Ethanol sensor based on self-assembled polystyrene photonic crystal

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Volatile organic compounds (VOCs), which have high vapor pressure at room temperature [1], are dangerous contaminants in the work and home environments. Alcohols are a class of VOCs, of which the most common are methanol, ethanol, 1-propanol, isopropanol and n-butanol. It is extremely important for human safety and health to be able to detect the presence of these contaminants at low concentrations. Recently, sensors based on Photonic Crystals (PCs) able to detect VOCs presence were presented [1,2]. PCs are periodic dielectric structures, which are characterized by a refractive index (RI) modulation. Opals are the simplest 3D-PCs, they are formed by dielectric spheres organized in a face centered cubic (*fcc)* lattice [3]. The diffraction of light by PCs is described by a combination of Bragg and Snell's laws [3]. In general, the working principle of these types of optical sensors is based on a variation of n_{eff} (effective refractive index) [4] and a consequent shift of the diffraction peak, since the n_{eff} of the PC depends on all the dielectric materials forming the devices (spheres and voids).

We fabricated very good quality opal films of polystyrene (PS) monodispersed spheres by *drop-casting* on pre-treated glass substrates. Figure 1 reports SEM micrograph of a polystyrene PC. We tested the samples as alcohol vapor detectors with methanol, ethanol, 1-propanol, isopropanol and n-butanol. In particular, we studied the time-dependence of the reflectance peak of the PCs in the presence of the different alcohols. In the presence of saturated vapor alcohols, the PC porosity is filled by the vapor and a subsequent condensation inside the pores determines an enhancement of the effective refractive index and a consequent redshift of the diffraction peak. When all the pore volumes are completely saturated, the reflectance-peak wavelength reaches a plateau value and the response of the PC can be considered as complete. Moreover, to justify the strong effect observed on the redshift, a second process has to be taken into account, namely a small swelling of PS particles induced by the alcohols. A different mechanism is valid for water since it shows a very small redshift. The surface nanostructuring (due to the nanospheres) makes the entire PC hydrophobic, thus avoiding the infiltration of the condensed water inside the porous structure. This effect is connected with the high polarity of the water. Responses (peak wavelength redshifts) of the PCs to different VOCs are presented in figure 2. The different behaviors of water and ethanol suggested that we investigate the possible use of PCs as a breathalyzer to test the content of ethyl alcohol. To modify the concentration of ethanol, we changed the relative volumes of water and ethanol in the sample chamber. Two regions can be identified. The first one, at high ethanol concentrations (> 80 % V_{EtOH}/V_{Sol}), where the presence of the alcohol is so high to saturate completely the voids between PC nanoparticles. In this range, the response is always maximum. The second region (below 70 % V_{EtOH}/V_{Sol}) is characterized by a linear behavior, here the condensation of ethanol is still valid, but its amount is not enough to completely fill the voids of the PCs, but it can fill them only partially and proportionally to its concentration. The estimated detection limit of ethanol for our sensor is of 2%.

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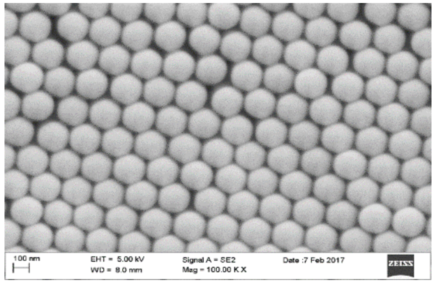

Figure 1. SEM micrograph of polystyrene PCs. sample.

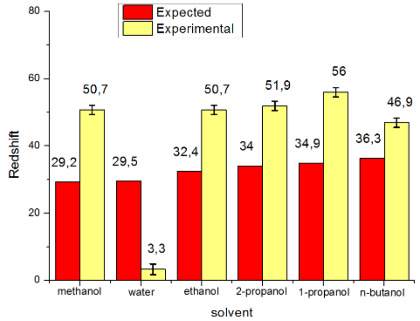

Figure 2. Comparison between theoretical calculation (red bars) and experimental data (yellow bars).