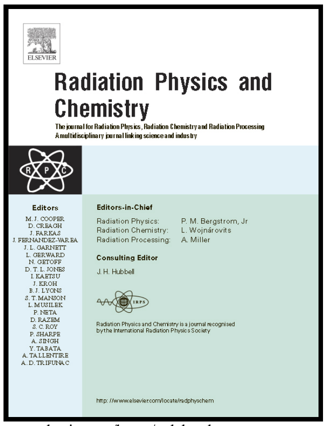
Author's Accepted Manuscript



www.elsevier.com/locate/radphyschem

Capacitance and conductance studies on silicon solar cells subjected to 8MeV electron irradiations

Sathyanarayana Bhat P, Asha Rao, Ganesh Sanjeev, G. Usha, G. Krishna Priya, M. Sankaran, Suresh E. Puthanveettil

PII: S0969-806X(15)00064-X
DOI: http://dx.doi.org/10.1016/j.radphyschem.2015.02.010
Reference: RPC6705

To appear in: *Radiation Physics and Chemistry*

Received date: 10 June 2013
Revised date: 8 February 2015
Accepted date: 11 February 2015

Cite this article as: Sathyanarayana Bhat P, Asha Rao, Ganesh Sanjeev, G. Usha, G. Krishna Priya, M. Sankaran and Suresh E. Puthanveettil, Capacitance and conductance studies on silicon solar cells subjected to 8MeV electron irradiations, *Radiation Physics and Chemistry,* http://dx.doi.org/10.1016/j.radphyschem.2015.02.010

Capacitance and conductance studies on silicon solar cells subjected to 8 MeV electron irradiations

Sathyanarayana Bhat P[a], Asha Rao[b]*, Ganesh Sanjeev[c], G Usha[d], G Krishna Priya[d], M Sankaran[d], Suresh E Puthanveettil[d],

[a] Department of Physics, Mangalore Institute of Technology and Engineering, Moodabidri, Mangalore 574 225, India.

[b] Department of Physics , M S Ramaiah University of Applied Sciences, Bangalore - 560058

[c] Microtron Centre, Department of Physics, Mangalore University, Mangalagangothri 574 199, India.

[d] Solar Panel Division, ISRO Satellite Centre, Bangalore 560 017, India.

* Corresponding author. Tel.: +91 9845687082

E-mail address: asharao76@gmail.com, asharao.pi.sh@msruas.ac.in

Abstract:

The space grade silicon solar cells were irradiated with 8 MeV electrons with doses ranging from 5 kGy – 100 kGy. Capacitance and conductance measurements were carried out in order to investigate the anomalous degradation of the cells in the radiation harsh environments and the results are presented in this paper. Detailed and systematic analysis of the frequency-dependent capacitance and conductance measurements were performed to extract the information about the interface trap states. The small increase in density of interface states was observed from the conductance – frequency measurements. The reduction in carrier concentration upon electron irradiation is due to the trapping of charge carriers by the radiation induced trap centres. The Drive Level Capacitance Profiling (DLCP) technique has been applied to study the properties of defects in silicon solar cells. The small variation in responding state densities with measuring frequency was observed and the defect densities are in the range 10^{15} cm^{-3} to 10^{16} cm^{-3}.

Key words: Electron irradiation, Carrier Concentration, Conductance method, Trap Density, Time constant, DLCP.

1. Introduction

c-Si solar cells provide electrical energy for the operation of satellites in outer space. High-energy particle damage to the semiconductor material of the solar cells is one of the most important issues to be addressed in outer space applications. The primary cause for the degradation of solar cells in space is due to the protons and electrons in the energy range of electron volts to hundreds of millions electron volts. As the satellites in their orbit suffer space radiations that consist mainly of high energy electrons and protons, it is essential to estimate the performance of solar cell after a substantial exposure to radiation; regardless of the initial performance.The estimated dose that can be received by any geostationary satellite during its lifetime in orbit is below 100 kGy.

