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Characterization Process of Silicon Solar Cell in BAEC Lab

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ABSTRACT

This paper represents the characterization process of mono-facial solar cell in Bangladesh Atomic Energy Commission (BAEC) Lab. Mono-facial solar cell characterization performance analysis using surface reflection method, Sheet resistance method, SEM, Surface photo voltage and LIV test. The morphology of silicon wafer surface has been studied using scanning electron microscopy. It is found that the pyramid type structures are formed on the textured surface which helps to trap more light during conversion to electricity. The sheet resistance of raw and diffused sample is measured by using four point probe method. Results show that the resistivity of the wafer is decreased after diffusion which indicates the formation of n-type layer during diffusion process. The surface photo voltage data is used to find the diffusion length and life time. It is found the diffusion length 81.5μm and life time is 2.5μs. Finally, the efficiency of monofacial solar cell measured by LIV tester. Results show that the monofacial solar cell achieved fill factor (FF) of 0.310423 with a conversion efficiency (η) of 5.193843% where the active surface area is 96 cm^2.

1. INTRODUCTION

Electricity crisis is the most important issues in the present days. To avoid this crisis, most of electricity comes from fossil fuel (oil, natural gas, coal) and nuclear energy. But fossil fuel and nuclear energy are limited, not available everywhere and also create greenhouse effect. Urgent need to find alternative energy resources to fulfill the global energy requirements. The alternative energy resource that meets the requirement of sustainable, cyclic, environmental-friendly, carbon-free, chemical-free, clean and inexpensive is in the form of a renewable energy resource. The Earth needs a safe and long lasting energy source. Our challenge is to save our world and provide a good environment, comfort and prosperity for our future generations. So, solar energy is the best option for using renewable energy [1]. Solar energy is the energy generated at the core of the sun. The sun creates this energy through a thermonuclear process that converts about 650 000 000 tons of hydrogen to helium every second. The electromagnetic radiation from the sun consists of Ultra-violet, visible light, near infra-red, and far infra-red radiation. Only a very small amount of the total radiation reaches the Earth. All energy resources on Earth trace owe their existence to solar energy [2]. It is important to note that almost all of world's energy requirements can be satisfied by solar energy. Solar cell characterization is important in sense of better utilization of solar energy [3]. Present discussion focus on the five characterization process of silicon solar cell.

2. EXPERIMENTAL PROCESS

Five characterization techniques were used to assist with the performance analysis of mono-facial solar cell process in BAEC Laboratory. Such as Surface Reflectance Method (SRM), Sheet Resistance Measurement (Four Point Probe Measurement), Scanning Electron Microscope (SEM), SPV (Surface Photo voltage) measurement and Light Current Voltage (LIV) Testing.

2.1 Surface reflectance method

The reflectance measurement system is used to measure the surface reflection of planar Silicon wafer and textured Silicon wafer. Reflectance measurement has been performed before saw removal process and then after the texturing process. Finally the results of these two were compared to the reflectance of a standard mirror. The lowest the reflectance indicates the best texturing regarding its ability to absorb more lights. The measurement system is based on a mini monochromatic driven with a stepper motor to vary wavelengths in ~ 400-1200-nm spectral range. Incident light is obliquely incident on the surface of device under test. The resulting signal is connected to a Stanford Research 510 lock-in amplifier. A Lab VIEW interface is used for system control and data acquisition. Figure 1 describes detailed system schematics of the SR measurement system.

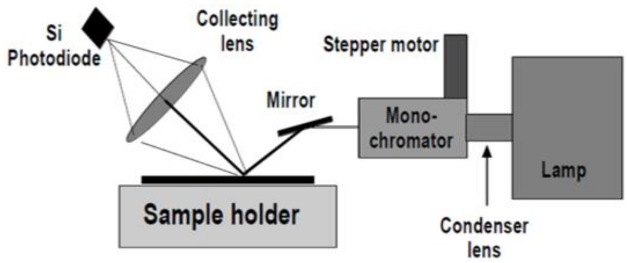


Figure 1. Schematic diagram of the surface reflection measurement system

2.2 Sheet resistance method

For-point Probe is used to measure sheet resistance of solar cells. Sheet resistance measurement has been performed right before saw removal process and after n-type diffusion process. The corresponding sheet resistance determines the quality of thin films deposited of silicon wafer as well as determines the heavily doped or shallow-doped p-n junction. Four-point measurements are carried out at five locations on the Si wafer, namely: North (N), West (W), East (E), South (S) and Center (C). This is in order to measure the emitter uniformity on the Si wafer. The theory of measuring sheet resistivity applies the formula [1] as below:

$$R_s = 4.5324(\frac{V}{I})$$

where, Rs – Ohms per square, V– Volts I – Current (amps).

