Eng. & Technology, Vol. 25, No.5, 2007

Photonic Devices Based on Porous Silicon Layers

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Received on: 14/11/2006
Accepted on: 10/6/2007

Abstract

The optoelectronic properties of (Al/c-Si) and sandwich structure type (Al/PS/c-Si/Al) were reported. The nanostructure porous silicon is obtained by photochemical etching without applying electric field. The photosensitivity of (Al/PS/c-Si/Al) structure is determined by porous layer photoconduction. Maximum spectral sensitivity of the porous layer is changed from (575-610)nm depending on preparation condition.

النبائط الفوتونية المستندة على طبقات السليكون المسامي

الخلاصة

تم دراسة الخصائص الكهروبصرية لمفرقي (Al/c-Si) و(Al/PS/c-Si) حيث تم تحضير السليكون المسامي الفائق الدقة بواسطة طريقة التنميش الضوء- كيمياوي بدون تسليط مجال كهربائي. وتم دراسة الحساسية الضوئية للمفرق (Al/PS/c-Si/Al) بالاعتماد على التوصيل الضوئي لطبقة مسامية وتم الحصول على اعظم حساسية ضوئية ضمن الطول الموجي nm(575-610) وبالاعتماد على ظروف التحضير.

Introduction

Recent studies have showed that both the electrochemical [1-4] and photochemical etching [5-8] of silicon can produce porous silicon (PS)/nanocrystalline material with strong photoluminescence (PL) and electroluminescence emission.

The photovoltaic effect of the PS prepared by electrochemical etching have been studied [9-13] under different fabrication conditions such as etching time, etching current and nature of the substrate. In photochemical etching using laser-induced etching of silicon, the absorption of the laser light and the band bending at the silicon/electrolyte interface provide the required holes in the irradiation area of silicon wafer to initiate the etching. This technique creates a PS layer without needing an external potential as in anodization; also a thick and thin porous layers can be synthesized [7]. In this study, a high power density photon source (100W) halogen lamp has been employed to prepare PS layer instead of laser light. The photosensitive structures (metal/PS/c-Si/metal) based on nanocrystallites layers produced by both electrochemical etching and stain etching were studied by [14,15,16]. Zheng *et al*. [14], demonstrated a highly sensitive (Al/PS/p-Si/Al) photodiode with porous layer thickness of about (4-10)µm. The sensitivity was around (0.6 A/W) and quantum efficiency close to unity in a wavelength range of (630-900)nm without using any antireflection coating [15,16].

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http s://doi.org/10.30684/etj.25.5.10
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Experimental Procedure

Fig.(1) shows a schematic diagram of experimental setup for photochemical etching process. A commercially available n-type (111) oriented silicon wafer of resistivity ρ = (4.3-5.6) Ω.cm was rinsed with acetone. Then the wafer is immersed in 40 HF acid and fixed on two Teflon plates in such a way that the current could pass from the back surface to the light irradiated area on the top surface through the electrolyte as shown in Fig.(1). In this electrode less photochemical etching process, there was no applied bias. The light beam of tungsten halogen lamp integral with dichotic ellipsoidal mirror was focused on a silicon wafer to a circular spot ($1.13cm^2$) area, the distance between the halogen lamp and the wafer is about (4cm). Bubbles were observed during the etching process.

Prior to the measurements, a thin rectangular $(5x5)mm^2$ aluminum film with a thickness of approximately (10-15)nm was deposited on the entire surface of the etched area. The main difficulty in obtaining proper contact on the nanostructure was eliminated from the device by thermally evaporating a thick secondary metal contact with a smaller surface area onto the transparent (thin) metal film as shown in Fig.(2). In this work, all measurements were achieved without depositing any antireflection coating on the thin solid state contact. Thick aluminum electrode was thermally evaporated on the back surface of the wafer. Measurements of the photosensitivity of (Al/PS/n-Si/Al) sandwich configured structure were carried out using monochromator with tuning range of (400-900) nm.