The charged particles in space produces large number of lattice defects in solar cells and it results in gradual degradation of cell performance affecting the reliability and lifetime of satellite (Hisamatsu et al., 1998). In order to evaluate the performance of the silicon cells in space, it is necessary to characterize the effects of charged particles on the electric properties of solar cells. Typically, electrons in the range 0.1 MeV to several MeV produce one to two displacements with an introduction rate of the order of 1 cm^{-1} at 1 MeV (Corbett, 1966). On an average, fluence of 10^{16} cm^{-2} is essential to create a homogeneous distribution of displacements with 10^{16} cm^{-3} concentrations. In silicon, the defects produced by irradiation at room temperature are secondary defects resulting from the interaction of the primary defects with impurities or with each others, because the primary defects are mobile well below 300 K (Bourgoin and Angelis, 2001).

The experimental techniques such as Capacitance – Voltage and conductance measurements can be used to estimate the radiation induced defects in solar cells. C – V curves gives information about the carrier concentration, built in voltage and the depletion layer width of the solar cells (Rao et al., 2009). The conductance method is one of the most reliable and commonly adopted interface trap density (N_{ss}) extraction techniques used to evaluate the passivation of interfaces (Nicollian and Brews, 1982). This technique involves the measurement of an equivalent parallel conductance (G_P) of the device as a function of frequency. This conductance represents the loss mechanism caused by capture and emission of carriers from the interface traps and can be used to extract the interface state density (Wei, 2010).

Drive level capacitance profiling (DLCP) is a useful technique to study amorphous and polycrystalline semiconductors. For the p-i-n c-Si:H device, defect densities nearly 10^{15} cm^{-3} were detected using DLCP technique and variation of these densities with temperature is quite small (Cohen, 2005). This technique directly yields the density of states within the band gap of the semiconductor as a function of both energy and of spatial position (Heath et al., 2004). The decrease of carrier concentration with the increasing fluence is because of carrier removal by radiation induced defects in silicon solar cells (Kawasuso et al., 1995; Ohshima et al., 1996). Mott-Schottky analysis is adopted to determine the built-in voltage (V_{bi}) and doping density (N_D) of c-Si solar cells. Compared with other semiconductor profiling techniques (spreading resistance, differential conductance, Hall effect, etc.), C-V method is an electric, non - destructive measurement of the barrier capacitance of semiconductor junctions.

Results obtained from the systematic analysis of C-V measurements, frequency-dependent conductance measurements, Drive-level capacitance profiling (DLCP) done on the solar cells before and after electron irradiation are presented in this paper.

2. Experimental techniques

Space-grade large area c-Si solar cells with size 6.5 cm x 4 cm and thickness 200 μm procured from Solar Panels Division, ISRO Satellite Centre, Bangalore, are used in the present study. To understand the high energy electron irradiation effects, these solar cells were irradiated with 8 MeV electrons at room temperature using Microtron accelerator at Mangalore University. The features of the Microtron accelerator has been reported already elsewhere (Siddappa et al., 1998; Ganesh et al., 1999). The cells were exposed to electrons of doses ranging from 5 kGy to 100 kGy. All the measurements were repeated after irradiation. Capacitance with frequency (C-F), Capacitance – Voltage (C-V), Conductance – Frequency (G-F) and Capacitance – AC voltage (DLCP) measurements were done on two silicon solar cells of the same type, under dark condition using Agilent 4294A Precision Impedance Analyser at Microtron centre. Electron irradiation and all the characterisations were performed for two silicon solar cells. The results obtained for both the cells were similar and therefore, only the results of one cell are presented.

3. Results and discussion

3.1. Capacitance – Voltage measurements

Capacitance – voltage characteristics of silicon solar cell under dark condition at various doses of 8 MeV electrons is shown in Fig. 1. C–V measurements were taken using a 1 MHz AC signal. It is observed that the capacitance decreases with increase in dose due to

Yamaguchi, M., Taylor, S.J., 1996. Analysis of damage to silicon solar cells by high fluence electron irradiation. 25th PVSC. 167-170.