2.3 Scanning electron microscope (SEM) method

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. In this research, SEM has been performing after cleaning and after texturing.

2.4The surface photo voltage (SPV) method

The surface photo voltage (SPV) measuring the minority carrier diffusion length and lifetime of semiconductors. Since the transport of minority carriers determines the behavior of the p-n junction that is ubiquitous in semiconductor device, surface photo voltage data can be very helpful in understanding their performance. As a contactless method, SPV is a popular technique for characterizing poorly understood compound semiconductors where the fabrication of ohmic contacts or special device structures may be difficult [3]. In this research, using mini monochromator driven with a stepper motor to vary wavelengths in ~ 400-1200 nm spectral range. Light-induced surface photovoltage (SPV) is measured as a function of the wavelength. SPV is measured using a Stanford Research 510 lock-in amplifier.

2.5 Light current voltage (LIV) testing

LIV measurement system determines fundamental device characteristics including short circuit current (Isc), open circuit voltage (Voc), fill factor (FF), series resistance (Rs), shunt resistance (RSHUNT), and maximum power (Pmax) of solar cell. Those collected results, can be used to determine the efficiency of solar cell.

LIV measurements using inexpensive, flash, xenon light source for illumination. LIV data acquisition is based on a custom-designed electronic interface integrated with high resolution, programmable voltage supply. Voltage across the solar cell is applied to measure the light generated photo-current. Spectral distribution of xenon high intensity plasma discharge lamp is light is closest to the solar spectra, and is industry standard. The flash LIV system is capable of measuring small (~ 10 cm^2) and large (up to ~15x15 cm^2) solar cells. The intensity variation is controllable in ~ 10 mW/cm^2 to 100 mW/cm^2 through simple absorptive metallic filters. Photo-generated photocurrent is measured across a one-ohm resistor. Figure 2 shows the LIV measurement system.

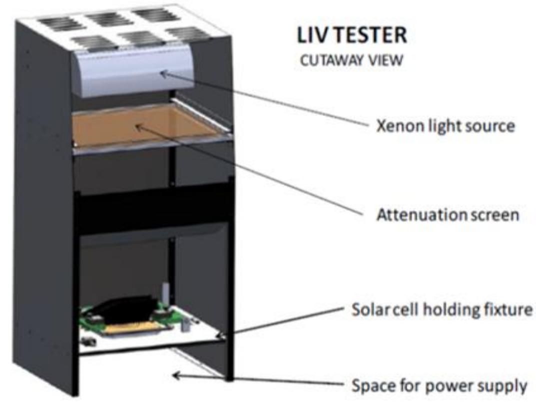


Figure 2. LIV measurement systems

3. EXPERIMENTAL RESULTS AND ANALYSIS

From the Figure 3, it is observed that, the average reflectance for the surface of raw silicon wafer 5.337619 AU and the average reflectance for the texturing silicon wafer is 3.763397 AU. The difference of average reflectance between raw wafer and texturing wafer in the same range is 1.614222 AU. Therefore the texturing silicon wafer is 30.40% lower than the surface of raw silicon wafer. Reflectance is lower in texturing solar cell wafer will high efficiency of the solar cell.

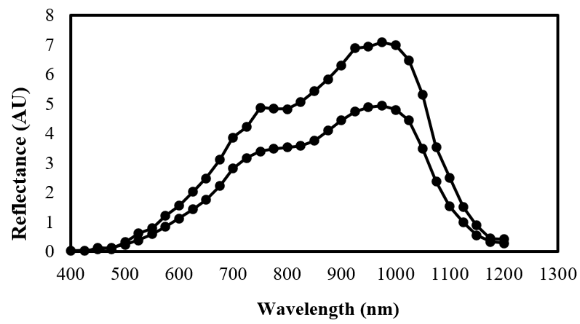
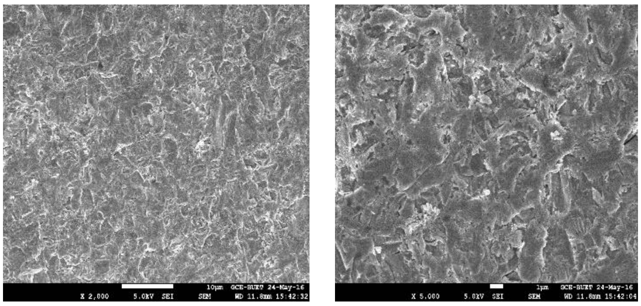