Results and Discussion

The transmittance of the (15)nm (Al) film deposited onto borosilicate glass substrate is presented in Fig. (3).

Fig.(4a&b) shows the J-V characteristics of (Al/c-Si). The dark J-V curve was illustrated in Fig. (4a). This figure demonstrates a good rectification with rectification ratio of about (32) at (0.5V). the forward characteristics exhibits an exponent variation with operating voltage of (0.25V) which is less than that of ideal Schottky contact. The background photocurrent (day light current) shown in Fig. (4b) presents a good optoelectronic response. This photoresponse is due to the formation of Schottky barrier between the thin (Al) layer and Si substrate.

J-V characteristics of (Al/PS/n-Si/Al) structure for (1800, 2400 & 5400)s etching times are presented in Fig.(5a&b). The forward and reverse currents are decreased with increasing etching time due to the increase in the thickness of porous layer which in turn leads to increase the series resistance of the device. The daylight current shown in Fig.(5b) shows an enhancement with increasing etching time. With increasing etching time, the size of the silicon nanocrystallites in the porous structure. This can lead to form a heterojunction type PS/c-Si. This heterojunction may cause an increase in the total depletion layer width and hence causes an increase in photocurrent.

Fig. (6a) illustrates the spectral sensitivity (R_λ) for Al/n-Si structure, this structure operates as a photovoltaic mode. From this figure, the spectral sensitivity lies within the spam of near UV-visible-near infrared. Peak of the spectral sensitivity lies at (575nm). In the region of short wavelengths, the spectral sensitivity is low, this is due to the high value of absorption coefficient in the crystalline silicon at this region, therefore the absorption depth is small and hence the light is absorbed near the surface where the recombination is high and no photo-generated carriers will reach the depletion region [17]. The reduction in spectral sensitivity at long wavelengths (greater than 800nm) [17], is due to the low absorption coefficient of the silicon and also in this region the transmission of Al thin film is small.

Figure (6b) shows the measured sensitivity as a function of incident wavelength. This measurement was achieved under (5V) reverse bias voltage and at different etching times (1800, 2400 & 5400)s. From this figure, the sensitivity lies with in the visible region, while the peak and the value of the sensitivity is varied with varying the etching time. A blue shift is observed in the peak of the sensitivity with increasing the etching time. The peak of the sensitivity is varied as (610, 596 & 580)nm with varying the etching time as (1800, 2400 & 5400)s respectively. The value of the sensitivity was increased from (0.43, 0.45 & 0.46)A/W by increasing the etching time from (1800, 2400 & 5400)s respectively. This blue shift in the peak of the sensitivity is due to the increase of the energy band gap of the silicon nanocrystallites layer above the energy band gap of the bulk silicon. This increasing is depended on the sizes of the silicon nanocrystallites in the porous layer [9,13,16].

Conclusion

In conclusions, the chemical etching assisted with light produces efficient photovoltaic (Al/PS/n-Si/Al) devices with large surface area as compared with the laser assisted and stain etchings. The peak of photoconduction of the porous layer related with the peak of the photoluminescence (PL) is under process.

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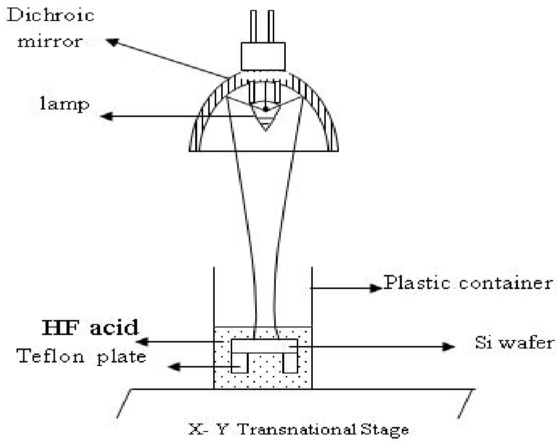

Fig. (1): Experimental setup of photochemical etching system.