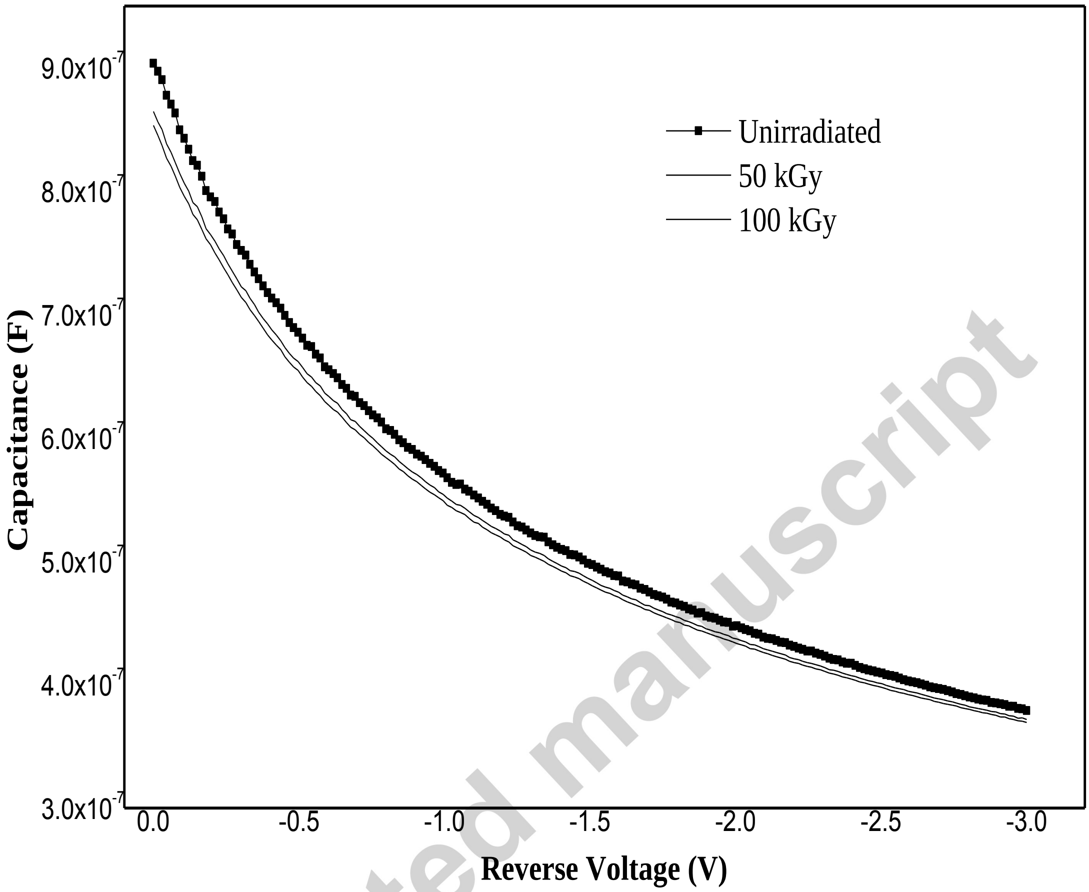


Fig. 1

the decrease in carrier concentration with increasing dose .The dependence of $1/C^2$ on applied voltage V of an electron irradiated silicon solar cell under dark condition at room temperature is shown in Fig. 2. A linear relation was observed at reverse voltages and its intercept with the voltage axis gives the depletion potential. The depletion layer capacitance, when a voltage V is applied to a junction is given by,

$$C = A\left[\frac{q\varepsilon_0\varepsilon_r N_D}{2(V_{bi}+V)}\right]^{1/2} \qquad (1)$$

