International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 7 No. 4 Aug. 2014, pp. 1479-1484

http://www.ijias.issr-journals.org/

Study of Surface Photo voltage for monocrystalline silicon solar cell fabricated at BAEC solar cell lab.

Md. Abdur Rafiq Akand, Md. Rakibul Hasan, Mohammad Khairul Basher, and Mahbubul Hoq

Solar Cell Fabrication and Research Division,
Institute of Electronics, AERE, Bangladesh Atomic Energy Commission,
Ganak Bari , Savar, Dhaka, Bangladesh

ABSTRACT: Surface photovoltage (SPV) method is a contactless technique for non-destructive characterization of Si wafers and monocrystalline Si solar cells, mainly for minority carrier diffusion length determination. The minority carrier diffusion length, *L* is a critical factor impacting the conversion efficiency and spectral response of the monocrysyalline Si solar cell and it is also essential for evaluation of the quality and transport properties of the P-type Si wafer. In 1961, A. M. 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 a simply steady state SPV method has been developed to determine the minority carrier diffusion length as well as lifetime of monocrystalline Si solar cells. In Bangladesh for the first time "Bangladesh Atomic Energy Commission (BAEC)" has set up a laboratory to fabricate and diagnosis of monocrystalline Si solar cell. This paper focused on the study of surface photvoltage (SPV) and determination of minority carrier diffusion length, *L* and lifetime, τ of monocrystalline Si solar cell. By calculating the experimental data obtained from monocrystalline Si solar cells measurements, minority carrier diffusion length and lifetime were derived and it was 81.5μm and 2.5μsec respectively.

KEYWORDS: P-type Silicon, Minority Carrier, Diffusion Length, Carrier Lifetime, Doping concentration.

1 INTRODUCTION

A photovoltage (PV) arises whenever light-induced excess charge carriers (electron-hole pairs) are separated within the space charge region (SCR) which exists inside the p-n junction (in the case of a solar cell) or in spontaneously created SCR under a free semiconductor surface [1]. 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 [2]. The SPV method is significantly cheaper and more reliable in comparison with other contactless methods such as EBIC (Electron Beam Induced Current) and μ-PCD method [1]. 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 [3]. Thus some of the minority carriers recombine before they reach the surface. In steady – state situation the generation and recombination rates are perfectly balanced [4]. According to Goodman assumption, by measuring of SPV as a function of wavelength, the minority carrier diffusion length can be determined [10]. 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 [5].

2 THEORY

Electrical properties of a free semiconductor surface are mainly determined by surface-localized electronic states within the semiconductor band gap or double layer of a charge, known as a surface dipole [1]. The charge transfer between bulk and surface induced by the appearance of surface-localized electronic states results in a non-neutral region named surface space charge region. If light falls on the pn-junction, the photons create electronhole pairs separated by the space charge.

Thus, in p-type silicon the majority carriers are holes, the charge in the depletion region is negative, and the electric field in the depletion region forces electrons to the surface, creating a surface photovoltage[10]. Photons are absorbed not only in the pn-junction but also in the p-type area. The electrons produced are minority carriers in those areas and their concentration is greatly reduced by recombination. The n-layer must therefore be sufficiently thin for the electrons of diffusion length *L* to pass through the n-layer.

i.e, $L >> t$,

Where t = thickness of n-layer [8].

When a typical 300 µm thick silicon wafer is illuminated by strong sunlight of irradiance 1000 mW/cm2, electrons and holes are generated at a rate of 9×10^{18} cm^{-3} s^{-1} [6]. The electric potential and the charge distribution are related to each other through the Poisson equation and the experimental value of the photovoltage coincides with the change of the surface potential [7]. Minority carriers that drift around in the bulk either eventually recombine with majority carriers, or they reach the surface, where they produce a surface photovoltage. The shorter the diffusion length, the less likely minority carriers will make it to the surface to cause surface photovoltage. Longer wavelength light penetrates deeper into silicon than short wavelength light. Therefore, if we compare the SPV signal produced by pulses of two different wavelengths of light (Fig. 1),[10] each containing the same number of photons, then the longer wavelength will penetrate more deeply into the silicon, the minority carriers created will be more likely to recombine before they reach the surface and the longer wavelength light will produce a smaller SPV signal than the short wavelength light [9].