Figure 3. Plots of spectral reflection measurement of raw silicon wafer and textured wafer

3.1 Surface characterization using SEM

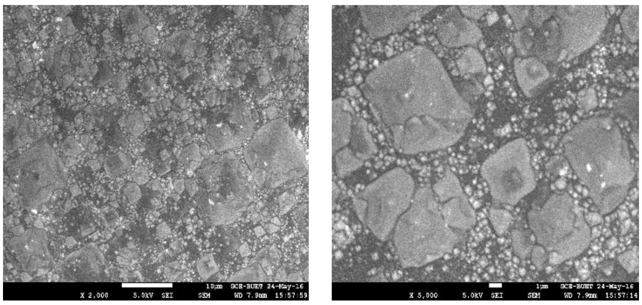
The scanning electron microscopy (SEM) has been performed on the sample surface to study the surface morphology before and after the cleaning processes and texturing processes. For the cleaning process, a chemical solution of sodium hydroxide (NaOH) and DI water (H_2O) at 1gm: 10ml volume ratio, respectively, was used at the temperature of 70°C for 10 minutes, for removing the surface damage. Figure 4 shows the Scanning Electron Microscope (SEM) image of the saw damage removed cleaned surface silicon wafer.

Alkaline-based wet-chemical texturing was investigated in detail in this study. For texturing, a solution of potassium hydroxide (KOH), isopropyl alcohol (IPA) and DI water (H_2O) with the ratio 1: 5: 125 respectively (discussed in Chapter 2) was used at 70°C for 10 minutes. The topography of textured surface after drying in compressed air is investigated using scanning electron microscopes (SEM). Figure 5 shows the SEM image of the textured surface at different magnification.



(a)2000 times magnification (b) 5000 times magnification

Figure 4. SEM image of saw damage removed clean surface silicon wafer at different magnification



(a) 2000 times magnification (b) 5000 times magnification

Figure 5. SEM microphotograph of textured surface after 10 minutes texturing in a solution of KOH, IPA and H_2O at 70°C

Form these images, it can be seen that alkaline texturing process a pyramid-like structures are formed on the surface of silicon wafer. These structures can provide a foundation for the front surface light trapping. The results of light trapping also verified using the surface reflectance data, which is shown in Figure 3.

3.2 Sheet Resistance of silicon wafer

The sheet resistance of raw silicon wafer was measured using a four point probe. In this research sheet resistance measured of the raw silicon wafer and diffused wafer. Based on the measured sheet resistance value, the emitter may be classified as shallow and moderate. Typically; a sheet resistance of a raw wafer silicon solar cell is 1-3 Ω-cm. Table 1 shows the resistivity measurements at different positions of the raw wafer.

From the measurements it is found that the average sheet resistances for raw wafer are 2.3 Ω-cm which is within the limit of sheet resistance 1- 3 Ω-cm. The result indicates that the diffusion can be taken place in the fabricated wafer. After diffusion process, the sheet resistance of the diffused wafer is measured at different positions. Table 2 shows the resistivity measurement at different positions of the $POCl_3$ diffused wafer.

From the measurements, the average sheet resistances of the diffused wafer are 0.801 Ω-cm. Results show that the resistivity of the wafer is decreased after diffusion which indicates the formation of n-type layer during diffusion process.

3.3 Surface photo voltage

Surface photo-voltage measurements have been carried out to determine the minority carrier life time from the front surfaces of silicon solar cell. Figure 6 plots SPV measurements as a function of wavelength from the front surfaces of a mono-crystalline silicon solar cell.

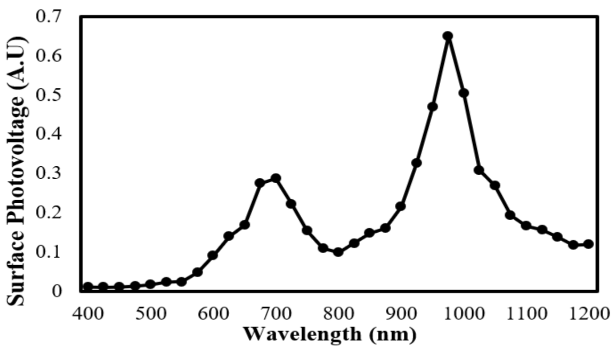


Figure 6. Surface photo voltage measurement of different wavelength for the front surface

where, L_n is the diffusion length for electron, D is the diffusivity, and τ is the lifetime. Minority carrier lifetime can be calculated from Equation, we get τ=2.5 µs (where L=81.5 µm, D=27 cm^2/sec).