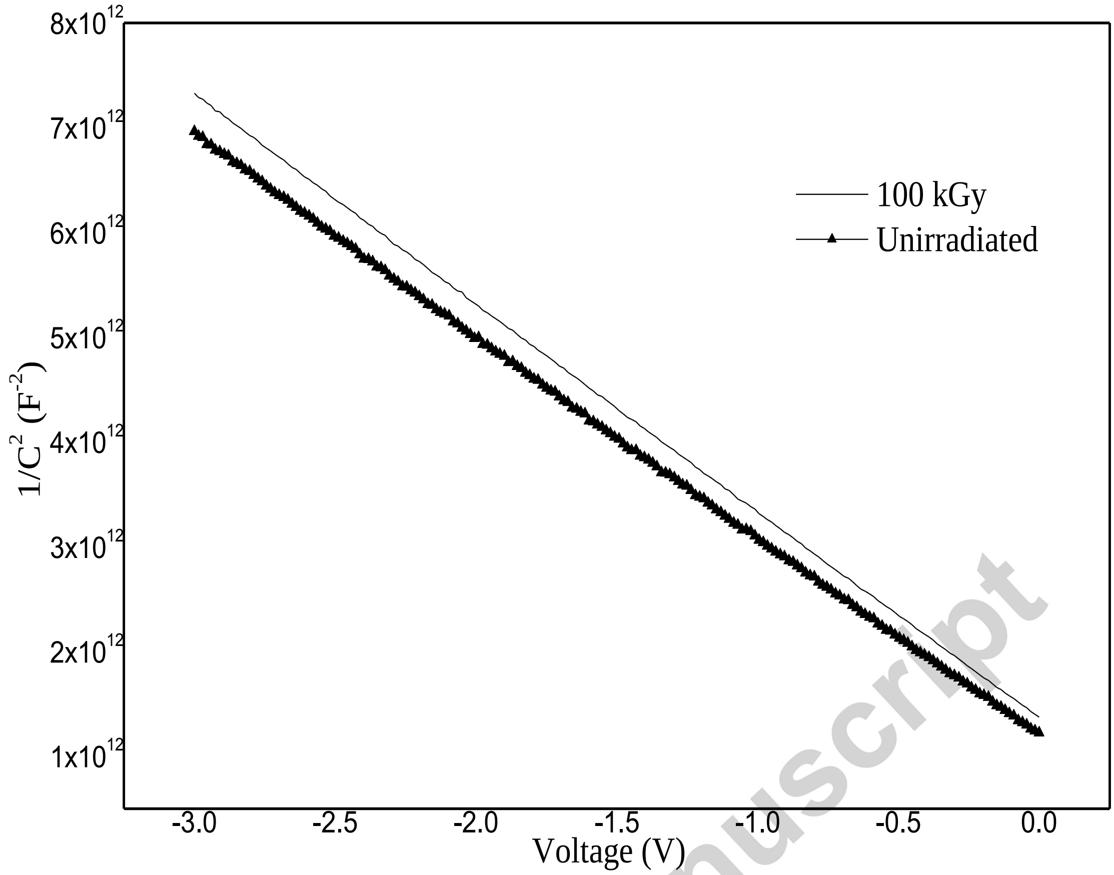
Where A is the area of the solar cell, q is the electronic charge, N_D is the carrier concentration, ε_r is the dielectric constant of silicon, ε_0 is the vacuum permittivity, V_{bi} is the built-in potential (Sze, 1981). N_D and V_{bi} can be estimated using Eq. (1).

Fig. 3 shows the variation of the carrier concentration, N_D with dose. A slight reduction in carrier concentration from 9.2 x 10^{15} cm^{-3} to 8.8 x 10^{15} cm^{-3} is observed due to 8 MeV electron irradiation with doses up to 100 kGy (Bhat et al., 2014). The diffusion potential is nearly the same for all doses. This observation suggests that a small decrease in carrier concentration is may be due to the radiation induced defects. These defects influence the carrier concentration by trapping the charge carriers. The change in carrier concentration of base layer of c-si solar cell causes the abrupt decrease in short circuit current and hence cell failure. The decrease in I_{sc} is caused by broadening of depletion region due to the trapping of majority carriers by defects produced through electron irradiation (Bhat et al., 2014).

