RESEARCH ARTICLE

Optical Properties of Porous Silicon Prepared at Different Etching Times

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ABSTRACT

This study presents porous silicon (PSi) samples preparation by electrochemical etching method of p type silicon wafers of 100 degree orientation with different etching time (15, 17, 19, 21) min and with fixed electrolyte solution (40% HF: 99.98% CH3OH) (1:1). The optical property is described by Photo-Luminescence (PL). The PL measurements of PSi samples show that the energy gap increased after the etching process, and all samples exhibit blue shift with the increasing PL intensity.

Keywords: Porous silicon, Electrochemical etching, Photoluminescence, PL measurements, Energy gap.

1. INTRODUCTION

To compete with the rising demand of compact devices, porous silicon, a Nano crystalline is one among the candidate elements that is being prioritized. It is comprised of voids therein and generally constructed via electrochemical etching mainly due to its high directional permeability nature. The resulting pore size and pattern depend upon the wafer resistance, dopant types, anodization and illuminant factors and electrolyte configuration. [1, 2]. The unique characteristics of porous silicon includes,

- Surface reactivity and functionalization
- Open porousness with larger specific surface area
- Easy fabrication
- Chemical consistency
- Compatibility with other typical silicon technologies

Possibly with all these features that are being applied in optoelectronic, biomedical, photonic and chemical sectors, PSi is extensively utilized in theoretical and practical studies. [3] studied the effects on current density on various properties of PSi. It analyzed the structural features of PSi as a result of electrochemical etching of n-Si by varying current density. The absorbent and photo luminescent study was conducted to perform the optical response of the porous Si layer. It resulted in red shift owing to the reduction of silicon crystallites size and formation of monoxide bond with silicon. It also stated that due to the enhancement of current density, PSi turns from hydrophilic to hydrophobic nature besides its increase in pore diameter and average roughness and decrease in inter pore distance. [4] also attempted to conduct research on etching current density on several attributes of PSi. It evaluated photoelectrochemical preparation of PSi heterostructure. Among the classical thermionic emission and Cheung’s method used for the estimation of certain prime features such as barrier height and ideality factor, the results of Cheung’s method are comparatively better. Likewise many showed interest in analyzing the structural/microstructural, optical, morphological and electrical aspects of porous silicon. But we have contributed in a broad sense to structure it with different etching time.

2. QUANTUM CONFINEMENT EFFECT (QCE) IN Psi

Quantum confinement in Nano materials of indirect gap semiconductors has gone to great
heights because of the variations in the electronic structures of such things that considerably enhance their efficiency of PL [5].

The quantum confinement effect is defined as the increase in energy gap of a semiconductor material as the particle size decreases. In other words, quantum confinement refers to the energy rise occurring due to the movement of a particle which is limited to fewer dimensions by a potential well. Figure A1 shows the simplified representation of the density of states in 3D, 2D, 1D and 0D semiconductors. When the confining dimension is larger than the particle wavelength, the particle remains to be free. PL may result from the recombination of the electron and the hole. The energy loss related with this electron-hole recombination manifests itself through shorter wavelength light emission (higher energy), also known as a “blue shift”. In essence, as the nanocrystal’s size decreases, the absorption and emission wavelengths decrease and the light emitted transforms to a bluer regime. This behaviour is the reason why quantum dots are being explored for many different applications [6].

Since the charge carrier is restricted in all the 3-dimensions in a quantum dot, its exciton has no degree of freedom to move, and so the electron shows a discrete atomic based spectrum resulting in a discrete absorption spectrum of quantum dots that determines the energy gap of semiconductors. This is different for the case of absorption spectrum of bulk semiconductors. [7].

3. SUBSTRATE AND PSi LAYER PREPARATION

The p-Si samples are purified using alcohol and ultrasonic cleaning and they are cut into a size of (1x1)cm, which are then etched with the help of hydrofluoric acid such that the native oxides are removed. Further, thin homogeneous porous silicon layer of variable widths is developed electrochemically.

A dense Al layer coating is provided to the lower electrode prior to the anodization method and ohmic contacts are enabled to measure the electrical attributes. It is obtained under vacuum of pure Al wire. The evaporation process is progressed at a pressure of $10^{-5}$ Torr.

3.1. Electrochemical etching

p-type Si with resistivity 1-10Ωcm, 565µm width and 100 degree orientation are used as starting substrates and are cut into squares with areas of (1cm×1cm). Electrochemically, etching was performed using (1:1) HF (40%) and C₂H₆O (99.98%) at room temperature by means of an Au electrode as in figure 1. Samples are prepared at different etching time (15, 17, 19, 21) min, where the etched area of sample is 1cm² and the prepared samples are shown in figure 2.

4. RESULTS AND DISCUSSIONS

Characteristics of visible Photoluminescence (PL) in porous silicon layers (PSi) have given an important impulse to material studies due to the vast possibilities for technological applications. The studies of PSi have aimed at greater stability in PL over long periods of time. Initial research into PSi is directed mainly at establishing the origin of the radiative recombination mechanisms. Photoluminescence spectrum of the PSi/p-si heterojunction developed at etching time (15, 17, 19, 21)min and etching current density 15 mA/cm² as shown in figure 3, indicates an emission peak at (743-753)nm for PSi.
Furthermore, increase of etching time increases the permeability and hence large porous structures are generated, thus leading to brighter photoluminescence at smaller wavelengths. PL is marked in the spectral band (1.636-1.669) eV, where it attributes to the luminescence from the confined silicon structure [8, 9].

Also figure 3 depicts that the PL peak position of PSi is blue-shifted as a function of the etching time. Based on the quantum confinement method, the peak shift is due to an increase in the energy gap (Eg) within the porous structure [10, 11]. The result also suggests that the gap energy increased from (1.636 to 1.669) eV due to the enhancement of the etching time from (15 to 21) min.

Figure 3. PL spectra for p-PSi prepared with different etching times at 15mA/cm² etching current density

Figure 4 illustrates Eg as a variation function of etching time. Increase in the etching time is attributed to the reduction of the Si to Nano size, which favours charge carrier quantum confinement.

The probability of recombination of e and h is higher in very small structures (quantum confinement effects), leading to higher emissions. High PL intensity is the result of the conversion of the material energy gap conduction from indirect to quasidirect [12, 13]. The quantum dimension of the structure in the sample favours PL shifting towards shorter wavelengths. Other researchers have also found a blue shift of PL peak when etching time gets increased.

Table 1 describes the emission peak of p-porous Si prepared at different etching times and constant etching current density at a fixed excitation wavelength of 380nm.

<table>
<thead>
<tr>
<th>Etching time (min)</th>
<th>Etching current density (mA/cm²)</th>
<th>Emission peak (nm)</th>
<th>Energy gap (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>15</td>
<td>758</td>
<td>1.636</td>
</tr>
<tr>
<td>17</td>
<td>15</td>
<td>752</td>
<td>1.648</td>
</tr>
<tr>
<td>19</td>
<td>15</td>
<td>745.5</td>
<td>1.658</td>
</tr>
<tr>
<td>21</td>
<td>15</td>
<td>743</td>
<td>1.669</td>
</tr>
</tbody>
</table>

Table 1. Emission peaks of PSi/p-Si and energy gap

5. CONCLUSION

Increasing etching time from 15 to 21 min results in change of PL peak position from 1.636 eV to 1.777 eV for porous silicon substrate.

REFERENCES


APPENDIX

Figure A1.(a, b, c and d) Simplified representation of the Density of states in 3D, 2D, 1D and 0D semiconductors [6]