Breathing sensors based on nano Fabry-Perot cavities formed on optical fibers by means of Electrostatic Self Assembly

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One of the most used optical fiber sensing schemes is based on the deposition of a sensitive material on the end-face of an optical fiber[1]. In this scheme, the reflected optical power is modulated according to the variation of the sensitive material (refractive index, thickness, absorption, …). Thus, the reflected optical power can be correlated to the variation of a target parameter. More specifically, if the coating material is sensitive to humidity and the response time of this device is shorter than the breathing time, then the device could be used for human breath monitoring since human exhalation typically contains more water vapor than the usual environment. Unfortunately, most of the humidity sensitive materials are characterized by high response time (several seconds), which disqualifies them for their possible utilization as human breathing sensors. Our group has experimentally demonstrated that the response time of the humidity sensing films can be drastically decreased by fabricating a nanostructured sensitive film consisting in the alternate deposition of hydrophilic and hydrophobic molecular layers[2]. The behavior of these sensitive coatings deposited on the ends of optical fibers can be modeled as a Fabry-Perot interferometric cavity whose reflectivity varies with the amount of adsorbed water[2,3].

In order to fabricate the device, we have used the Layer-by-Layer Electrostatic Self-assembly method (ESA). It consists in the alternate deposition of polyanionic and polycationic molecules on a substrate. The substrate, in this case the tip of the fiber, must be previously chemically treated to produce a charged surface. It is then dipped into solutions of the chosen cationic and anionic solutions. The process is repeated until the desired thickness is achieved. The coating is formed by a structure of bilayers adsorbed onto another, and its thickness grow rate can be adjusted by varying the dipping parameters. A solution of Poly R-478 (a polymeric anthraquinone dye) was chosen as the anionic polyelectrolyte, and poly(diallyldimethyl ammonium chloride) (PDDA) was the cationic polyelectrolyte. Both chemicals were obtained from Sigma Aldrich. The dipping can be set so that the bilayer thickness be 7 nm. The construction of the structure was monitored by using a sensor arrangement in reflection. Different light sources were employed: a 635 nm laser, a 1310 nm laser and a 1310 nm LED. Among other results, figure 1a shows the reflected optical power as a function of the number of bilayers for the two different laser wavelengths. The results agree with the expected Fabry-Perot response; the period of the 1310 nm laser curve is about twice the period of the 635 nm one. Moreover, the coherence of the optical source is not critical due to the nanoscale length of the cavity, smaller that the source wavelength. It is illustrated in figure 1b, where the response of the structure to 1310 nm laser and LED sources are compared.

The response to humidity was measured by introducing it inside of a climatic chamber where the temperature and relative humidity were controlled. Figure 2 depicts the response after more than 100 hours of alternate cycles of rising and falling humidity and constant temperature of 25ºC. The cross-sensitivy to temperature was negligible for temperatures ranging between 15ºC and 40ºC. Finally, the sensor was attached to a surgical mask with the fiber parallel to the face of several volunteers and placed at 5 cm of the mouth. Several tests were carried out to measure the response of the sensor to different breath states. Some of the results can be seen in figure 3.

References:

[1] Eric Udd, editor, John Wiley & Sons, (1991), ISBN 0471830070
[2] F.J. Arregui et al., IEICE Trans.Electron vol.EE83-C,no.3,(2000) 360-365.
[3] F.J. Arregui et al., Opt. Lett., vol. 24, no.9, (1999) 506-598.

Figures:

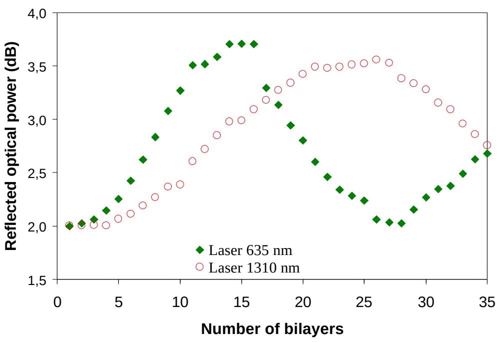

Figure 1a
Reflected optical power during the building up for two different laser wavelengths

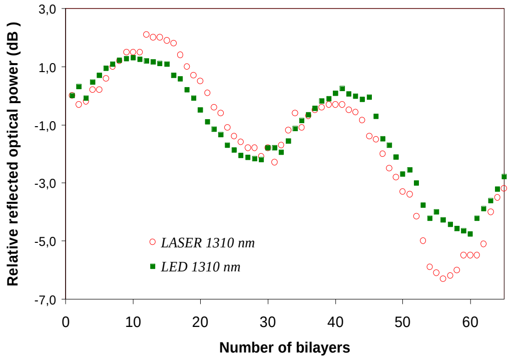

Figure 1b
Reflected optical power during the building up for two different types of light source

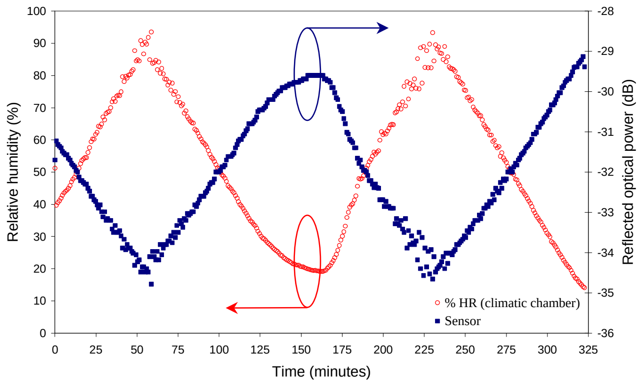

Figure 2
Response of the sensor to changing relative humidity at 25ºC

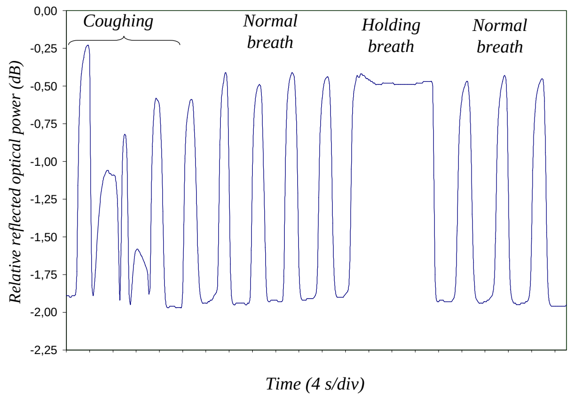

Figure 3
Response to human breathing in several situations