The total thickness of the depletion layer W of the junction can be given by (Sze, 1981)

$$W = \frac{\varepsilon_0\varepsilon_r A}{C} \qquad (2)$$

The calculated depletion layer widths for the silicon solar cell before irradiation are 0.29 µm at zero bias and 0.71 µm at -3 V bias. At 100 kGy, the depletion width has increased to 0.32 µm at zero bias and 0.73 µm at -3 V bias. Broadening of depletion region may be due to majority carrier trapping by the defects produced by electron irradiation, since the width of depletion region is approximately depends on the majority carrier concentration (Yamaguchi and Taylor, 1996).



8x10^12
7x10^12
6x10^12
5x10^12
4x10^12
3x10^12
2x10^12
1x10^12
1/C^2 (F^-2)
100 kGy
Unirradiated
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
Voltage (V)

Fig. 2

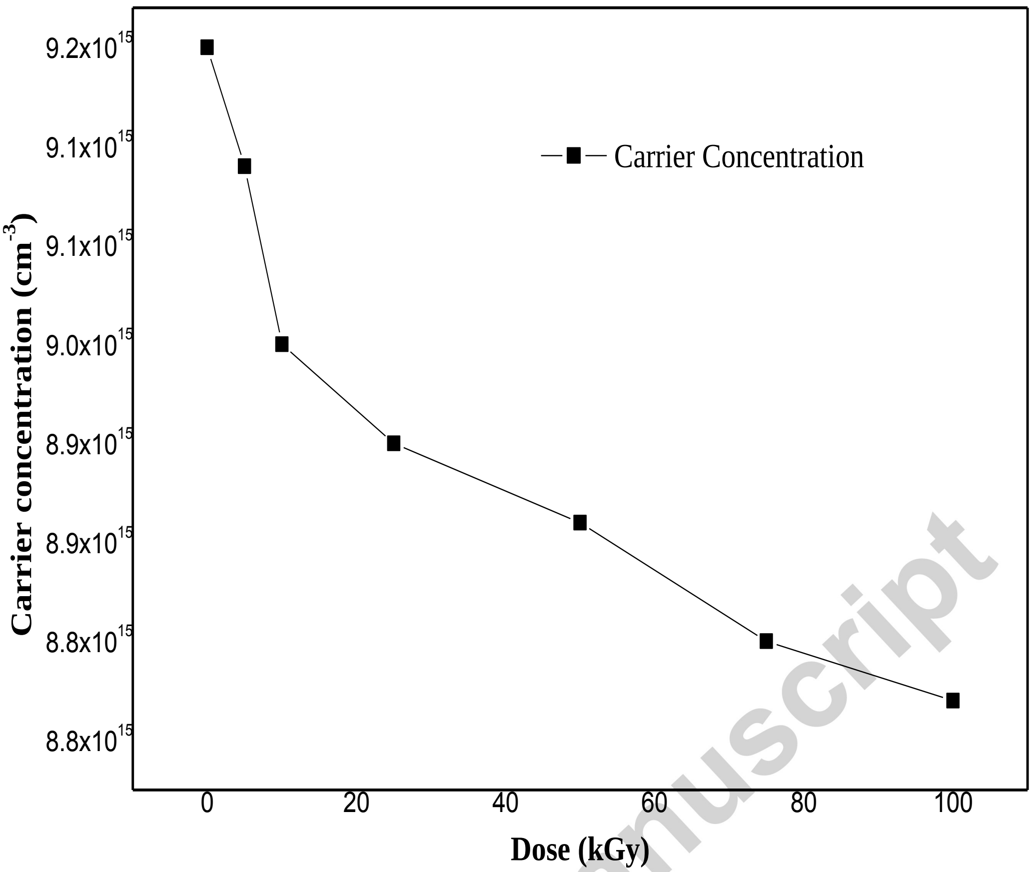

Carrier concentration (cm^{-3})
9.2x10^{15}
9.1x10^{15}
9.1x10^{15}
9.0x10^{15}
8.9x10^{15}
8.9x10^{15}
8.8x10^{15}
8.8x10^{15}
Carrier Concentration
0
20
40
60
80
100
Dose (kGy)

Fig. 3

3.2. Conductance – Frequency measurements

The frequency dependent conductance measurements have been effectively used to investigate the interface trap states in silicon solar cells. Conductance study is mainly suitable to resolve the effects of the interface trap states on the performance of solar cells. Using this method it is possible to extract the interface trap density in the depletion and weak inversion portion of the band gap and the times for the charging and discharging of trap centres by investigation of the silicon solar cells at different frequencies.

