CHAPTER - 5

A Device with Photo Luminescent Porous Silicon

5.1. Introduction..............................................................................116
5.2. Applications .............................................................................117
5.3 Background ..........................................................................118
  5.3.1 Transport properties..........................................................120
  5.3.2 Enhancement of photoluminescence................................120
5.4 Synthesis and Characterization of PS.....................................124
  5.4.1 Preparation of Porous Silicon............................................124
  5.4.2 AFM and SEM...................................................................125
  5.4.3 Cyclic Voltametry ..............................................................126
  5.4.4 Mass (etched) measurements..........................................127
  5.4.5 Photoluminescence measurement....................................128
    5.4.5.1 Experimental setup .....................................................128
    5.4.5.2 Room Temperature Photoluminescence (RTP)........129
5.5 Characterization of Gold coated PS as a Solar cell ............130
5.6 Conclusion...............................................................................132
5.7 References..............................................................................134
Abstract

The recent discovery of room-temperature photoluminescence (PL) of porous silicon (PS) has aroused a great interest for the development of silicon based optoelectronic devices. Hence, in continuation of the radiation damage study of H\textsuperscript{+} ion implanted n-GaAs, chemically etched Si crystals is investigated for possible device fabrication.

The feasibility of Porous Si as a photoluminescent device is studied in line the present studies on semiconducting crystals with ion doping. PS behaves as a direct band gap semiconductor (similar to GaAs and GaP) with a large quantum efficiency. In the present study in PS, photo-luminescence (PL) is observed at room temperature. Similarly, the excitation and emission PL spectra are also observed. Finally, a device by coating gold over the porous layer of the PS material has been successfully fabricated and its electrical characteristics are studied.
5.1. Introduction

In the last few chapters, the lattice damages and defects were studied in detail both by experiment and theory. All those were aimed at the fabrication of optoelectronic devices. But, it is known that Si is a very important elemental semiconductor, which has been in use for years. To get more efficient devices, now silicon with artificially induced damages is being investigated extensively.

Porous Silicon (PS), grown on a silicon substrate by anodic etching in hydrofluoric acid is currently of great interest due to its potential applications. After the discovery of Porous Silicon in 1956 [1], attempts were made to utilize porous silicon in the applications of microelectronics devices [2]. The recent discovery of the room temperature photoluminescence (PL) in porous silicon (PS) by Canham [3] has aroused a great interest [4-6] for the development of silicon based optoelectronic devices. The origin of this new phenomenon is attributed to the quantum confinement in nano meter size silicon particles. The discovery of PL was soon followed by the observation of electroluminescence (EL) of PS also in the visible range and at room temperature either in liquid phase [7] or in solid phase [8,9].

The structure of PS is now understood as a crystalline porous material [10]. In 1984 Barla et al [11,12] reported an interesting result that a PS layer behaves as a single crystal and gives diffraction peaks nearly as narrow as
those of the perfect silicon substrate. They also found a small expansion of the lattice parameter of the porous layer of the order of $10^{-4}$ Å in the direction perpendicular to the sample surface, in $p$-type samples. Young et al [13] observed a larger lattice expansion of the order of $10^{-3}$ Å, for $n$-type samples.

It is known that silicon crystallizes in the cubic diamond lattice with a lattice constant 5.431 Å a and nearest neighbour separation 2.35 Å. The failure of silicon in opto electronic field has been due to the presence of indirect band gap. The other semiconductors like GaAs, InP, etc, show good recombination of electron-hole pairs leading to light emission in visible spectrum, whereas silicon does not have such proper recombination energy, shifting the emission to the infrared part of the spectrum.

### 5.2. Applications

PS is now considered as a potential material, which could be used as a biomaterial [14] or for gas adsorption [15]. Optical filter is another recently emerged domain of application [16]. High quality Fabry-Perot filters with PS material have been fabricated [17]. Such systems clearly exhibit a strong enhancement of the emitted light, since the active PS layer behaves as a medium for resonant wave propagation, including a modification of photon density of states. Moreover by adjusting the etching parameters, the tuning of the operating central photon wavelength is possible [18]. Applications of PS
systems have been recently demonstrated for colour sensitive photo detectors [19].

