Evaluation of Surface Photovoltage (SPV) in Al-Back Surface Fields Bifacial Solar Cell

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Abstract - Crystalline silicon, in its single crystalline or multi-crystalline (mc) format, dominates the photovoltaic (PV) industry. PV energy generation cost is still higher than energy-conversion costs of carbon-based fossil fuels. Since the price of silicon wafer accounts for almost 50 % of the energy conversion cost, historically, reducing Si wafer thickness has been successful approach. Bifacial solar cells appear to be the most desirable candidates for overcoming limitations discussed above. Bifacial solar cell is a specially designed solar cell for the production of electricity from both sides of the solar cell. Bifacial solar cell becomes an active field of research making photovoltaic (PV) more competitive together with current efforts to increase the efficiency and lower material costs. By developing a thin, bifacial solar cell, the expensive semiconductor material use is significantly reduced. This paper focused on the evaluation of surface photvoltage (SPV) and determination of diffusion length, *L* in bifacial solar cell. The diffusion length obtained was 81 μm and 63.5 μm for front and back surface of bifacial solar cell, respectively.

Key-Words : - Silicon, Bifacial Solar Cell, Back Surface Field (BSF), Surface Photovoltage and Diffusion Length

1 Introduction

The surface photovoltage (SPV) technique utilizes the change of the electrochemical potential in the space-charge region of a semiconductor during excess carrier generation due to illumination of the sample with light of suitable wavelength and intensity [1]. The SPV method is a well- established contactless technique for the non-destructive characterizations of semiconductors bulk materials, multi-layers, nanostructures, and actual devices [2].

In 1961, Goodman showed that, under certain assumption, by making measurements of SPV as a function of wavelength, the minority carrier diffusion length can be determined. Therefore, the primary of the SPV technique is the determination of the diffusion length of minority carriers in the region of essential light absorption inside solar cells and wafers under dc conditions [3].

The minority carrier diffusion length, *L* is essential to study the quality and transport properties of the material. In a base region, the diffusion length is an important factor affecting the conversion efficiency and spectral response of the cell. The SPV produced when some of the minority carriers that drift around in the bulk reach the surface. The statistical distance that carriers travel in the bulk before they recombine is the diffusion length. Thus some of the minority carriers recombine before they reach the surface. The shorter the diffusion length, the less SPV due to the high recombination. Longer wavelength will penetrates deeper into silicon than short wavelength.

In this paper, an approach to determinate *L* from SPV measurements of solar cells and correlate it with spectral response (SR) measurements using the same optical illumination system; all the work has been carried out on npp+ bifacial solar cell structures.

2 Methodology

Fig. 1 shows npp+ bifacial device schematic diagram. As-cut Si wafers were etched in NaOH solution to remove saw damage. Texturing was carried out in KOH/IPA solution to form inverted pyramids. After the texturing process, the wafers were subjected to the n-type diffusion procedure using phosphorous oxychloride ($POCl_3$) as the diffusion source in the quartz tube furnace. For bifacial solar cells with Al- back surface field (BSF), a blanket of Al pastes was screen-printed on the back side of the Si wafer. The paste was annealed at 150℃ for 10 minutes prior to firing at a temperature of 870˚C in a rapid thermal annealing (RTA) furnace to form Al-diffused p+ layer. Excess Al was removed by etching in hydrochloric acid (HCl) solution. Using plasma enhanced chemical vapor deposition (PECVD), silicon nitride (SiN) films were subsequently deposited on both sides of the Si wafer to serve as passivation and anti-reflection coating (ARC). Finally, the metallization processes were carried out through screen printing of Ag and Ag/Al pastes using identical grid masks on a front and back surfaces respectively. Screen-printed contacts were fired at ~ 870℃ to form ohmic front and back contacts.

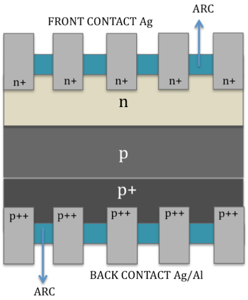


Fig.1. Bifacial solar cell configuration.

Fig.2 describes detailed system schematics of the minority carrier lifetime measurement system. Light from a tungsten-halogen lamp is focused onto the entrance slit of the monochromator. Light from the exit slit of the monochromator is guided to the wafer at normal incidence. Stepper motor is used to vary monochromator output wavelength. A light chopper is placed at the exit slit of the monochromator to provide reference signal to the lock-in to ensure all the stray light is rejected by the system and enhance system sensitivity from nano-volt to mV range. Capacitive SPV voltage is measured by placing an ITO/Au coated quartz plate on top of the wafer to be measured. A thin-sheet of Teflon film is placed between the top glass electrode and the wafer to create electrical isolation. The bottom electrode is connected to the Si wafer and is Au- coated to provide reduced contact resistance. The lock-in output and stepper motor are controlled by a PC using a LabVIEW interface. The system wavelength range is from ~ 500-1200-nm. All data is written to a file in text form for subsequent plotting and processing.

