These are described by its refractive index which, in general, is a complex number $\hat{n} = n + j \cdot k$. The imaginary part k, called extinction coefficient, is related to the dielectric absorption losses. The higher the imaginary part, the higher the absorption losses and the lower the Q-factor of the transmitted peak. In fact, the study of perfect Photonic Crystals implies the absence of losses. Real materials, however, present optical losses that will influence the actual characteristics of the sensors. In this work, the impact of the material losses in the reflection/transmission peaks are studied, and their influence is evaluated. The goal of this work is to elucidate guidelines to determine the upper boundary of optical losses that can be tolerated for a correct operation of the devices.

3. Simulation and conclusions

Electromagnetic propagation in the considered Photonic Crystals has been simulated by the FDTD technique using Optiwave's OptiFDTD software package. The photonic structures consist of an array of pores inside a silicon wafer. This structure is an approximation of the ones we can fabricate in our laboratory (see Fig.1). In this work the dependence of the characteristics of the reflection peaks are studied. .

In Fig. 2 we observe that the decline of the band reflectance respect to the absorption depends as an exponential function. Results of this work also show that the width of the transmission peak remains fairly constant while the height of the peak decreases, as losses increase.

References

[1] E. Yablonovitch, Phys. Rev. Lett., vol. 58, 1987, p. 2059.

[2] S. John, Phys. Rev. Lett., vol. 58, 1987, p. 2486.

[3] D. Hernández, App. Phys. Lett. vol.100, 2012, p. 091901.

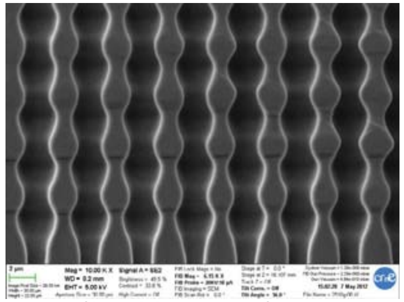

Fig.1. Profiles made by MNT group for gas sensors applications.

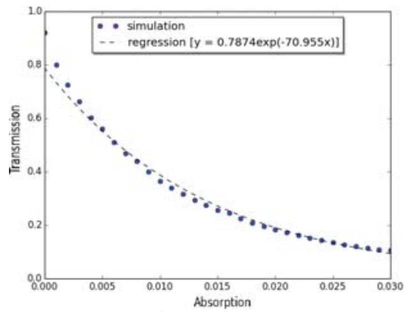

Fig.2. Response of the transmission amplitude depending on the silicon absorption.