Takahashi et al [20] have demonstrated that the refractive index-controllable nature of luminescent PS is directly applicable to the development of a three dimensionally buried optical wave guide. The PS wave guide is fabricated on a p-type silicon wafer by monolithic processes such as photolithography, ion implantation, anodization and thermal oxidation. An induced high contrast of refractive indices leads to efficient confinement and propagation of visible light. The PS wave guide is potentially useful as a component of silicon based photonic integration.

5.3 Background

The porous silicon has attracted the scientific community only after the observation of photo luminescence (PL) by Canham [3]. There is a strong belief that the emission of photo luminescence (PL) in PS in the red and blue region of the electromagnetic spectrum is due to the quantum confinement effect, which causes a band gap widening resulting in the absorption of photon having energy higher than 2eV. The origin of infrared PL [21] is considered to be the effect of nanocrystallinity and quantum wire transport.

A blue shift of the PL peak with reduction of Si particle size caused by post treatments such as oxidation or dissolution is reported to be an evidence for the quantum size effect in PS [22]
The origin of photoluminescence is still a open question. Two possible models of PL are (i) the luminescence is ascribed to “bulk” recombination in the nano structures that constitute porous silicon [23] and (ii) the luminescence takes place at the surface of the nano structures. [24]

The importance of surface arises as the surface area of PS is typically 200-600 m$^2$/cm$^2$ of sample [25]. Narasimhan et al [26] have experimentally shown that the surface recombination dominates the luminescence. They have also shown that there is more than one mechanism which determines the luminescence and the mechanism for PL at room-temperature may not be the same as that at low temperature.

Fredriksen et al [27] have shown that the electrical band gap (1.08±0.01) eV, in porous silicon is of a molecular nature and cannot be related to quantum confinement properties of nano crystals of elemental Silicon. According to Banerjee et al [28], it is not possible to explain the PL in PS on the basis of quantum confinement effect alone.

In finite crystals, the excited electron and hole created will have no free space to move as in the case of bulk material. Due to this confinement effect, the probability of electron-hole recombination increases. This increases the intensity of light emission and the quantum confinement effect also results in widening of band gap which leads to light emission in the visible range.
5.3.1 Transport properties

Though quantum confinement may explain the luminescence properties of PS, it is still not understood whether the same is applicable to the transport properties. PS is an insulator and has a typical resistivity at room temperature, that is five orders of magnitude higher than that of intrinsic Silicon [29]. The high resistivity of PS can be attributed to various effects; for example, if the PS material is assumed to be a semiconductor then quantum confinement would result in a wider band gap and reduce the thermal generation of intrinsic free carriers. The high resistivity observed for PS would require the depletion of carriers supplied by impurity doping. Depletion of carriers is known to occur during the preparation of the PS material. This is either because the dopant energies are increased or because of the creation of deep surface levels.

Mathur et al [30] have shown that the basic transport mechanism in PS at temperature below 150 K is due to “variable range hopping” in the localised states near the Fermi level and at temperatures above 150 K the transport is due to thermally activated tunneling of carriers in the band edges. The possibility of free electron conduction in the temperature range 100-300 K is ruled out.

5.3.2 Enhancement of photoluminescence

Sen et al [31] have doped porous Si layers with B and/or P using the spin-on doping technique. Under certain conditions, pore filling by the dopant solution
was measured to be near 90-95% leading to a homogeneous coverage of the porous skeleton. Near two orders of magnitude decrease in diode resistance was achievable following rapid thermal activation in a N₂ atmosphere of B only or B+P double-doped porous Si. Photoluminescence intensities observed in B+P double-doped porous layers were significant. Relative to as prepared samples, the PL intensities of double doped samples were weaker for porous silicon on n-type and stronger for porous Si formed on p-type Si. In both cases, the PL magnitudes after double doping were comparable.

The aging phenomena of porous silicon, over a 192-day time span have been studied by Fakuda et al. [32]. As prepared PS exhibits red PL peaking near 650 nm. The PL intensity increases with time to some equilibrium value. The PL peak shows no blue shift during aging. Infra red analysis reveals that Si-O bond content in PS increases with time and correlates to the PL intensity. The PL lifetime increases with aging and its value ranges from 3 to 37 μs. Transmission electron microscopic (TEM) observation indicates the presence of Si nano particles and amorphous substances in the PS layer. These results suggest that the PL from aged PS might be attributed to the combined effects of quantum confinement in Si nano particles and some defects in Si oxide covering the nano particles.