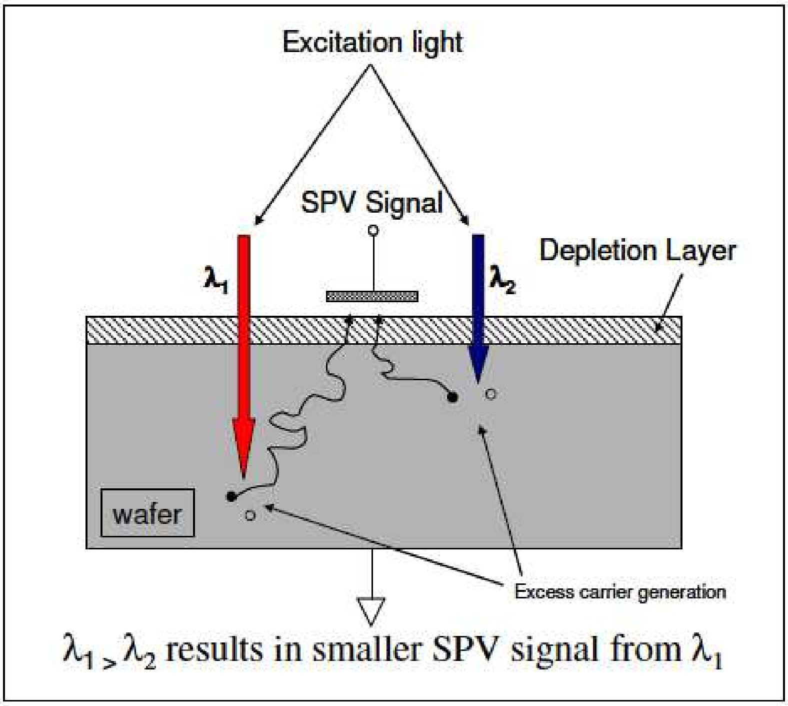

Fig. 1.   SPV Signal Changes with Penetration of incident light and wavelength λ.

One can determine the diffusion length by comparing these two SPV signal produce by the two different wavelengths.

If we plot the light flux, Φ, divided by the SPV signal V_{SPV} (Fig.2) for each wavelength, as a function of the penetration depth into silicon of that wavelength, the result is a straight line whose Y intercept tells the diffusion length L.

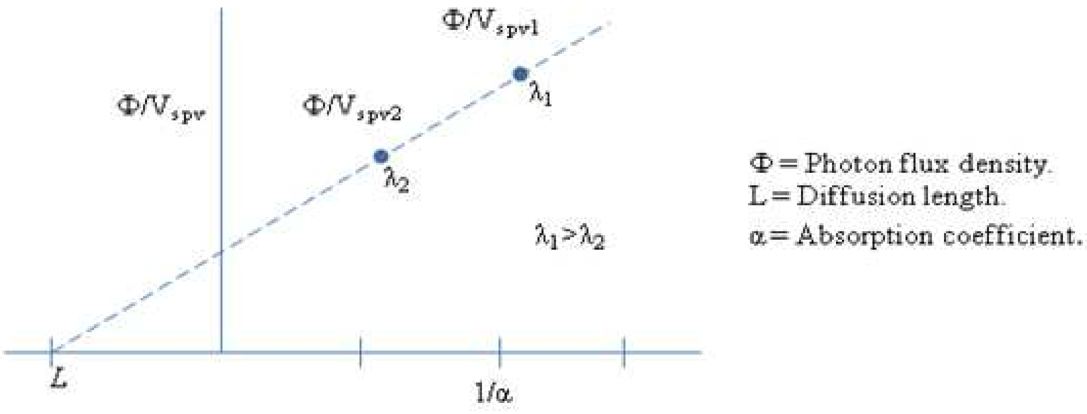

Fig. 2. Graphical Calculation of Diffusion Length via SPV Signals

3 METHODOLOGY

A simple, computer-controlled, normal incidence measurement system was designed for SPV measurements of minority carrier diffusion length and lifetime of Si solar cell. Measurement system is based on a 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. This system can be modified to measure SPV as a function of wavelength as well as a function of flux density at fixed wavelength. A LabVIEW interface is used for system control and data acquisition.

