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Study of Photovoltaic Properties of Porous Silicon

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Abstract: In this study, Porous Silicon (PSi) samples are prepared by electrochemical etching method of p-type silicon wafers of 100 orientation with different etching current densities (15, 17, 19 and 21 $mAcm^{-2}$) for 15 min etching time and different etching times (15, 17, 19 and 21 min) for 15 $mAcm^{-2}$ etching current density with fixed electrolyte solution (40% HF: 99.98% CH_3OH) (1:1). The photovoltaic properties is described by spectral Responsivity (R_λ) and specific Detectivity ($D_{\lambda *}$). The photovoltaic measurements of PSi samples showed that the increasing in both current densities and etching times caused a blue shift in the peak of the responsivity and the maximum responsivity 0.41 A/W appears at 800 nm despite the fact that this region is far from the cutoff wavelength in order to coincide with mass action law.

Key words: Photovoltaic properties, responsivity, detectivity, measurements, porous silicon, etching method

INTRODUCTION

There is a rising demand of highly efficient compact devices for a broad range of applications in various disciplines. Among the candidate materials, Porous Silicon (PSi) has drawn an increasing research interest, a side from its obvious potentially straight forward integration with the standard Si technologies and its present applications span from biomedicine to biosensing from photonics to photovoltaic devices. Four major causes that have led to the continued widespread attention given to PSi are the following (Cube and Kmura, 1971).

Its efficient visible luminescence gives rise to the opportunity of all-silicon-based optoelectronic devices. Its compatibility with current silicon microelectronic processing makes integrated silicon based optoelectronic devices an opportunity. Its production is low cost and simple. It is a very large surface-to-volume ratio makes the PSi matrix an excellent host of biological and chemical species.

The detectors parameters: The detector parameters that will be studied are responsivity and detectivity.

Spectral Responsivity (R_λ): The responsivity is an important parameter that is usually specified by the manufacturer knowledge of the responsivity allows the user to determine how much detector signal will be available for a specific application. The responsivity is given by:

$$R_\lambda = \frac{I_{Ph}}{P_{in}}(A/W) \quad (1)$$

Where:
I_{ph} : The photo current
P_{in} : The input power

Specific Detectivity ($D_{\lambda *}$): The detectivity is reciprocal noise equivalent power NEP of detectors (Chen *et al*., 1997). Because the NEP of detectors depends on the area of the detector. To provide a figure of merit that depends on the intrinsic properties of the detector, not on how large it happens to be, a term called detectivity which takes the form:

$$D_\lambda = \frac{1}{NEP} = \frac{R_\lambda}{I_n} \quad (2)$$

Where, I_n: is noise current, given by:

$$I_n = \sqrt{2qI_d\Delta f} \quad (3)$$

Where:
Δf : The noise bandwidth
q : Electron charge
I_d : Dark current

Specific detectivity is represented by the symbol D_λ^* which is defined as:

$$D_\lambda^* = (A'' \cdot \Delta f)^{\frac{1}{2}} D_\lambda \quad (4)$$

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$$D_\lambda^* = R_\lambda \frac{(A'' \cdot \Delta f)^{\frac{1}{2}}}{I_n} \quad (5)$$

where, A″ is the area of the detector. Thus, the specific detectivity gives a measure of the intrinsic quality of the detector material itself. When a value of D_λ^* for an optical detector is measured, it is usually measured in a system in which the incident light is modulated or chopped at a frequency (f) which is then amplified with an amplification bandwidth Δf. These quantities must also be specified.

Substrate preparation: The p-type Si samples are cleaned with alcohol with an ultrasonic bath in order to remove the impurities and residuals from their surface. These substrates were cut into (1×1 cm) compatible with the dimension of substrate holder by using a steel cutter tool and etched with HF (40%) for 5 min to remove the native oxide. Thin homogenous PSi layer of various thickness is formed on the frontal surface of the material using Electrochemical Etching method (ECE).

MATERIALS AND METHODS

Preparation of porous silicon layer: In the next section how to prepare porous silicon (Chen and Chen, 2000):

Electrodes deposition: The bottom electrode is coated with thick aluminum layer before the anodization process and measuring the electrical properties, ohmic contacts are needed. It is obtained under vacuum of aluminum wire of high purity (99.99%). The evaporation process is started at a pressure of 10^{-5} Torr (Algun and Arikan, 1999).

