Influence of magnetic field on the characteristics of n-type PSi prepared by photo-electro-chemical etching process

Akram A. Khalaf, Ali H. Attallah, Amer B. Dheyab, Alwan M. Alwan
1Physics Department, College of Education for Pure Sciences, University of Tikrit, Tikrit, Iraq.
2Department of Applied Science, University of Technology, Baghdad, Iraq.
3Directorate of Material Research, Ministry of Science and Technology, Baghdad, Iraq.
Akram_aljbory@yahoo.com

Abstract. The surface uniformity of porous silicon (PSi) morphologies will enhance the overall properties of the PSi layer. In this study, the role of perpendicular magnetic field (MF) on structural, optical, and electrical properties of (PSi) substrates are reported. The (PSi) is prepared with a photo-electrochemical etching process in the front-side illumination pathway with and without a perpendicular magnetic field (MF). The application of (MF) on the path of the electric charge carrier leads to modify the morphologies of PSi surface. The pores shape, sizes, orientation, and homogeneity, and electrical properties will vary with the (MF). The role of (MF) will contribute to an increase in the number of pores and decrease the overlapping process. And also, promotes the orientation of the relatively more defined pores across the Psi surface. The observed noticeable changes in PL spectra, electrical properties, and charge carrier transport mechanisms may be owing to the surface reconstruction process. The influence of (MF) on the characteristics of Au thin layer / PSi /c-Si/Al structures will lead to converting its behavior from the resistor to Schottky-like junction.

Keywords: Magnetic field; surface reconstruction; Porous silicon; photo-electrochemical etching process.

1. Introduction
Different forms of Psi morphologies can be attained based on preparation parameters like current density, hydrofluoric acid (HF) concentration, wafer orientation and resistivity, and the illumination wavelength and intensity of the photonic source [1]. Furthermore, morphological features (i.e., pore dimensions, shape, degree of uniformity, and orientation) [2, 3] also varied with the wafer type (n OR p-type) [4]. In spite of most of the Psi based devices are manufactured on p-type Si wafer, for photonics applications, n-type Si is favorite for the application of large pores dimensions such as gas and biosensors. Alternatively, the regulator of the morphology is essential when distinct structural features are required on the Psi samples (density, forms, width, uniformity, and the thickness of Psi) [5-8]. The role of laser wavelength and power density on the uniformity of (pSi) layer were studied extensively by Alwan et al [9]. They found an increased in porous layer thickness with decreasing the wavelength of the laser. Also the porosity will increased with laser power density without any changing of surface uniformity. Photo-electrochemical etching process has been well recognized for n-type (Psi) fabrication, due to its property in providing the...
required photo-generated valance band holes for silicon dissolution. The effect of applying an external magnetic field (Hall effect within the range of 0 to 20 mT) on Psi in the electrode-assisted lateral electric field [10,11], resulting in modifying the optical properties of Psi. However, the effects of (MF) on the resultant morphology of the sample under the photo-electrochemical etching process have not been explored yet. In this paper, we report the influence of the magnetic field on the characteristics of Au thin layer / Psi / c-Si/Al structures in which the Psi layer was prepared by the photo-electrochemical etching process. The morphological, optical, and electrical properties were studied extensively.

