Organic Vapors Sensor Based on Photosynthesize Porous Silicon

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Abstract

In this paper, a photo synthesis porous silicon (PS) layer is investigated as a sensing material to detect the organic vapors with low concentration. The structure of the sensor consisted of thin Al/PS/n-Si/Al, where the PS was etched photo chemically. The current response of the sensor is governed by the partial depletion of silicon located between two adjacent (porous regions). This depletion is due to the charges trapped on the surface states associated with the silicon – native silicon oxide.

Keywords: Porous Silicon, Sensing, Photochemical etching.

Introduction

Although porous silicon was first discovered by *Uhlir* [1] in 1956, significant interest in the material is shown after the observation of room temperature photoluminescence properties by *Canham* [2]. The porous silicon /silicon substrate junction has been used for sensing applications as a gas sensors based up on the changing current due to the dipole moment of the gas [3-5], and a humidity sensor based up on the changing current with humidity [6-8]. In this paper, the current response of thin Al/PS/n-Si/Al sandwich structure in the presence of organic vapors such as ethanol and methanol are quantitatively discussed based up on the existence of the dangling bonds (DB) associated with the porous silicon.

Experimental

The porous layer was prepared by photochemical etching process of a mirror- like (111) oriented silicon wafer of resistivity of 0.22–0.38 Ω.cm in an HF (40%) with etching time of 35 min under 33.5W/cm^2 optical etching power density of tungsten halogen lamp as shown in figure (1). The porosity was 38% and the thickness equal to 41µm, the value of the porosity and the thickness of the porous layer were determined gravimetrically. The surface morphology of the PS was carried out using high resolution scanning electron microscopy type (JSM-5510). The SEM measurements were carried out in Bio and Nano systems Institute in Germany. The current–voltage characteristics by evaporated on the back side of the sample an ohmic contact using a thick aluminum electrode. On the top etched side of the sample, we evaporated an aluminum thin film of 10-15nm thickness directly on the porous layer in order to produce (Schottky-like) diode. The gas vaporized from diluted organic solutions was warmed by a heater and was injected through a tube into a chamber with N_2 gas as a carrier gas. Every measurement was carried out after 60 sec exposure time to the gas. The I-V measurements were carried out using fine dc power supply and 616 kethily digital electrometer.

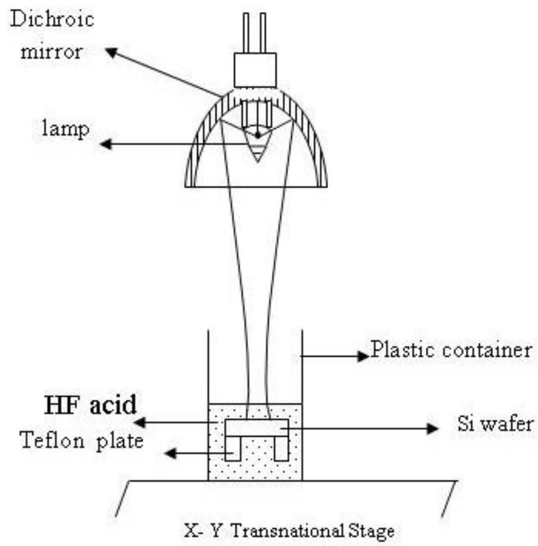


Figure (1) shows, the scheme of photochemical etching process.

Results and Discussions

Figure(2a,b,c) shows, the SEM micrographs of the etched surface at constant light power density of 33.5w/cm^{2}for 35 min etching time.

The surface morphology of light etched silicon sample exhibits a significant divergence in, structure. It can easily distinguish two regions in the photochemical etched surface. The first region is crystalline silicon while the second region is a porous region, the porous regions are randomly distributed over the silicon surface and the silicon regions are bounded among the porous regions. These porous region have a pore-like structure with different pore sizes and the pore diameter is found to be in the range less than 0.5μm.