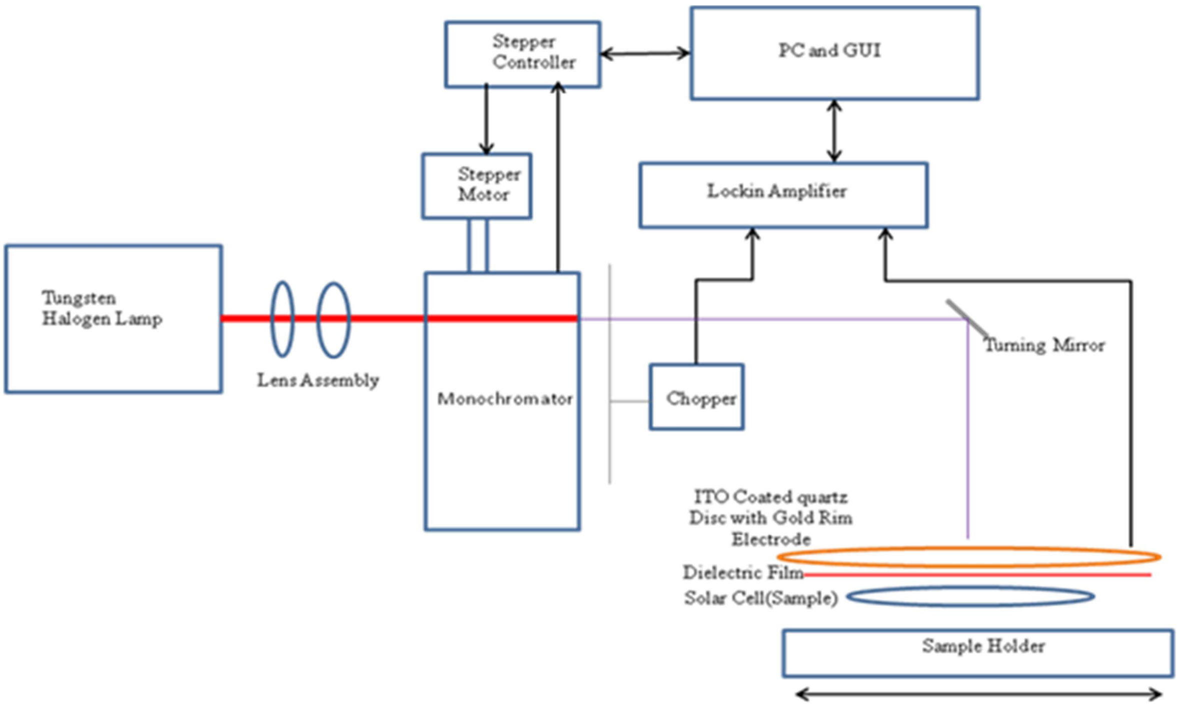

Fig. 3. The Schematic Diagram of Minority Carrier Diffusion Length measurement system.

Figure 3 and 4 describes detailed system schematics of the minority carrier diffusion length and 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 solar cell 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 amplifier to ensure all the stray light is rejected by the system and enhance system sensitivity from nano-volt to mV range.

Fig.: 4. Picture of SPV Measurement system.

Capacitive SPV voltage is measured by placing an ITO/Au coated quartz plate on top of the solar cell to be measured. A thin-sheet of Teflon film is placed between the top glass electrode and the solar cell to create electrical isolation. The bottom electrode is connected to the Si solar cell and is Au-coated to provide reduced contact resistance. The lock-in amplifier output and stepper motor are controlled by a PC using a LabVIEW interface. The system wavelength range is from ~ 400-1200-nm. All data is written to a file in text form for subsequent plotting and processing.

4 RESULTS AND DISCUSSIONS

For SPV measurement system we were used Laboratory fabricated silicon solar cell (which was fabricated in our BAEC Lab.) Fig.5 shows a typical light current-voltage (I-V) measurement of fabricated mono-crystalline silicon solar cell under 100 mW/cm2 xenon- arc light illuminations. The LIV curve also represents the quality of fabrication process and the efficiency of a solar cell. The open circuit voltage (V_{oc}) and short circuit current (I_{sc}) obtained from this measurement were 0.56V and 18A respectively. Small values of short circuit current (I_{sc}) indicate the efficiency of fabricated cell is low but the appearance of LIV curve looks like a standard curve.