Xiao et al. [33] have reported a treatment that enhances and stabilizes the photoluminescence (PL) from porous Si films. Films prepared by
anodization in 50 % HF/ethanol solution were annealed at 450°C in vacuum, exposed to air and then exposed to remote hydrogen plasma. Infrared absorption spectroscopy revealed that the concentration of oxygen, rather than hydrogen, was increased by the processing steps and that silicon dihydride species had been eliminated from the surface. The PL from a treated film was initially around 30 times more intense than from the as-etched films. The PL intensity increased with illumination time in air until a steady state intensity was reached.

Brandt et al [34] recently proposed that Si-O-H compounds derived from siloxene cover the surfaces of PS are responsible for the PL. After Xiao et al's [33] treatment, laser irradiation in air, produced a further increase in the PL intensity. The improved PL emission was stable even after long term exposure of the PS to air, in sharp contrast to the behaviour of as etched or HF treated PS. The incorporation of both oxygen and hydrogen in forming H-Si-O complexes can result in surface terminations that enable PS to emit intense and stable visible PL.

Room temperature luminescence observed in PS has been attributed either to direct radiative recombination in nanometer size silicon in the PS network or to chemical complexes in silicon, hydrogen and/or oxygen. A blue photoluminescence band, centered at 2.6 eV was observed in thermally and
chemically oxidized light emitting porous Si layers by Tsybeskov et al [35]. They suggest an oxygen related origin for the blue PL band.

Petrova-Koch et al [36] have improved the stability of porous Si (PS) prepared by electrochemical etching. They made use of rapid thermal oxidation (RTO). During RTO processing, the hydride coverage of the internal surface of the pores is replaced by a high quality oxide while retaining nm size Si grains. With increasing process temperature $T_{ox}$ the luminescence is first quenched. It is recovered with comparable intensity for $T_{ox} > 700^\circ C$.

But Banerjee et al [28] have reported that it is very difficult to establish a direct correlation between the visible luminescence in PS and any particular chemical specie(s) such as silicon hydride(s), oxide or siloxene. The shifts in the PL emission energy together with the enhancement in the PL intensity as a result of passive HF etching as well as chemical oxidation and subsequent removal of oxide are not very consistent with a simple “quantum confinement model” for the origin of luminescence. The chemical oxidation and oxide removal experiments could not establish a direct correlation between the luminescence in PS to oxygen related compounds such as siloxene. The enhancement in the PL intensity (0.7 – 0.75 $\mu m$ range) by hydrogen termination of PS surface is still striking. However the oxide removal experiments and the passive etching experiments indicate that a better hydrogen passivation may not be entirely responsible for the enhancement in
the PL intensity because an equivalent change in hydride absorption spectra was not observed.

As many experiments on PS are still in progress, not only to understand the mechanism behind the enhanced PL but also to improve the fabrication of newer devices, a study on PS particularly towards the fabrication of a device, is undertaken.

5.4 Synthesis and Characterization of PS

Since photovoltaic measurements on gold coated PS is planned, to start with porous Si is first synthesized. Also no such reports are available in literature except that of Martin et al [37], employing gold oxide.

5.4.1 Preparation of Porous Silicon

PS is formed by electrochemical or anodic dissolution of crystalline silicon in hydrofluoric acid solution. The electrolyte is prepared by mixing HF, H₂O and ethanol in 1:1:2 ratio. Normally silicon does not dissolve. If a current flows through the interface of the crystal and the solution, electrochemical etching occurs. This dissolution is possible only when the current delivers holes in the interface. This is the case if the silicon wafer is the anode of the electrochemical process. For this reason, the etching of porous silicon, is called anodization.
During the anodization of the silicon substrate, the electrochemical dissolution of the silicon atoms occurs in the vicinity of the interface between the already formed PS layer and the substrate (i.e., at the pore tips). Therefore the thickness of the porous layer is controlled by the etching time. The relevant parameters for the pore formation are the current density, the doping type and level of the substrate, the electrolyte concentration and the illumination [38]. The voltage variations across the electrodes are noted down during the anodization or the etching process when fixed current densities like 10, 20, 30, 40 or 50 mA/cm\(^2\), are passed through the electrodes. The chronopotentiogram recorded for the polished sample is shown in Fig. 5.1.

