Organic Vapors Sensor Based on Dangling Bonds of Porous Silicon

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Received on:4/4/2007
Accepted on: 26/9/2007

Abstract

In this paper, a porous silicon (PS) layer is investigated as a sensing material to detect the organic vapors with low concentration. The structure of the prepared sensor consists of thin Au /PS/n-Si/Au thick where the PS is 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 dangling bonds associated with the silicon – porous silicon interface .

Keywords: gas sensor, porous silicon

متحسس الأبخرة العضوية بالاعتماد على الأواصر المتدلية للسليكون المسامي

الخلاصة

في هذا البحث أجريت دراسة على خصائص طبقة السيليكون المسامي التي تعمل كمتحسس للأبخرة العضوية. تم تحضير تركيب شرائحي يتكون من thin Au /PS/n-Si/Au thick. وتم تحضير طبقة السيليكون المسامي بطريقة التنميش الضوء كيمياوي. إن أستجابة المتحسس للتيار الكهربائي يتم السيطرة عليها بواسطة منطقة السيليكون البلوري المستنفذة جزئياً والواقعة بين مناطق السيليكون المسامي المتجاورة، هذا الاستنزاف سببه عمليات إقتناص حاملات الشحن بواسطة الأواصر المتدلية المرافقة للحد الفاصل بين السيليكون والسيليكون المسامي.

Introduction

Although porous silicon was first discovered by *Uhlir* [1] in 1956, significant interest in the material is shown after the observation at room temperature of photoluminescence properties by *Canham* [2] .The porous silicon /silicon substrate junction has been used for sensing applications as gas sensors based upon the increase in current due to the dipole moment of the gas [3-5], and a humidity sensor based upon the changing current with humidity[6]. In this paper , the current response of thin Au /PS/n-Si/Au sandwich structure in the presence of organic vapors such as ethanol and methanol which quantitatively discussed based upon 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 ohm.cm in an HF (40%) with etching time of 35 min under 33.5W/cm^2 optical etching power density of tungsten halogen lamp. More details of this process can be found elsewhere [7,8] . The porosity

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is 38% and the thickness equal to 41µm , the value of the porosity and the thickness of the porous layer are 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 School of Physics/ Nanostructures and Optoelectronics Research Center (NOR) Lab University Sian, Malaysia. The current–voltage characteristics was studied out by evaporating the back side of the sample ohmic contact using a thick gold electrode. On the top etched side of the sample , thin gold thin film of 10-15nm thickness we evaporated directly on the porous layer in order to produce (Schottky – like) diode. Fig.(1) shows, the measurement setup for vapor sensing . As shown in this figure , 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 .

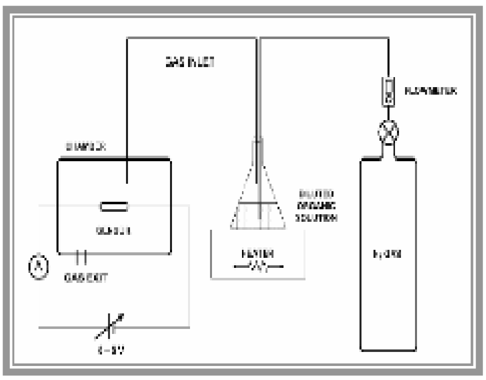
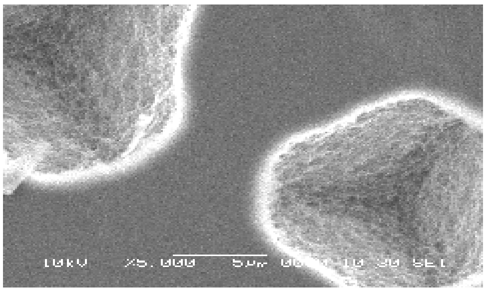


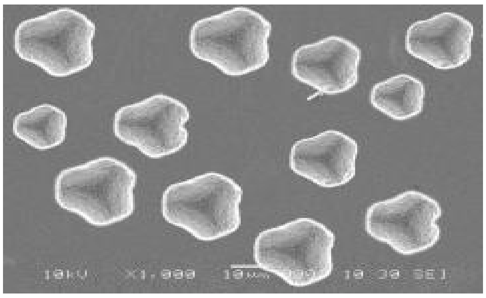
Figure (1) Scheme of the apparatus for the gas sensing measurement

Results and Discussions.