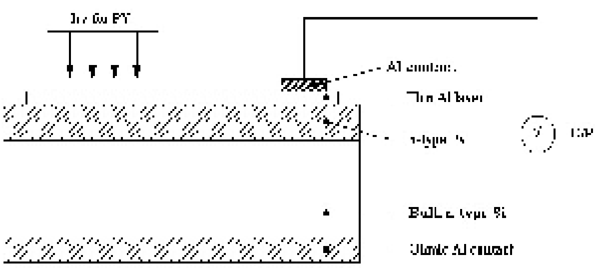

Fig. (2): The used setup in the photovoltaic measurements.

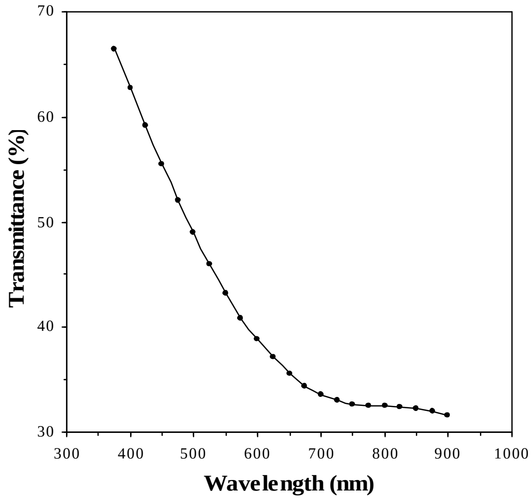

Fig. (3): Spectral transmittance of (Al/c-Si) structure.

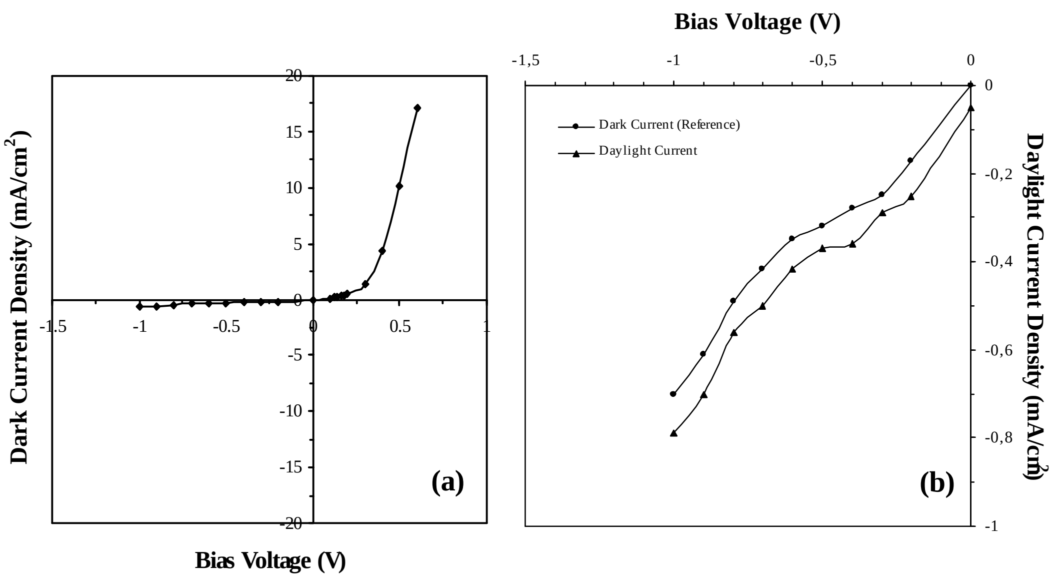

Fig. (4): Dark and illuminated (J-V) characteristics of (Al/c-Si) structure.