During anodization, hydrogen evolution takes place and this has been associated with inhomogenities. In the region of reaction, it is possible that the HF concentration varies, as HF may not be able to reach into the pores. To get around this difficulty, Hou et al [38] proposed that one could use pulsed etching rather than continuous etching. This will allow HF to diffuse into the newly etched areas. Hou et al [39] and Grover et al [40] have shown that the luminescence efficiency increases in samples made by pulse etching.

### 5.4.2 AFM and SEM

The Atomic Force Micrographs are recorded for the three samples of the porous silicon, prepared in the present study, (10mA/30min, 20mA/30min and 30mA/30min), by Siemens Atomic Force Microscope. The different levels of
Fig. 5.1 Chronopotentiograms for the formation of PS under different anodic current densities.
porosity could be clearly seen in the pictures. (Figs.5.2). In the first sample (10mA/30min) though the maximum height (depth) of the pores formed is found to be 2.57 \( \mu m \), the number of pores with this height is very less, as can be seen on the upper edge of the picture. Also a small number of pores are formed with a height (depth) of nearly 1.28 \( \mu m \). In the second sample (20mA/30min) the maximum height (depth) of the pores formed is found to be 0.47 \( \mu m \). But a number of such pores are found with this height and the number of pores formed with a height (depth) of around 1.28 \( \mu m \) is also very large, when compared to the previous case. As the number pores formed is large, the area offered by the sample to the incident light will also be large. In the third sample (30mA/30min) the maximum height (depth) of the pores formed is found to be 0.70 \( \mu m \). The number of such pores is larger than the number of maximum height pores in the first sample. The number of pores, formed with a height (depth) of around 0.35 \( \mu m \) is found to be greater than the first sample, but less than the second sample.

The Scanning Electron Micrographs of the above three samples are also recorded and given in Fig 5.3. These pictures further confirm the observations of AFM.

### 5.4.3 Cyclic Voltametry

The sample is kept in the electrolyte of HF mixture as given in the previous section and connected to the anode of the galvanostat/potentiostat whereas a
Fig. 5.2 Atomic Force Micrographs of PS samples.
Row 1 — (10 mA/cm$^2$ — 30 min)
Row 2 — (20 mA/cm$^2$ — 30 min)
Row 3 — (30 mA/cm$^2$ — 30 min)
Fig. 5.3 Scanning Electron Micrograph of PS samples.  
(a) 10mA/cm² – 30 min  
(b) 20mA/cm² – 30 min  
(c) 30mA/cm² – 30 min
platinum plate is connected to the cathode. The voltage across the electrodes is allowed to vary with different sweep rates of 50 mV/sec, 100 mV/sec, 150 mV/sec, 200 mV/sec and 250 mV/sec both in the forward and backward directions. The cyclic voltamogram for all the cases are recorded and shown in Fig. 5.4(a).

As the potential is applied between the electrodes, some of the Si atoms are oxidized and dissolved in the medium (HF). During the reverse sweep, the dissolved Si ions are redeposited on the Si electrode. This process results in some irregularities on the surface of the Si, as these will not redeposit on the same place as the original and thereby creating pores. This is also evident from the AFM and SEM pictures of the PS crystals. This process can be observed in cyclic voltametry at the slow scan rates of 50 and 100 mV/s. During the slow scans only a few Si atoms may be removed from the surface and redeposited during the forward and reverse sweeps respectively. For clarity the Fig. 5.4(a) is split into two, as Fig. 5.4(b) – for slow sweep rates and Fig. 5.4(c) – for faster sweep rates. At the faster sweep rates the reverse path almost retraces the forward path.