The electrochemical etching process: Crystalline wafers of p-type silicon with resistivity of (1-10 Ω.cm, 565 µm) thickness and (100) orientation are used as starting substrates. The substrates are cut into square with areas of (1×1 cm). Electrochemical etching then performed in a mixture (1:1) HF (40%)-Ethanol(99.98%) at room temperature by using a (Au) electrode as in Fig. 1. Sample prepared at different etching current densities and different etching times, the etched area of sample is 1 cm^2. Figure 2 shows the photos of this sample (Naderi and Hashim, 2012).

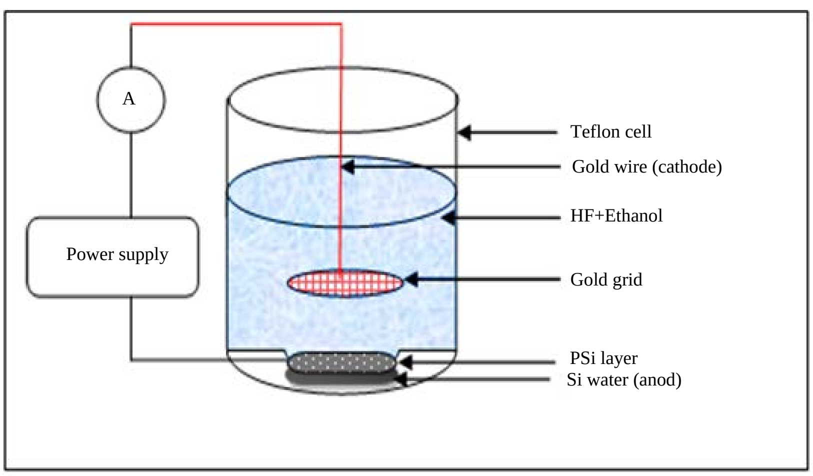

Fig. 1: Schematic diagram of the electrochemical etching set-up

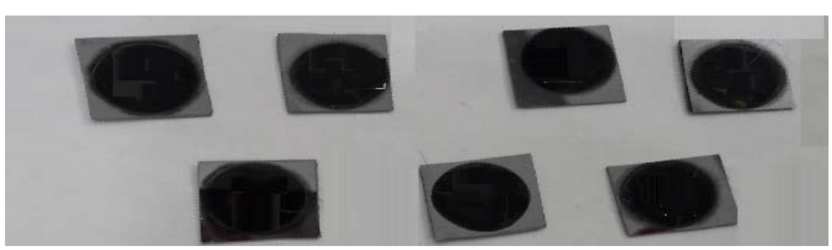

Fig. 2: Photos of prepared samples of PSi

RESULTS AND DISCUSSION

Spectral Responsivity (R_λ): The responsivity as a function of wavelength for both samples prepared with different etching current densities (15, 17, 19 and 21 mAcm^{-2}) for 15 min etching timeand different etching times (15, 17, 19 and 21 min) for 15 mAcm^{-2} etching current density as shows in Fig. 3 and 4.

In both devices, we have two different regions on the curve. The first one (short wavelengths) represents a small increase in the sensitivity and this increase relates to the high absorption coefficient related to the porous layer at wider band gap while the peak and the value of the sensitivity is varied with varying the etching current density and etching times where for the increasing in both current densities and etching times there is a blue shift in the peak ofthe responsivity. The absorption at the wider gap leads to lower absorption depth and fast recombination process compared with any other region inside the material and this is called the probability of carrier concentration which increases with the departure from the surface region which means a rise in the responsivity in this region.

This is followed by the decrease in responsivity value which is related to the large surface recombination processes. In the second region 800 nm, we observe the highest value of the wavelength-dependent responsivity as these wavelengths are absorbed at the active region of the PSi/p-Si junction interface (depletion region) and along a distance equal to the diffusion length of minority carriers. In this region, the generated electron-hole piars move due to the internal electric field besides the negligible recombination process in this region. The maximum responsivity 0.41 A/W appears at 800 nm despite the fact that this region is far from the cutoff wavelength in order to coincide with mass action law. The higher value of resposivity in the case of the increasing etching times is related to the better surface morphology and photocurrent as previously discussed.