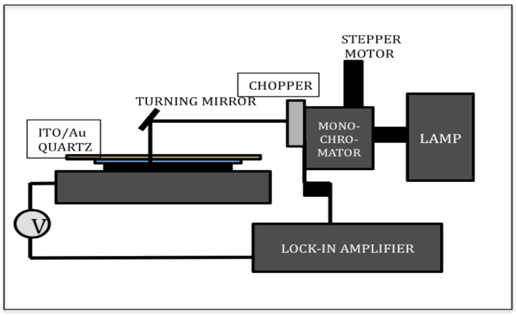


Fig. 2. The schematic diagram of the minority carrier lifetime measurement system

3 Results and Discussions

Fig.3 shows a typical light current-voltage (I-V) measurement of bifacial solar cell for a front and back surface under 60 mW/cm^2 xenon light illumination. Open circuit voltage (V_{oc}) obtained from the device was 579 mV and 554 mV for illumination from front and back sides respectively. The current densities are ~ 17 mA/cm^2 and ~ 8 mA/cm^2 for the front and rear sides; respectively. In general, for all the solar cells fabricated using this method, the current density from the rear surface was approximately ½ of the front surface. A detailed simulation analysis using PC1D has been carried out and a paper submitted to this conference summarizes salient features. The analysis reveals that in bifacial solar cells, the rear surface efficiency is a sensitive function of back surface field, surface, and bulk recombination velocities. These are verified by the lifetime and Al BSF measurements described below.

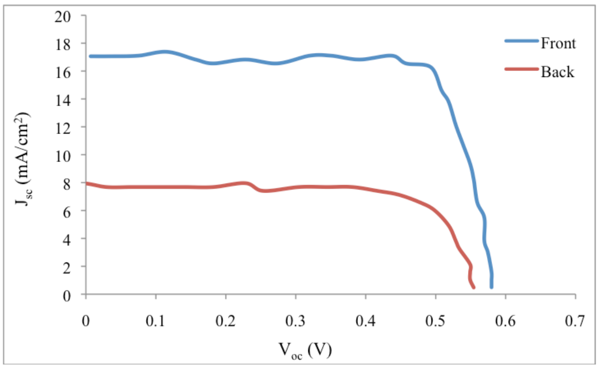


Fig.3. LIV measurement of a typical bifacial solar cell for front and rear surfaces.

Surface photovoltage measurements have been employed to determine minority carrier lifetime from front and rear surfaces; detailed description of the method is provided in a paper submitted to this conference. Fig.4 plots SPV measurements as a function of wavelength from the front and rear surfaces of the bifacial solar cell. The peaks in the SPV signal at ~ 700 nm and 990 nm are system related. By taking a ratio of the SPV signal from front and rear surfaces, this system-related artifact can be removed. Green line in Fig. 4 represents the ratio, which slowly decreases from a maximum of ~ 5 at 550 nm to ~ 1 at 1000 nm. For an ideal case with no defects, the SPV response would approximately be identical from both surfaces, so the ratio would be 1. However, in this case, the ratio is substantially less than 1 in the short wavelength region due to recombination losses at and near the surface as well as reduction in minority carrier lifetime. From the SPV data, minority carrier lifetime from front and rear surfaces can be estimated.

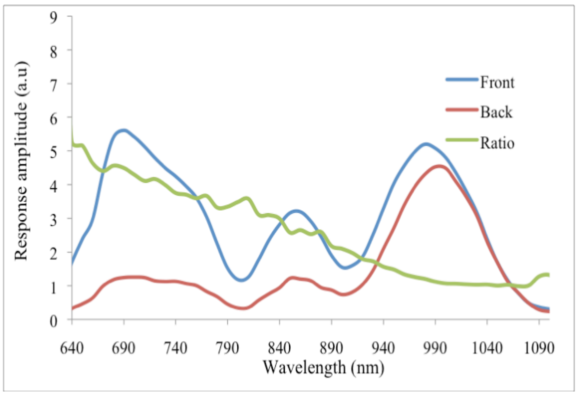
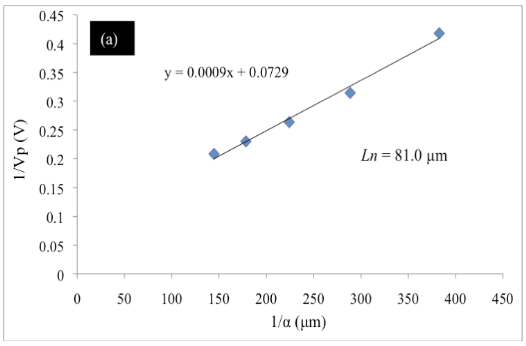


Fig.4. The SPV measurements from front and rear surfaces of the bifacial solar cell

The SPV data was plotted as a function of 1/α for both front (Fig. 5-a) and rear (Fig. 5-b) surfaces. The minority carrier diffusion lengths from front and rear surfaces were determine to be 81 μm and 63.5 μm respectively. The diffusion length from the rear surface is lower than the front surface, which helps explain its poor performance. However, as described in our companion papers (experimental and simulation submitted to this conference), lack of effective back surface filed and surface passivation also play a major role in back surface response.



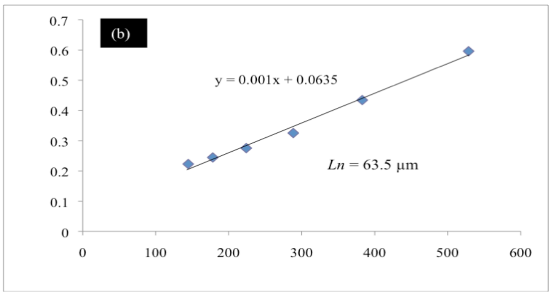


Fig.5. Minority carrrier diffusion length for the front (b), and rear (c) surfaces.

4 Conclusion

The diffusion length in Aluminum BSF bifacial solar cell has been determined through SPV method. It was found that the small value of diffusion length at the back surface shows that more recombination occured at the back side. This is tally with I-V results that shows front side performance is better than back side performance. As our intuition on the poor performance of back surface may be due to lack of BSF, our future research on alternative method to form BSF such as boron solid source diffusion will be investigated.

Acknowledgement

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