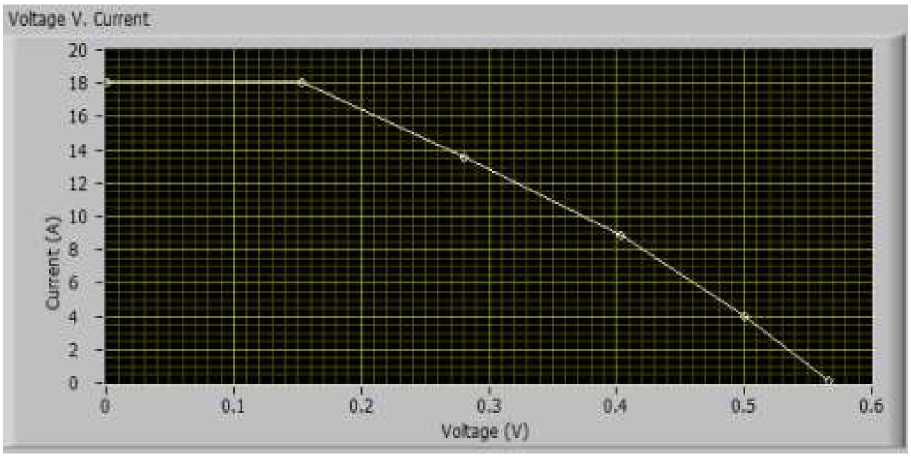

Fig. 5. LIV Measurement of Laboratory Fabricated Silicon Solar Cell

Surface photo-voltage measurements have been carried out to determine minority carrier diffusion length from front surfaces of silicon solar cell; detailed description of the method is provided in the previous section. Fig.6 plots SPV measurements as a function of wavelength from the front surfaces of a mono-crystalline silicon solar cell. The peaks in the

SPV signal at ~ 700 nm and 975 nm are system related. This system-related artifact can be removed by taking a ratio of the SPV signal from front and rear surfaces.

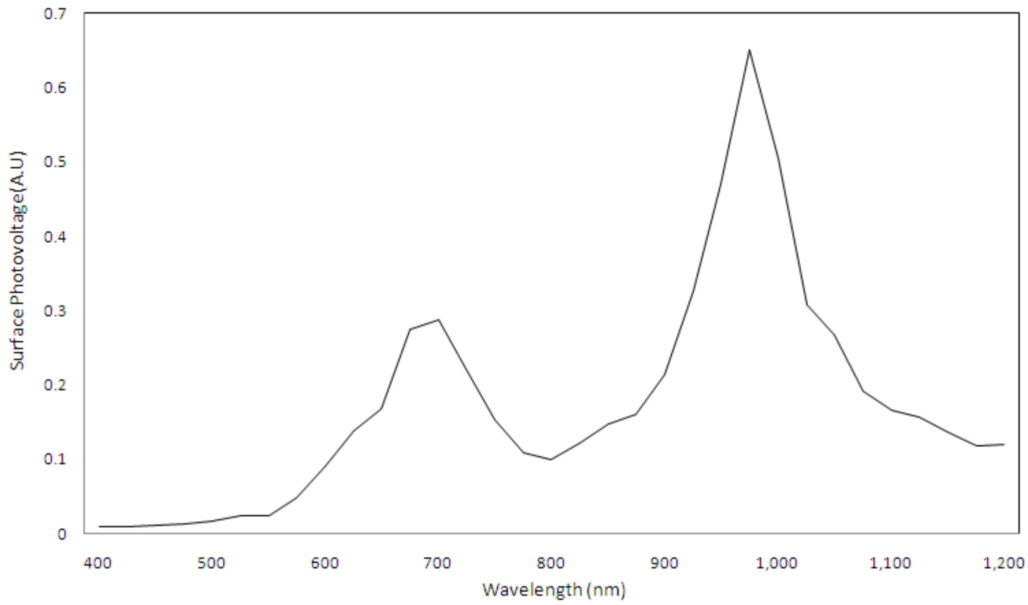

Fig. 6. Surface Photovoltage Measurement of Different Wavelength for Lab. Fabricated silicon solar cell.

From the SPV data, minority carrier diffusion length from front surfaces can be estimated. The measurement can be made using three wavelengths of light. Using additional wavelengths, and determining the best-fit straight line, can result in a measurement that is more accurate [11]. The SPV data was plotted as a function of penetration depth 1/α for front surfaces (Fig. 7). The minority carrier diffusion length and lifetime was derived and it was 81.5μm and 2μsec respectively.

Since the difference of penetration depth value 1/α between the wavelength 700 nm to 750 nm is too small rather than the value between 975 nm to 1025 nm so we use three different wavelength (975, 1000, 1025 nm) starting from 975nm to determine minority career diffusion length and lifetime.