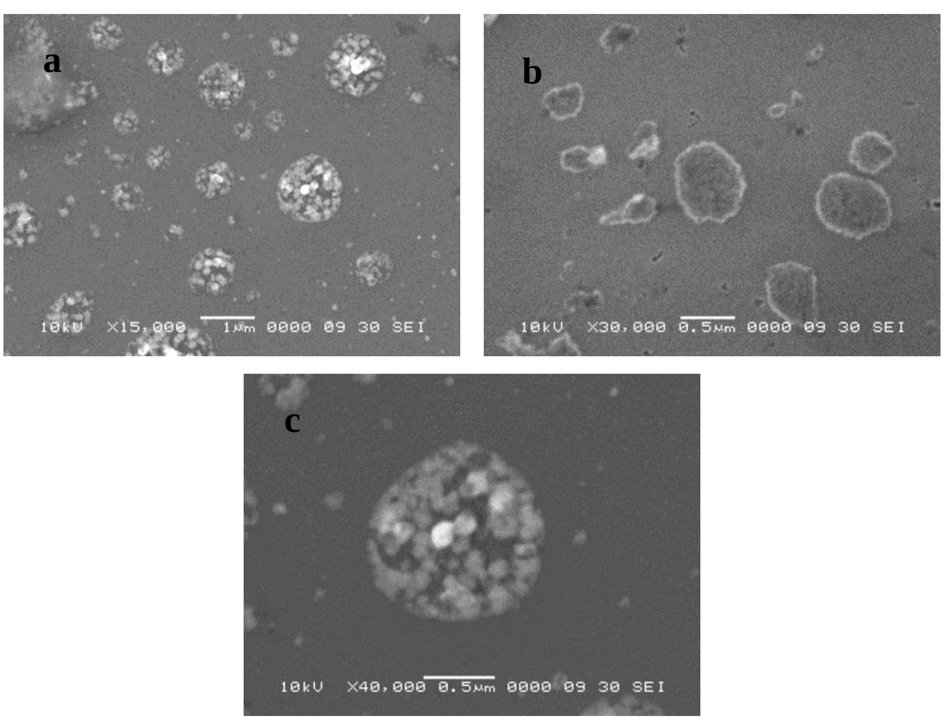
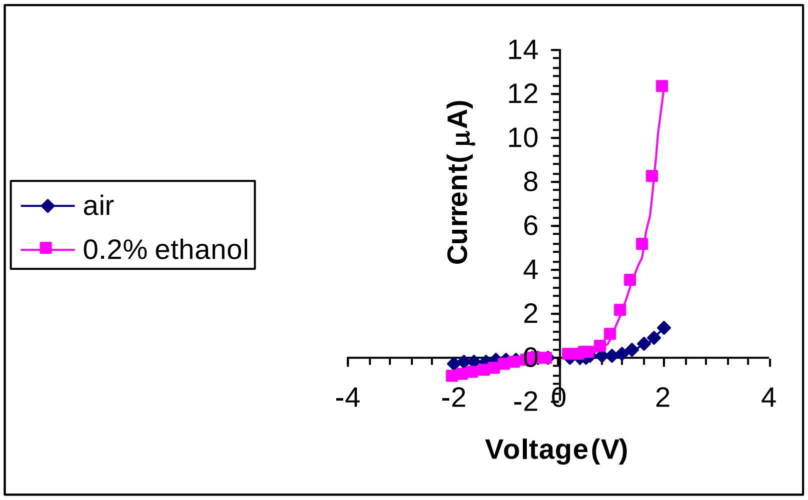


Figure (2), shows SEM images of different magnifications of the silicon surface etched by a33.5w/cm^2 power density from tungsten halogen lamp, for etching time 35 min.



Figure(3), Current-Voltage characteristics of the sensor in air and ethanol.

Figure(3) gives the IV characteristics of the sandwich structure in the presence of air or 0.2%ethanol at room temperature. Under 2volt forward biasing the current is increased by a factor 10, where as the increasing is by a factor 3 for the same voltage under reverse biasing. for this reason all the measurements were done under forward biasing.