Fig.(2a,b) 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. one 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 regions have a pore-like structure with different pore sizes and the pore diameter insid the porous region is found to be in the range less than 1µm.



(a)



(b)

Figure (2)

Fig.(2). SEM images of different magnifications of the silicon surface etched by a 33.5w/cm^2 power density from tungsten halogen lamp , for etching time 35 min.

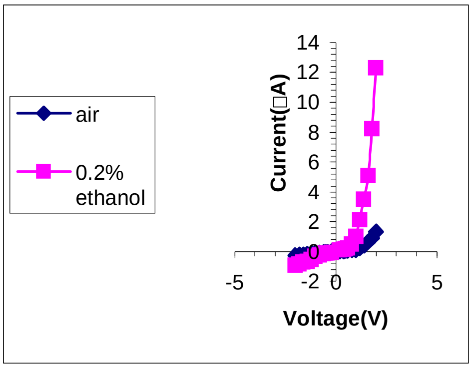


Fig.(3). Current-Voltage characteristics of the sensor in air and ethanol

Fig.(3) gives the IV characteristics of the sandwich structure in the presence of air and 0.2% ethanol at room temperature. Under 2volt forward biasing the current is increased by a factor 10 , whereas 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.

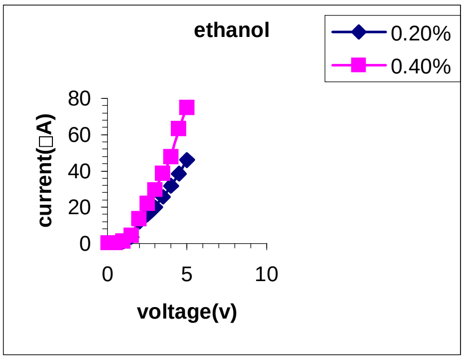


Figure (4). current-voltage curves for ethanol

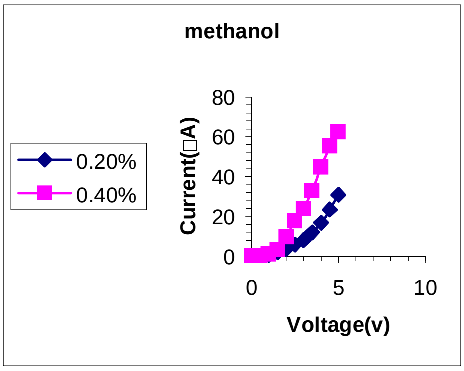


Fig.(5).current- voltage curves for methanol

Fig.(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 Au thin film and the etched surface and this junction has a large value of the series resistance [9] and one can easily distinguish, that the current response PS sensor of 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[4,10,11].

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 distance of the crystalline silicon between two porous regions(d) is in the range from 5 to 12µm 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 channels of width (d-2w), where d represent of 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].

$$W = \delta / N_D \quad \text{------(1)}$$

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 passivat 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 $600 m^2/cm^3$, therefore the density of the dangling bonds is of order of 10^{12} --- 10^{13} cm^{-2} [2]. As the initial doping concentration of the silicon wafer is of 2x 10^{16} cm^{-3}, there are enough dangling bonds to passivate the free charge carriers . In our samples , (d)is in the range from 5 to 12µm. 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 IV characteristics of the porous silicon sandwich structures, the Photosynthesized porous silicon which is 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.

The author wants to thank Dr. N.M.Alrawi for the SEM tests and Dr. B.G.Rasheed for Fruitful discussions .

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