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Porous Silicon Based Humidity Sensor

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Porous silicon (PS) is well known as a photovoltaic material. However, in the last couple of years, research has focused on the use of porous silicon as chemical-biological sensors. This paper discusses the use of PS as an optical humidity sensor. Photo-luminescence (PL) quenching measurements in a controlled humidity atmosphere (mixed Nitrogen gas and water vapor) were performed to test the sensor response towards the water vapor. Surface morphologies of the PS samples were characterized by a scanning electron microscopy (SEM) and structural properties were investigated via Fourier Transform Infrared (FTIR) spectroscopy. It was found that PS surface is very sensitive to the water vapor. The experimental results suggested that PS surface is a promising candidate material to be used as a humidity sensor.

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1. Introduction

Porous Silicon has attracted much attention due to wide variety of possibilities for electronics, opto-electronics and sensor applications [1]. Moreover, owing to its sponge-like structure, it is an ideal candidate material for a sensor. It has a high internal surface to volume ratio of 700–800 m^2/cm^3 which can be altered through production conditions [1, 2]. Its large ratio and surface bond configuration enhances sensing properties of PS against various chemical species.

The traditional methods such as chromatography for detecting various gases require costly equipment and need professional laboratories with specialized staff [1, 3]. The advantage of PS based humidity sensor over the traditional ones is that it is compact, has low power consumption, low cost and can operate at room temperature.

Porous silicon based humidity sensors with capacitive transduction principle have been studied in recent years [4]. It is also designed as a humidity sensor through changes in its electrical properties [5]. Photoluminescence (PL) quenching of PS was reported as a gas sensor [6].

This study reports the effects of water vapor on PL spectra of PS. Hence, we measured the PL spectra of PS under various relative humidity (RH) levels under a controlled atmosphere. The results show that PL spectra are affected by water vapor and this can be used as a PS based humidity sensor.

2. Experimental

The porous silicon samples were prepared from p-type boron-doped crystal silicon (c-Si) wafer with resistivity of 2.5 Ω cm. Before electrochemical etching, c-Si wafers were cleaned by ultrasonic treatment. They were then kept in a solution of 1:24 volume ratio of 50% HF acid and de-ionized (DI) water for 5 min in order to remove surface oxidation from c-Si surface. The etching process was performed in a mixed HF-ethanol solution with 1:3 volume ratios. The contact area of the HF-ethanol solution with the silicon substrate was 1.13 cm^2 and current density was 8.85 mA/cm^3. After electrochemical etching, the porous silicon samples were rinsed with ethanol and dried with nitrogen gas. The PS sample was then placed in a chamber containing a mixture of nitrogen and with various ratios of water vapor to measure its luminescence response to water vapor.

The etching process was carried out in a double tank cell as described in [7]. The cell was separated into by c-Si as seen in Fig. 1. Two platinum (Pt) electrodes were immersed in the electrolyte of each half cell, respectively. Etching process and all sensor measurements were carried out at room temperature.

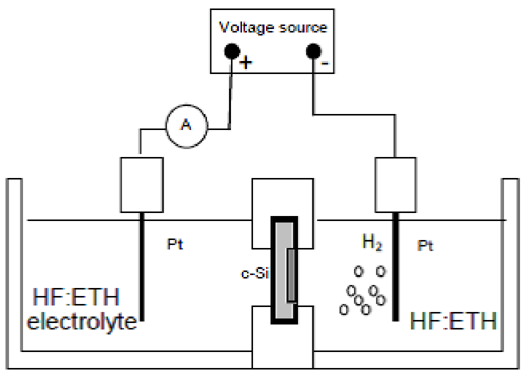

Fig. 1. Schematic diagram of double cell for etching process of crystal silicon.

The PL quenching measurements of PS were performed in sensor test chamber which is made from Teflon for sensing of water vapor. Schematic diagram for the sen-

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sor test chamber and other required equipment are shown in Fig. 2 where, nitrogen gas was used as a carrier gas for water vapor. Two flow-meters bought from Sierra Instruments (smart track 100 and micro track 101) which have maximum flow 200 sccm and 4 sccm were used as a nitrogen gas controller. Nitrogen gas was separated into two lines. A line was connected to a bubble bottle to obtain water-gas mixture. Water concentration was adjusted by the flow meters and relative humidity (RH) measured by a reference humidity sensor of Thermo-Hygrometer 8711. 254 nm wave length of UV-light from a UV lamp (Konrad Benda) was used for PL excitation. The structure and surface bond configuration of PS layer were characterized by a Scanning Electron Microscopy (SEM) and a Fourier Transform Spectrometer (FTIR), respectively.

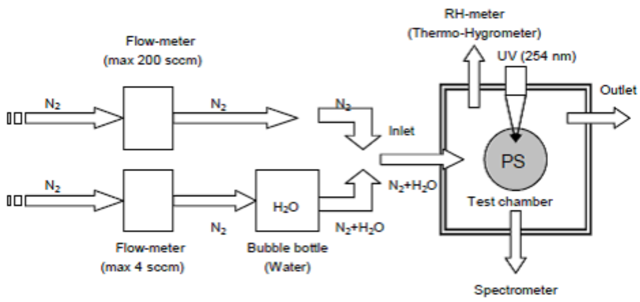

Fig. 2. Experimental set-up to sense water vapor.