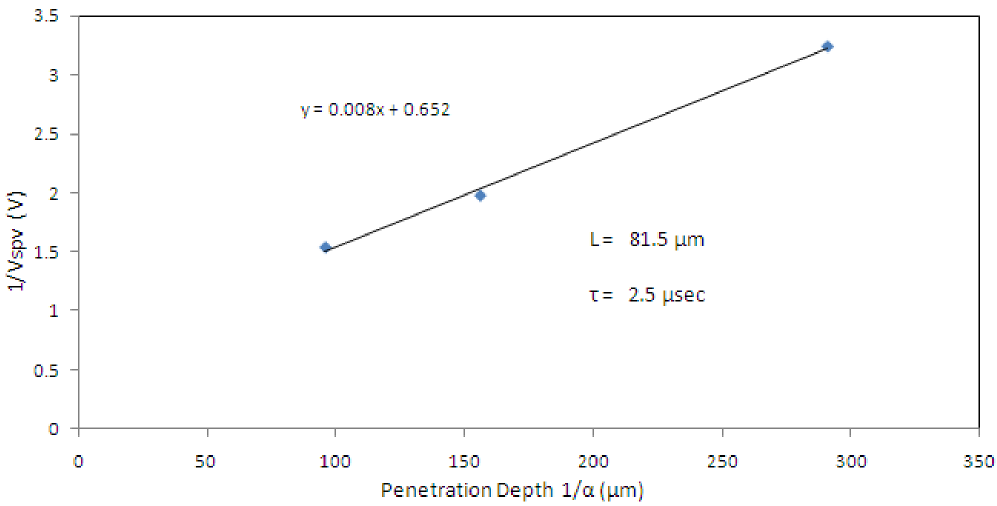

Fig. 7. Measured Minority Carrier Diffusion Length and Lifetime of Silicon Solar Cell.

5 CONCLUSIONS

In Bangladesh for the first time a laboratory has been set up by "Bangladesh Atomic Energy Commission (BAEC)" to fabricate and diagnosis of Si solar cell. Surface photo voltage method has been determined to be low-cost, non-destructive and process monitor for solar cell research environment in comparison with other contactless methods such as EBIC (Electron Beam Induced Current) method. The diffusion length of Si solar cell has been determined through SPV method. In silicon, the lifetime can be as high as 1 msec and for a single crystalline silicon solar cell; the diffusion length is typically 100-300 µm [11]. It was found that the small value of diffusion length at the front surface shows that more recombination occurred at that surface. It may be happened due to the variation of doping concentration of the front surface. To optimize the flow rate of $POCl_3$ and additionally the doping concentration have to be further optimized and carefully characterized we can get more improvement. Our future research will be optimizing all of the challenges and increase diffusion length to get more efficient solar cell.

REFERENCES

[1] L. Votoček and J. Toušek, "Surface Photovoltaic Effect and Its Applications to Si Wafers and Monocrystalline Si Solar Cells Diagnostics", *WDS'05 Proceedings of contributed papers,* part III, 595-600, 2005..

[2] R.Stangl, "Specific Characterization Method, Surface Photovoltage", *Silicon Photovoltaic,* 2009, pp.1-3.

[3] Suhaila Sepeai, Saeem H. Zaidi, S.L.Cheow, M.Y.Sulaiman, K.Sopian, "Evaluation of Surface Photovoltage (SPV) in Al-Back Surface Fields Bifacial Solar Cell", *Proceedings IEEE* PVSC 39, 2013.

[4] Mohammad Ziaur Rahman, "Modeling Minority Carrier's Recombination Lifetime of p-Si Solar Cell", *International journal of renewable energy,* Vol.2, No.1, 2012.

[5] K. Kirilov, V. Donchev, Tsv. Ivanov, K. Germanova, P. Vitanova, and P. Ivanova, "A surface photovoltage spectroscopy system used for minority carrier diffusion length measurements on floating zone silicon", *Journal of Optoelectronics and Advanced Materials,* vol. 7, No. 1, 2005, pp. 533 – 5362.

[6] A. Cuevas, D. Macdonald, "Measuring and interpreting lifetime of silicon wafers", *Solar Energy* 76 (2004) 255-262.

[7] L. Kronik, Y. Shapira, "Surface photovoltage phenomena: theory, experiment, and applications", *Surface science,* reports 37, p. 1- 206, 1999.

[8] J. Toušek, D. Kindl, J. Toušková, "Contactless photovoltage method for measurement of diffusion length of minority carriers in solar cells", *Solar Energy Materials & Solar Cells,* 64, p. 29-35, 2000.

[9] Suhaila Sepeai, M. Khairunaz, A.W. Azhari, M.Y. Sulaiman, K. Sopian, and Saleem H. Zaidi, "Fabrication and Characterization of Al-BSF Bifacial Solar Cell" *Proceedings IEEE,* PVSC 39, 2013.

[10] The theory of SPV for measuring of diffusion length, Technical note 201. [Online] Available: http://www.semilab.com.

[11] Diffusion length, [Online] Avalable : http://www.pveducation.org/pvcdrom/pn-junction/diffusion-length