Table 1. Four point probe measurement on raw wafer

Wafer	N	S	C	W	E	Average R_{sh}
Raw wafer	1.9 Ω-cm	2.1 Ω-cm	2.8 Ω-cm	2.1 Ω-cm	2.6 Ω-cm	2.3 Ω-cm

Table 2. Four point probe measurement on $POCl_3$ diffused layer

Wafer	N	S	C	W	E	Average Rsh
$POCl_3$ diffuse wafer	1 Ω-cm	0.77 Ω-cm	0.68 Ω-cm	0.87 Ω-cm	68.5 Ω-cm	0.801 Ω-cm

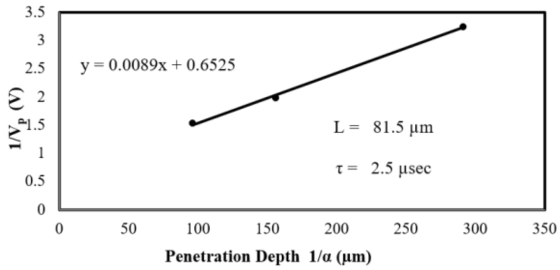
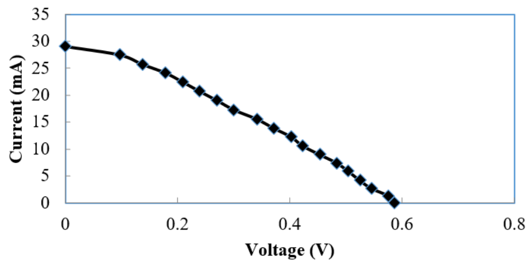
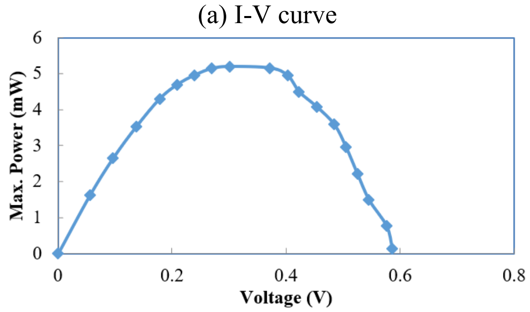


Figure 7. The linear curve that gives the value of diffusion length at X-axis intercept



(a) I-V curve



(b) P_{max}-V curve

Figure 8. LIV measurement of the nonofficial solar cell using Lab VIEW software

From the Figure 6, show that the wavelength 700 nm to 750 nm is too smaller than the value between 975 nm to 1025 nm. So use three different wavelength (975, 1000, 1025 nm) for determine the minority career diffusion length and lifetime.

For the measurement of the minority career diffusion length and lifetime using penetration depth $(1/\alpha)$, where α light absorption coefficient. The spectral dependence of the penetration depth is obtained by [3]

$$\alpha = \left(\frac{83.18*1000}{\lambda} - 74.87\right)^2$$

where, λ is wavelength.

By using SPV data for the wavelength range 975-1025nm to plot a plotting SPV^{-1} vs 1/α (penetration depth for silicon) graph and then drawing an average linear curve.

From the Figure 7, we get the value of minority carrier diffusion length (L) = 81.5µm at the negative X intersection shown in Figure 4, 5.

We know the diffusion length

$$L_n = \sqrt{D\tau_n}$$

3.4 Performance analysis of the monofacial solar cell by LIV test

The LIV test identifies the characteristics of the short circuit current (I_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and power maximum (P_{max}). The measured LIV data are shown in Figure 8, where light illumination of $100mW/cm^2$, active surface area is $96cm^2$ and sheet resistance of the fabricated solar cell is 0.801 ohm-cm.

From the LIV data, the following results of fabricated monocrystalline silicon solar cell are found, which are, Maximum power (P_{max}) is 5.193843mW, maximum Voltage (V_{max}) is 0.300532V, maximum Current (I_{max}) is 17.282163mA, Open circuit voltage (V_{oc}) is 0.575857V, and Short circuit current is (I_{sc}) 29.054970mA. The efficiency of cell is 5.193843% with corresponding Fill factor (FF): 0.310423.

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