Specific Detectivity ($D_{\lambda*}$): Figure 5 and 6 are illustrated the specific Detectivity ($D_{\lambda*}$) of the PSi/p-Si photodetectors were measured at room temperature as a function of incident light wavelengthfor both samples prepared with different etching current densities (15, 17, 19 and 21 mAcm^{-2}) for 15 min etching timeand different etching times (15, 17, 19 and 21 min) for 15 mAcm^{-2} etching current density.

Results of $D_{\lambda*}$ in the maximum valueis about (6.84×10^{12} cm.Hz$^{1/2}$W^{-1}) at 800 nm for PSi/p-Si/Al photodetector prepared at 15 min for 21 mAcm^{-2}. The maximum value of the specific Detectivity ($D_{\lambda*}$) agrees

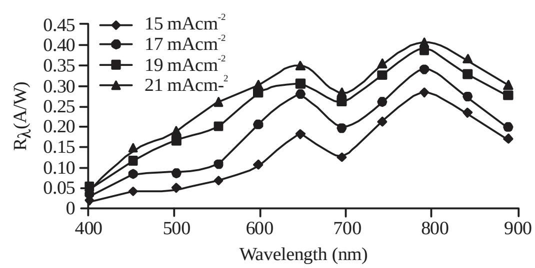

Fig. 3: Responsivity as a function of wavelength of the Al/PSi/p-Si/Al prepared at different etching current densities and 15 min etching time

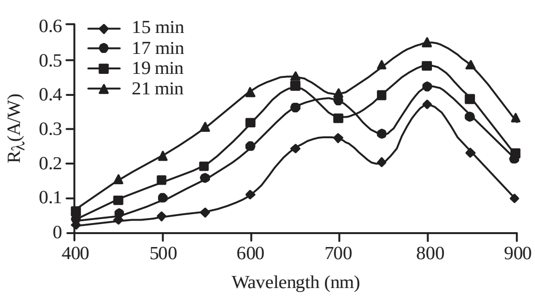

Fig. 4: Responsivity as a function of wavelength of the Al/PSi/p-Si/Al prepared at different etching times and 15 mA/cm^2 etching current density

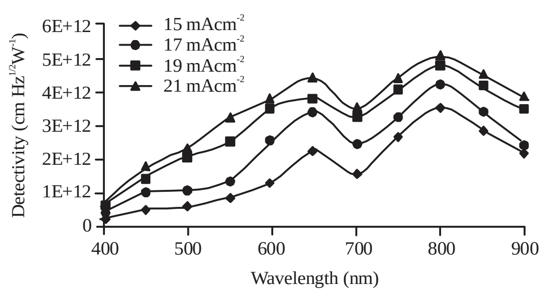

Fig. 5: Specific detectivity plots for the Al/PSi/p-Si/Al prepared at different etching current densities and 15 min etching time

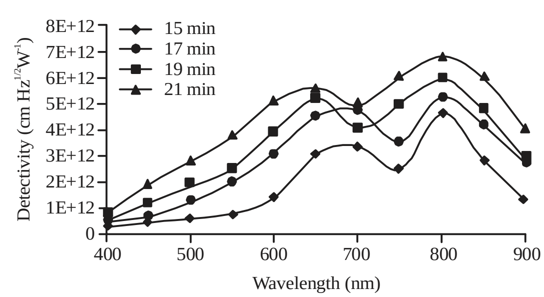

Fig. 6: Specific detectivity plots for of the Al/PSi/p-Si/Al prepared at different etching times and 15 mA/cm^2 etching current density

with the result that the maximum value of spectral Responsivity measurement (R_λ) at wavelength range 800 nm. The high detectivity of the devices indicates the increasing of the responsivity as shown in Fig. 3. The high values of the detectivity indicate that a good photodetector is fabricated (Abdulridha, 2015).

CONCLUSION

The maximum responsivity 0.41 A/W appears at 800 nm despite the fact that this region is far from the cutoff wavelength in order to coincide with mass action law. The maximum value of detectivity is about (6.84×10^{12} cm.$Hz^{1/2}W^{-1}$) at 800 nm for PSi/p-Si/Al photodetector prepared at 15 min for 21 $mAcm^{-2}$. The high detectivity of the devices indicates the increasing of the responsivity.

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