5.4.4 Mass (etched) measurements

During the etching process the material in the Si electrode is corroded and hence the mass of the electrode would be continuously decreasing. The decrease in mass is measured using a sensitive balance and is shown in
Fig. 5.4(a)  Cyclic voltamogram at sweeping rates

(a)  50  mV/s  
(b)  100  mV/s  
(c)  150  mV/s  
(d)  200  mV/s  
(e)  250  mV/s
Fig. 5.4(b) Cyclic voltamogram at sweeping rates
(a) 50 mV/s
(b) 100 mV/s
Fig. 5.4(c) Cyclic voltamogram at sweeping rates
   (a) 150 mV/s
   (b) 200 mV/s
   (c) 250 mV/s
Fig. 5.5, for both the polished and the unpolished samples. It is found from Fig. 5.5, that the polished sample is corroded faster, indicating that the pores formation will be more and deeper.

5.4.5 Photoluminescence measurement

With the preliminary measurements on the PS, photoluminescence excitation and photoluminescence emission spectra for the solid porous silicon samples, electrochemically anodized at different etching time, are recorded using a spectrofluorophotometer, [Shimadzu RF-5000].

5.4.5.1 Experimental setup

The schematic diagram of the spectrofluorophotometer is shown in Fig. 5.6. It essentially consists of a source of UV radiation (Xenon lamp), an excitation monochromator to choose the wavelength of the radiation to be used to excite the sample, a sample compartment, a fluorescence emission monochromator to observe the radiation emitted at a particular wavelength, a photo detector to translate the emitted radiation into electrical signal. In addition slits are present on either side of the monochromator to collimate and limit the range of wavelengths of the exciting and emitted light. A cut off filter is placed between the samples and emission monochromator, which transmits all radiation above a specified wavelength and absorb completely at lower wavelengths to filter scattered beam of excitation light.
Fig. 5.5 Decrease in mass Vs time during the etching process.
(a) Polished sample (Si)
(b) Unpolished sample (Si)
Fig. 5.6 Schematic diagram of spectrofluorophotometer.
5.4.5.2 Room Temperature Photoluminescence (RTP)

The unetched silicon crystal did not show any appreciable photoluminescence. The recorded spectra of the sample (20 mA/cm\(^2\) – 30 min) for different durations are shown in Figs.5.7(a)&(b). Both the excitation peaks and emission peaks are clearly seen in the figures. The observed excitation peaks are mostly centered at about 395 nm and 430 nm. The emission peaks are found to be located around 605 and 650 nm.

The RTP data for the porous silicon surface formed at current densities 10, 20, 30 mA/cm\(^2\) are presented in Tables 5.1, 5.2 & 5.3 respectively. It is observed that the emission peaks changes from a minimum of 595 nm to a maximum of 655 nm.

From the Table 5.1, for current density 10 mA/cm\(^2\), it is observed that the one emission peak is almost fixed at 605 nm and another one is centered around 645 nm. This is observed when the developing time is increased from 2 to 60 minutes. The peak intensities vary randomly and appreciable peaks are seen at the 10 minutes etched sample. However, an overall increased intensity is observed for the duration of 10 minutes.

The PL results for the PS formed at 20 mA/cm\(^2\) (Table 5.2) show that intensity of the emission peaks increases first and then decreases as we go from 2 minutes to 60 minutes. It is found that the overall maximum peak intensity in the samples developed for 30 minutes.
Fig. 5.7 (a) Excitation PL spectra for the PS sample (20 mA/cm$^2$ – 30 min)
Fig. 5.7 (b) Emission PL spectra for the PS sample (20 mA/cm$^2$ – 30 min)
Table 5.1

The Photoluminescence peaks for Porous Silicon at current density 10 mA/cm².

<table>
<thead>
<tr>
<th>Anodization Time (min.)</th>
<th>Excitation Spectra</th>
<th>Emission Spectra</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak position (nm)</td>
<td>Intensity</td>
</tr>
<tr>
<td></td>
<td>430</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>395</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>408</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>396</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>430</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>385</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>405</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>430</td>
<td>3.3</td>
</tr>
</tbody>
</table>
Table 5.2

The Photoluminescence peaks for Porous Silicon at current density 20 mA/cm².