2. EXPERIMENTS

PSi substrates were produced on (100) n-type wafers of mirror like crystalline Si with resistivity of 10 Ω cm by photo-electro-chemical etching process. The Si wafers were etched in electrolyte contained a mixture of aqueous 40 wt. % HF (hydrofluoric acid) and ethanol (99.8%) in a ratio of 1:3, correspondingly. Etching was done via a small cell made of Teflon with and without utilizing a perpendicular MF (B) of about 80 mT on the path of electric charge carrier as shown in Figure (1) of conventional photo-electro-chemical etching process and with a perpendicular MF respectively. The etching conditions involves current density of 40 mA/cm2, etching time of about 50 min and a 150 W light of tungsten halogen lamp was used as front side illumination during etching. After etching, the substrates were rinsed in de ionized water and dried in air and stored in plastic container filled with high purity methanol to prevent the normal oxidation process. To fabricate the sandwich structure, Au thin layer / Psi / c-Si/Al, an Au thin layer of 15 nm and a thick Al electrode were deposited on Psi and Si respectively by vacuum thermal evaporation process. The morphological feature of Psi was examined via field emission- scanning electron microscopy (FE-SEM). Furthermore, the optical properties of the Psi substrates were inspected via the photoluminescence PL spectra through using CW 320 nm, 400 mW He-Cd laser of (PL) system supplied from Horiba Jobin-Yvon T64000 spectrometer. The electrical measurements of the sandwich structure, Au/PS/c-Si/Au, were taken by means of digital multimeter KEITHLEY 4200 semiconductor characteristics system. All the electrical properties were done in dark condition at room temperature.

Figure 1. Photo-electro-chemical etching process without MF, and with perpendicular MF.
3. RESULTS AND DISCUSSION

In order to study the Influence of MF on the characteristics of PSi, two types of samples were fabricated in the presence and absence of MF. Fig. (2 a, b) shows the surface morphology of the prepared PSi layer. For the sample was etched without MF, the surface morphology is characterized with high degree of non-uniformity in porous surface and the pores have random sizes and distribution. While in the presence of MF, the FE-SEM images display that the PSi has a semi regular macro pores like structure. The pores in the presence of MF are in regular circular shape and as they have 23.5nm to 35.6nm diameter. Moreover, the PSi surface was nearly smooth and flat. Also, many of pores was seen on the surface of the PS is distributed in a high regularity with a circular form, as shown in Fig.2b, which is due to the effect of Lorenz force in rotating the pathway of fluorine ions during the etching process.

During the photo-electrochemical etching process, the photo generated positive charge as a result of absorption of the incident photons will assist the Si dissolution process, and this accouri when the fluorine ions interact with the Si substrate and hence leading to generate a depleted region of carriers. The existence of a depletion layer is accountable for photocurrent localization at pore tips. Afterward attainment to a critical thickness (Psi layer thickness), pore walls are empty of holes and henceforth passive to lateral etching, so the PSi can be modified to form pore-like structure with ring like distribution based on the effects of magnetic Lorenz force $F_m$ in rotating the pathway of fluorine ions during the etching process [12].

$$F_m = qv \times B$$

If $v$ the drift velocity of charge carrier $q$ and $B$ are at right angle, then the magnetic force is given by $F_m = qvB$ ........(1)
Figure 2. FE-SEM images of the PSi etched (a) without MF, (b) with perpendicular MF.

PL spectra of PSi substrates produced without and with perpendicular MF using photo-electro-chemical etching process are presented in Figure 3. The PL signal resulting from PSi has been essentially attributed to the effects quantum confinement [13], dominant PL can be attributed to the Si nano crystallites prevailing on the whole PSi surface. From this figure, we can note that the presence of MF leads to a lessening in FWHM, an improvement of the PL peak intensity, with a redshift of the PL peak wavelength. Improvement of the peak PL intensity is mainly related to an increase of the density Si nano crystallites and to the decrease of the surface state within the Psi layer, where these state acts as non-radiative recombination centers. The decreasing of these state will improve the surface quality of the porous layer and enhance the PL spectrum. The resulted redshift in the PL peak emission wavelength from the sample in the presence of MF is probably owing to relatively increase the silicon crystallites formed within the porous layer. The peak value of Si nano-crystallites was varied from 23.5nm to 35.6nm. The dependence of the energy band-gap of Psi substrates $E_{g}^{(eV)}_{PSi}$ on sizes of Si nanocrystallites $L$ is given by the following equation [6]

$$E_g^{(eV)} = E_{g}^{bulk \text{ Si}} + \frac{h^2}{8m_e} \left( \frac{1}{m_e} + \frac{1}{m_{h^*}} \right) + \frac{h^2}{8m_{h^*}} + 1 \times 10^{-15} eV s \text{ Planck's constant, } m_e^* = 0.19m_0, m_{h^*} = 0.16m_0, \text{ and } m_0 = 9.1 \times 10^{-31} \text{ kg.}$$

Figure 3. PL spectra of the PSi etched without MF, and with perpendicular MF.

