A Porous Silicon Microcavity As An Optical And Electrical Multiparametric Chemical Sensor

C. Baratto[1], Z. Gaburro[2], G. Faglia[1], G. Sberveglieri[1], L. Pavesi[2]

[1] Dept. of Chemistry and Physics, University of Brescia
via Valotti 9, I-25133 Brescia, Italy

[2] Dept. of Physics, University of Trento,
via Sommarive 14, I-38050 Povo (Tn) Italy

The lack of selectivity of chemical sensors encourages the investigations of single sensors with different mechanism of interaction with the gases. In fact, the wider the spectrum of information that can be extracted from one sensor, the more the sensor can be made selective by the analysis of the response pattern.

We experimentally demonstrate that porous silicon optical microcavities (PSM) can be effectively used as multi-parametric gas sensors. Semiconductor microcavities are formed by a layer structure similar to a Fabry-Perot filter: a central active medium is embedded between two dielectric multilayer mirrors. The parameters monitored in our sensors are the DC electrical conductance, the photoluminescence (PL) intensity and the spectral position of the resonance cavity peak.

Measurements are carried out at room temperature in a controlled flux of a mixture of dry air and gaseous traces. The examined species are NO_2 (1-21 ppm), relative humidity (20% - 80%) and ethanol (500 – 60000 ppm). The PSM were produced by electrochemical etching of p type (6-9 Ω cm) and p+ type (0.005-0.02 Ω cm) silicon wafers [1]. For electrical measurements two gold contacts were sputtered on the top surface of p+ PSM.

PL spectra are taken from a p type PSM, in dry air and after adding 21 ppm of NO_2. The main effect produced by NO_2 (at 21 ppm) is a drop of a factor two of the PL intensity (not reported). This large drop suggests that lower concentrations are likely to be detectable looking at the PL quenching. Unfortunately, in preliminary characterisation the PL intensity did not recover to the initial value after the forced flux was switched back to dry air, probably because NO_2 at so great concentration (one hundred times greater than the typical environmental limit) produces sample oxidation [2]. Sample preoxidation and chemical sensitisation are expected to reduce this irreversible effect. No shift of the cavity peak is observed.

Figure 1 shows the electrical response of a p+ type PSM to 1, 2 and 4 ppm of NO_2. Clearly, the presence of NO_2 can be detected down to a concentration of 1 ppm and the current recovers completely to the initial value. The relative response $\Delta G/G$ of the PSM was of 6.6 at 2 ppm. We have recovered sensitivity levels typical of p+ porous silicon [2].

In the case of ethanol, we have so far tested only the two optical parameters: the peak-shift and the PL quenching. Ethanol causes a reversible decrease in PL integrated intensity and a shift in the cavity peak (see Figure 2). Also the response times involved in shift of the cavity peak and in the quenching of PL are different being of 10 seconds the former and of about 10 minutes the latter.

The PSM response to humidity has been examined. While NO_2 affects only two of the three parameters detected, change of relative humidity at T=20°C in the range from dry to saturation produces a reversible modification of both two optical parameters and a reversible increase in electrical conductance (not reported).

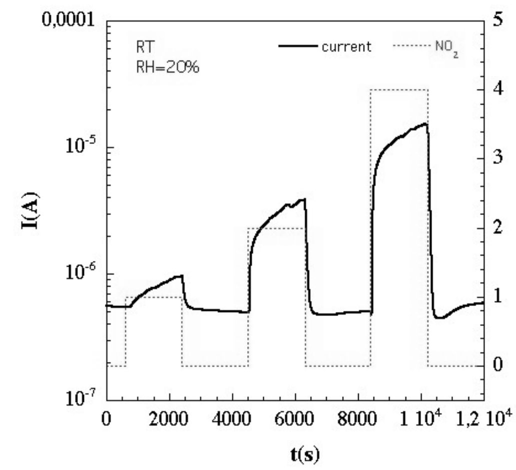

Figure 1. Electrical current through a p+ PSM under controlled flux (0.3 l/m) of humid air (20%) containing 1, 2 or 4 ppm of NO_2.The dotted line represents the NO_2 concentrations referring to the right scale, while solid line represents device current referring to the left scale.

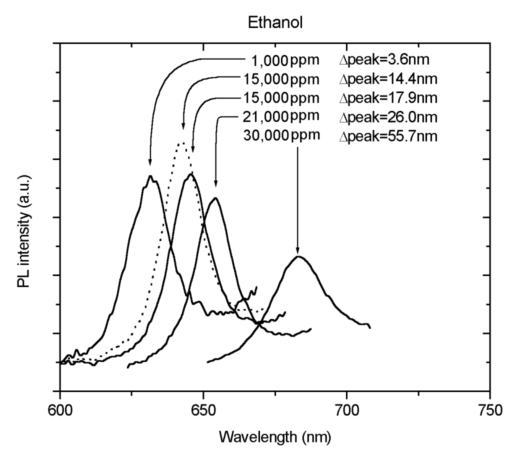

Figure 2. PL spectra of a high resistivity PSM, under controlled flux of air containing ethanol (0.3 l/m), at room temperature. Spectra have been acquired 10 minutes after the switching of the flux with the indicated concentration. Dry air + ethanol (1,000, 15,000, 21,000 and 30,000 ppm). Dashed line: dry air + ethanol, 15,000 ppm, 30 seconds after the switching of the flux.

References

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