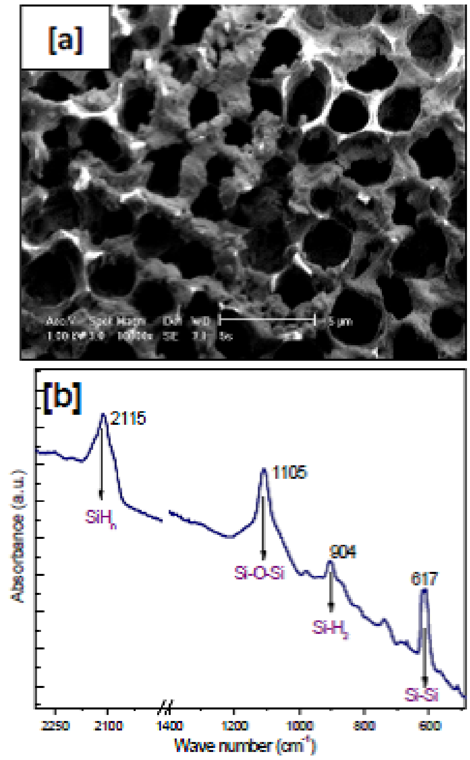

Fig. 3. SEM micrograph and FTIR spectrum of PS (a) and (b), respectively.

3. Results

Surface morphology of the porous silicon was studied by scanning electron microscope as shown in Fig. 3a where it was clear that there is a continuous distribution of pore sizes ranging between 1 and 2 μm. Fourier transform infrared measurements showed that the typical PS surface is characterized by chemical species such as Si-H and Si-O bonds as shown in Fig. 3b. From the FTIR spectrum, it can be concluded that PS surface after the anodisation is covered with hydrogen and oxygen atoms. The bonds can play important role in sensing the water vapor.

Figure 4 shows PL spectra changes of PS humidity sensor with increasing RH levels. The figure shows that PL intensity decreases with increasing RH level. Figure 5 also shows recovery of the spectra with decreasing RH levels where it is seen that PL intensity decreases with increasing RH levels. From the Figs. 4 and 5, we can conclude that PL intensity is affected from RH levels. PS humidity sensor shows same response to various RH levels. This phenomenon can be described with capillary condensation of the water vapor within the pores of the PS [8]. During exposure to water vapor, the air in the pores of the PS is replaced with water vapor. We can therefore conclude that PL intensity decreases due to capillary condensation.

Figure 6 shows the variation of PL intensity of PS relative to RH levels. The graph was obtained from Fig. 4.

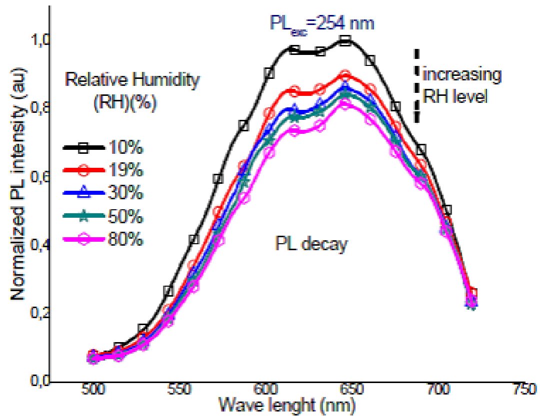

Fig. 4. PL spectra change of porous silicon with increasing RH levels.

Figure 6 clearly shows that PL intensity decreases with increasing RH level and an exponentially decaying function can be fitted to this decrease.

The quantity of water molecule being absorbed to the PS surface depends on the bond configuration of the PS surface. Si-H and Si-O bonds can play a critical role for the water molecule adsorption on the PS surface. PL intensity of PS decreases due to the adsorption. Quenching of PL spectra through adsorption of water molecules on PS surface can be explained by electron transfer mechanism described in detail in Ref [1].

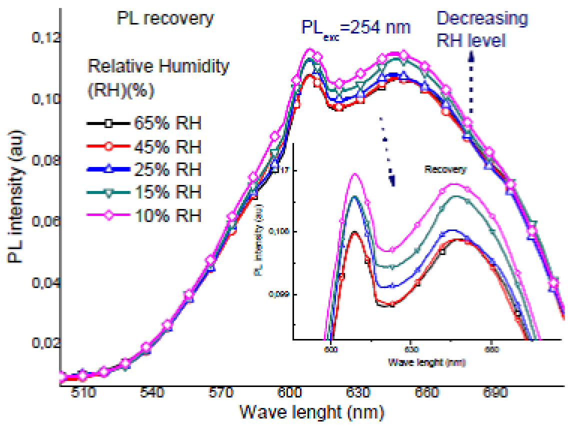

Fig. 5. Recovery of PL spectra with decreasing RH levels.

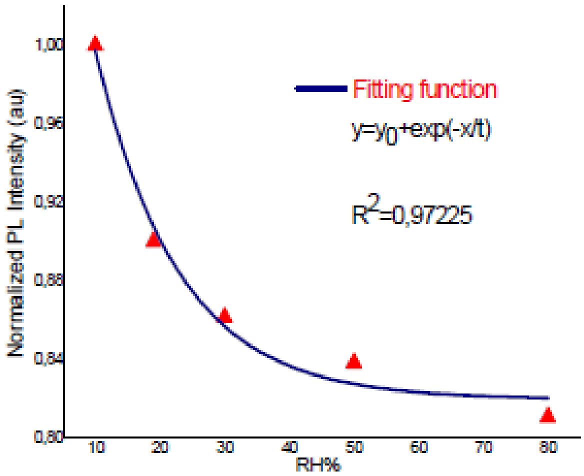

Fig. 6. The PL intensity changes with RH humidity levels. Solid line in the figure shows linear fitting.

4. Conclusions

In this study, we explored the possibility of a humidity sensor based on porous silicon layer. The PL spectra changes with various RH levels. We observed that PL intensity decreases during exposure to increasing water vapor levels or vice versa due to capillary condensation of the vapor into the pores at the surface. The decrease obeys to an exponentially decreasing function. It is possible to conclude that PS can be considered as a humidity sensor.

Acknowledgments

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