The current–voltage characteristics (I–V) without MF and with perpendicular MF of Au thin layer / PSi /c-Si/Al structures were measured for applied voltage ranging from 0 V to 5 V ranges as shown in Fig.4. When the sandwich structure, Au thin layer / PSi /c-Si/Al was operated without MF, the behaviour of the (I–V) is seems looks like a resister with a small value of rectification ratio (I_{forward} /I_{reverse}) of about (1) was observed compared with that of the device with perpendicular MF, the value of rectification ratio has a high value of about 4. The difference between the two structures is strongly related with the morphological of the PSi under MF and the current controlled mechanism of conduction in Au thin layer / PSi /c-Si/Al structures. The I–V characteristics of the case of absence of MF, does not exhibited considerably rectification manner (purely ohmic). The semi linear relationship between the current and the voltage can be understood in terms of the growing of the ideality factor(n) because of the presence of the hydrogenated dangling bonds (Si—Hx) bonds which performances as a defect in the porous structure[14,15]. The value of (n) which accounts for any deviation on the measured foreword I–V characteristics from ideal behavior at room temperature was extracted from the semi-log plots which are depicted in Figure (4) is about (36).
and (6) for Psi with out and with presence of applied MF during the fabrication process. For Schottky junction between the porous silicon layer and the metallic thin layer, the relation between the current and the applied voltage is given by equation (3) [16-20]. As showing in the equation, the growing of (n), lead to covert the I–V characteristics to become more linear relation rather than exponential.

\[
I = I_{sat} \left( \frac{qV}{nKT} - 1 \right)
\]  

(3)

Where I is the current, \( I_{sat} \) is the saturation-current density, \( q \) is the electronic charge, \( V \) is the applied voltage, \( n \) is the ideality factor, \( k \) is Boltzmann's constant, and \( T \) is the absolute temperature.

Figure 4. (I-V) characteristics of the PSi etched (a) without MF, (b) with perpendicular MF.

But the case of MF, the Au thin layer / PSi /c-Si/Al structure the Au thin layer / PSi barrier played a significant role in the carrier transport mechanisms and the lower value of (n) confirms this behavior. The SEM images showed that the sample etched for. But the case of MF, the Au thin layer / PSi /c-Si/Al structure the Au thin layer / PSi barrier played a significant role in the carrier transport mechanisms and the lower value of (n) confirms this behavior. The SEM images presented that the PSi sample etched with MF has many uniforms circular pores on the surface (Fig.2b), which leads to lessening the ideality factor of the structure. Furthermore, the intensity of PL peak increases with increasing the density Si nanocrystallites and to the decrease of the dangling bonds (Si—Hx) bonds within the Psi layer, where these bonds act as non-radiative recombination centers, as shown in Fig.3. But When the sample was etched without MF, the surface morphology is characterized with high degree of non-uniformity in porous surface resulting in the large ideality factor of the structure. Also the intensity of PL peak is decrease due to the high density of Si—Hx) bonds. This significant c behavioure in controlling mechanism of the electrical behavior is strongly related to the role of applied magnetic field in the surface reconstruction process of the PSi layer. The further study is essential to exploit the real effects of MF

**Conclusions**

In this work, the effect of external (MF) on the characteristics of (PSi) which prepared with photo-electrochemical etching process was studied. The results show that application of perpendicular (MF) on the path drifted electric charge carrier leads to modify the morphological, optical and electrical properties of Psi. The pores shape, sizes, orientation and homogeneity and hence the PL spectra, electrical properties was improved successfully. The advantages of controlling the drifted charge carrier transport mechanisms
within the etching solution by the (MF) is the main reason behind this improving of the PSi properties. More future work on the effect of MF density and orientation was required to complete a clear vision on its effects.

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