<table>
<thead>
<tr>
<th>Anodization Time (min.)</th>
<th>Excitation Spectra</th>
<th>Emission Spectra</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak Position (nm)</td>
<td>Intensity (arb.unit)</td>
</tr>
<tr>
<td>2</td>
<td>390</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>399</td>
<td>3.15</td>
</tr>
<tr>
<td></td>
<td>428</td>
<td>3.6</td>
</tr>
<tr>
<td>10</td>
<td>399</td>
<td>4.25</td>
</tr>
<tr>
<td></td>
<td>428</td>
<td>3.4</td>
</tr>
<tr>
<td>30</td>
<td>420</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>533</td>
<td>6.45</td>
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<td>60</td>
<td>396</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>428</td>
<td>3.1</td>
</tr>
</tbody>
</table>
Table 5.3

The Photoluminescence peaks for Porous Silicon at current density 30 mA/cm².

<table>
<thead>
<tr>
<th>Anodization Time (min.)</th>
<th>Excitation Spectra</th>
<th>Emission Spectra</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak Position (nm)</td>
<td>Intensity</td>
</tr>
<tr>
<td>2</td>
<td>395</td>
<td>4.25</td>
</tr>
<tr>
<td></td>
<td>430</td>
<td>3.85</td>
</tr>
<tr>
<td>10</td>
<td>394</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>433</td>
<td>1.7</td>
</tr>
<tr>
<td>30</td>
<td>402</td>
<td>2.05</td>
</tr>
<tr>
<td></td>
<td>430</td>
<td>2.3</td>
</tr>
<tr>
<td>60</td>
<td>399</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>425</td>
<td>4.3</td>
</tr>
</tbody>
</table>
In the case of PS formed at 30 mA/cm\(^2\), (Table 5.3) the emission peaks are centered around 600 nm and 645 nm. It is interesting to note that the samples developed for 2 minutes and 60 minutes show similar response and they give maximum peak intensity, while the peak intensities of the other two cases, 10 and 30 minutes, are lesser.

### 5.5 Characterization of Gold coated PS as a Solar cell

The porous silicon samples were then coated with a very thin film of gold, in order to form a device for solar cell. Now the characteristics of the gold coated porous silicon functioning as a solar cell are determined following the usual procedure.

For testing and characterising the solar cell, the following measurements were performed [41].

1. Open circuit voltage \(V_{oc}\)
2. Short circuit current \(I_{sc}\)
3. Fill factor (F.F)
4. Maximum power output \(P_{max}\)
5. Efficiency \(\eta\)
6. Series \(R_s\) and shunt resistance \(R_{sh}\)
7. Diode ideality factor \(n\)

The I-V curves of the different gold coated porous silicon samples are shown in Fig.5.8. The current and voltage of the cells were measured under
Fig. 5.8 V-I Characteristics of the gold coated PS solar cell.
(a) PS sample – 20 mA/cm$^2$ – 30 min (with light)
(b) PS sample – 10 mA/cm$^2$ – 30 min (with light)
(c) Both sample (without light)
standard test conditions (Temperature 300 K and light intensity 50 mW/cm²) and also in dark (no extra light) conditions. i.e., photovoltaic measurements are done. The current is measured using the high impedance ORIEL Multifunction optical power meter and the voltage by a digital voltmeter. From these curves all the parameters (1 to 7) are all calculated, as follows.

The open circuit voltage \( V_{oc} \) and the short circuit current \( I_{sc} \) are noted down.

The series resistance \( R_s \),

\[
R_s = \left. \frac{dV}{dI} \right|_{I=0}
\]  

(5.1)

The shunt resistance \( R_{sh} \)

\[
R_{sh} = \left. \frac{dV}{dI} \right|_{V=0}
\]  

(5.2)

\( I_{max} \) and \( V_{max} \) are fixed from the curves for which the product of \( I_{max} \) and \( V_{max} \) is maximum, which gives the maximum power.