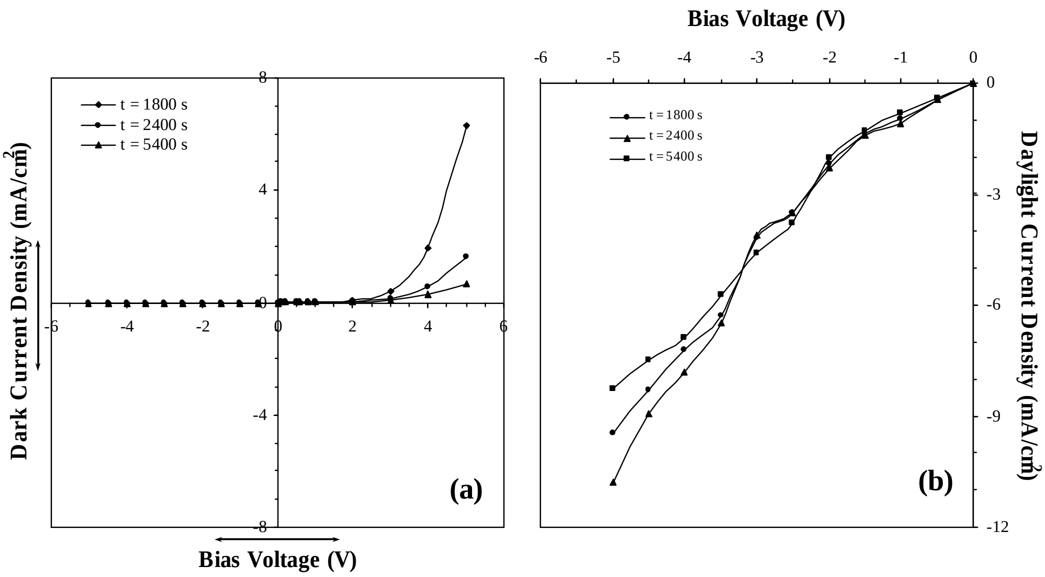

Fig. (5): Dark and illuminated J-V characteristics of (Al/PS/n-Si/Al) structure.

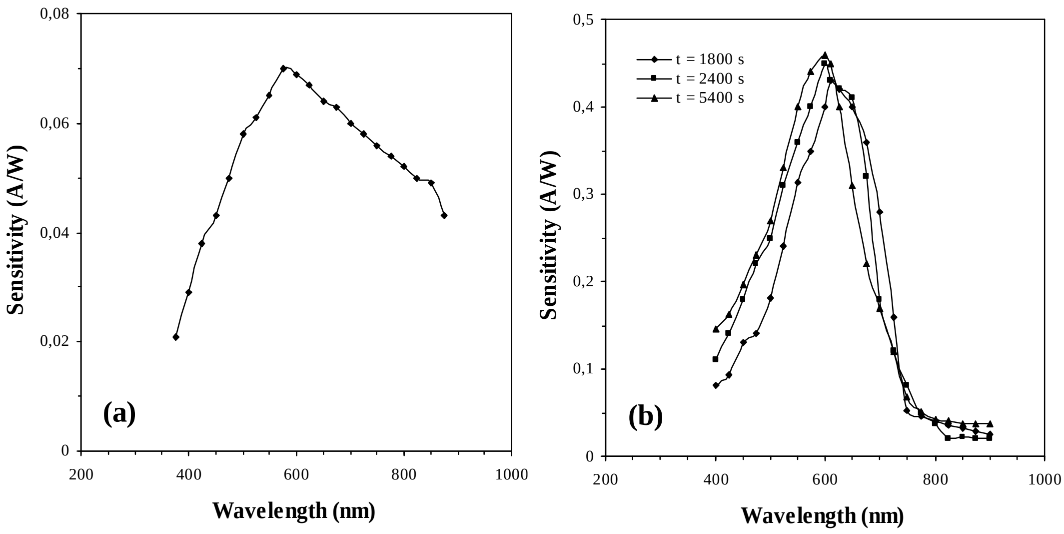

Fig. (6): (a) Spectral sensitivity of the Al/n-Si structure and (b) (Al/PS/n-Si/Al) structure.