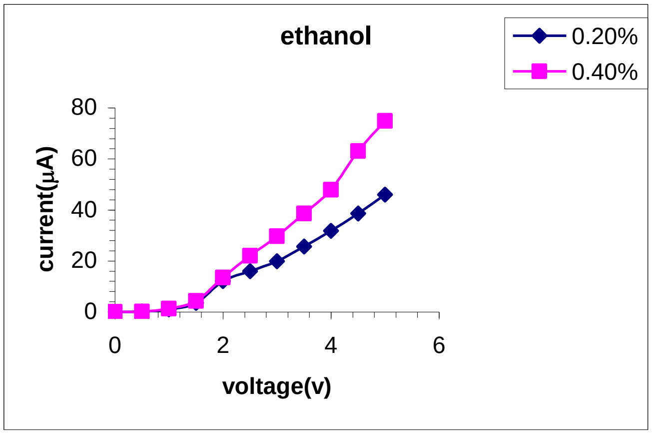
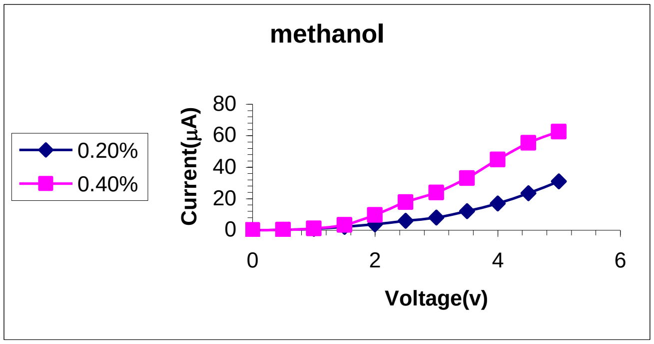


Figure (4), current-voltage curves for ethanol.



Figure(5), current- voltage curves for methanol.

Figure (4) and (5) show, the current response of the sandwich structure for 0-5 V bias voltage against ethanol and methanol vapors evaporated from 0.2-0.4% solutions concentrations. The figures show a non–linear shape with small slope below 2 volt, by increasing the applied voltage above this value the current increased rapidly. Such rectifying nature in the current response is caused by the Schottky junction between the Al thin film and the etched surface and this junction has a large value of the series resistance [9] and it can easily distinguished, that the current response PS sensor for ethanol is higher than that of methanol, this is probably due to that the silicon is a good absorber for the ethanol than methanol and this will lead to efficient passivation of the dangling bond of the PS.

The electrical behavior of the sensor is analyzed with the aid of the model described by *Stievenard* and *Deresmes* [12], in which the absorption of the vapor is mainly occur by the Si-H bonds (dangling bonds). Based on the SEM micrographs of the etched surface, the average distance of the crystalline silicon between two porous regions (d) is around 5µm since the resistivity of crystalline silicon is much less than that of the porous silicon [11], therefore the current will pass in a zig-zag way within the crystalline silicon regions instead of the porous regions. At the interface between the silicon and the pore, there is a thin layer of silicon dioxide and the associated interface states, having a density $\delta(cm^{-2})$. Due to the charges trapped on the interface states, there is a depleted region in the crystalline silicon channel over the distance (W). By assuming that the situation is symmetric and, depending on the value of (w), there is a central channel of width (d-2w), where d represent the distance between two adjacent porous regions. The charge carriers can move when a potential is applied on the sandwich structure. The integration of poisson's equation leads to a simple relation between (w) and(δ) given by [12].

$W = \delta / N_D$ ------(1)

Where N_D is the doping concentration in the silicon wafer. Therefore the dc current can be controlled by δ. The effect of the gas is to passivate the active dangling bonds, perhaps through a screening mechanism, so that (W) decreases and the width of the channel increases. The density of the dangling bonds from electron paramagnetic (EPR) measurements [13] is about 10^{20} DB/cm^{-3} and as the developed surface area of the PS layer of order 600m^2/cm^3 , therefore the density of the dangling bonds of order of 10^{12} - 10^{13} cm^{-2}. As the initial doping concentration of the silicon wafer of 2x 10^{16} cm^{-3}, there are enough dangling bonds to passivate the free charge carriers. In our samples, (d) is around 5µm. Using equation (1), we find that (w) is of order of few micron, so that the channel can be easily pinched.

Conclusions

Based on the I-V characteristics of the porous silicon sandwich structures, the Photosynthesized porous silicon which prepared by the photochemical etching can be used as a sensor for low concentrations of an organic vapor in the range 0.2 - 0.4 % . This study depends on the interaction of the absorbed vapor and the dangling bonds in the porous network.

Acknowledgments

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