Maximum power \( = I_{max} \times V_{max} \)  

(5.3)

The Fill Factor (F.F)

Fill factor \( = \frac{\text{Maximum power}}{\text{Open Circuit Voltage} \times \text{Short circuit current}} \)  

(5.4)

The efficiency (\( \eta \))

Efficiency \( = \frac{\text{Maximum output power (watt)}}{\text{Area(cm}^2\text{)} \times \text{Incident irradiance(watt/cm}^2\text{)}} \)  

(5.5)
The diode ideality factor ($n$)

$$n = \frac{q}{k_B T} \times \frac{V_{oc}}{\ln 2}$$

(5.6)

All these parameters for the designed cell are worked out and tabulated in Table 5.4.

The shunt resistance is found to have a lower order in the second sample. A good quality solar cell must have a value for shunt resistance greater than 20 kΩ [41]. The series resistance also has to be lower than the observed values for a higher efficient device. The efficiency of the devices is also of a very low order and the diode ideality factor is found to be very high. The highest efficiency is achieved in the 20mA/30min sample and the same sample gave the highest PL intensity also.

5.6 Conclusion

In brief, the photovoltaic effect is clearly demonstrated in Table 5.4 i.e., when there is no light, current is only 16 μA and when the light falls on the sample, the current is enhanced to 100 μA. The porous silicon is found to be a very useful optoelectronic material. The porous silicon is prepared in the laboratory and then coated with a thin film of gold to fabricate a solar cell. The photoluminescence and other studies give a clear idea that this porous silicon can be used for the fabrication of optoelectronic devices. But there are
Table 5.4
Characteristic parameters of the gold coated PS solar cell designed (Photovoltaic measurements).

<table>
<thead>
<tr>
<th>Sample</th>
<th>( I_{sc} ) ( \mu A )</th>
<th>( V_{oc} ) ( mV )</th>
<th>( R_s ) ( k\Omega )</th>
<th>( R_{sh} ) ( k\Omega )</th>
<th>( I_{max} ) ( \mu A )</th>
<th>( V_{max} ) ( mV )</th>
<th>F.F</th>
<th>( \eta % )</th>
<th>( n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>20mA/30min. (with light)</td>
<td>100</td>
<td>180</td>
<td>0.083</td>
<td>67.5</td>
<td>82</td>
<td>150</td>
<td>0.683</td>
<td>0.10</td>
<td>10</td>
</tr>
<tr>
<td>10mA/30min. (with light)</td>
<td>60</td>
<td>180</td>
<td>0.625</td>
<td>15.0</td>
<td>42</td>
<td>135</td>
<td>0.525</td>
<td>0.05</td>
<td>10</td>
</tr>
<tr>
<td>Both Samples (Dark)</td>
<td>16</td>
<td>180</td>
<td>6.430</td>
<td>13.3</td>
<td>10</td>
<td>90</td>
<td>0.313</td>
<td>0.01</td>
<td>10</td>
</tr>
</tbody>
</table>
some difficulties in fabricating a high efficient device under laboratory conditions. The gold coating was given after a long interval and this has to be avoided to reduce the oxide coating over the pores. The carrier collections are to be made in a better and efficient way.

Eventhough no reports (data) are available in literature for gold coated PS, the some of the present measurements are compared with that of PS reported by Kore et al [42], as given in Table 5.5.

A clear enhancement of the photovoltaics is observed from Table 5.5, and hence the gold coated PS can be visualized as a very good optoelectronic material, particularly for the design of the solar cell. Thus, the present investigations on PS will be potentially very useful in fabricating a high quality solar cell.

Martin et al [37] in 1998, have reported that deposition onto the porous silicon, a thin film of aluminium and gold semiconducting films (like ITO gold chock oxide) would improve the ratio between the dark current and the current under illumination by 10 %, compared to the others. This not only increases the collection efficiency of the photogenerated current, but also protects from material degradation.

The present gold coated PS, because of the enhanced fill factor compared to ordinary PS, this can be effectively used in the fabrication of solar cells.
Table 5.5  Comparison of the characteristics of the device

<table>
<thead>
<tr>
<th></th>
<th>$I_{sc}$ (mA)</th>
<th>FF</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS</td>
<td>-0.21</td>
<td>0.23 0.24</td>
<td>[42]</td>
</tr>
<tr>
<td>PS:gold (20 mA/30 min)</td>
<td>-0.01</td>
<td>0.683</td>
<td>Present work</td>
</tr>
</tbody>
</table>
5.7 References


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