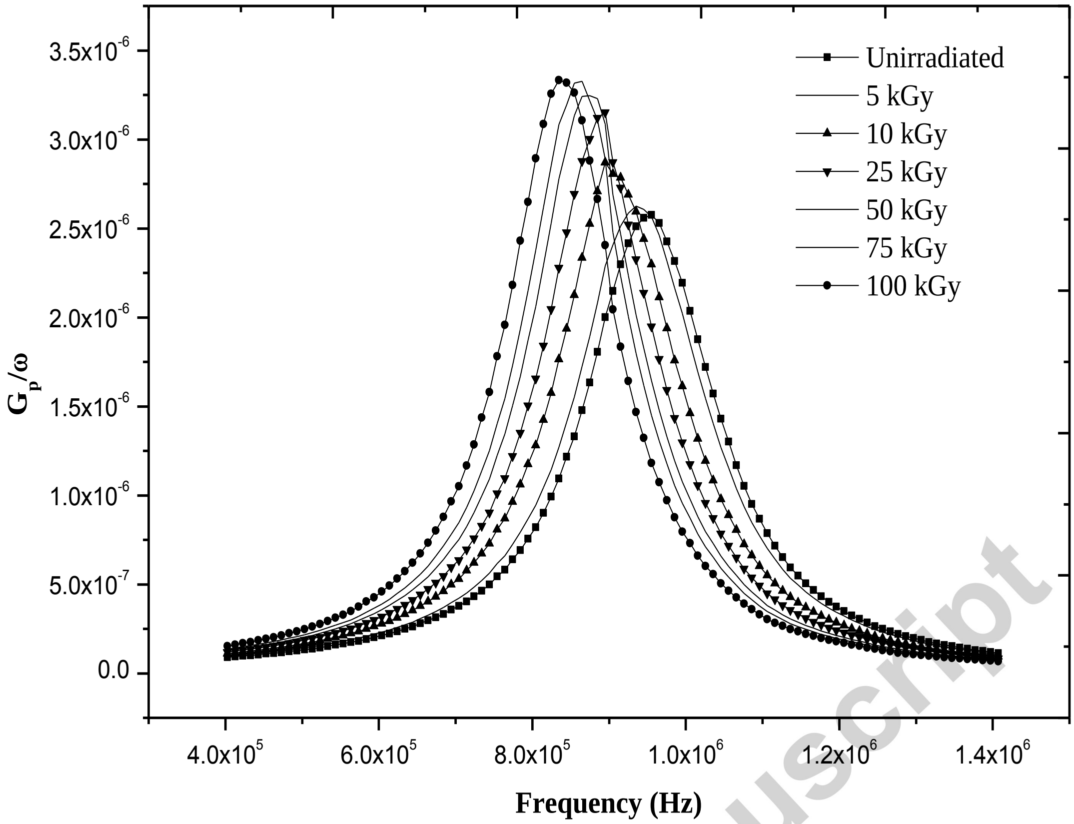
An estimated expression giving the interface trap density (N_{ss}) in terms of the maximum conductance is,

$$N_{ss} = \frac{2.5}{q}\left(\frac{G_p}{\omega}\right)_{\max} \qquad (3)$$

Where $\omega = 2\pi f$. q, f and G_p are the charge of an electron, frequency and the conductance (Hussain et al., 2012; Schroder, 1998). From the peak of G_p/ω versus frequency plot, the density of interface states and the interface trap time constant can be calculated. The peak in the G_p/ω versus frequency plot is caused by the presence of interface traps, which occur at the interfaces of the solar cells (Cakar et al., 2007).

The variations of G_p/ω values calculated from the measured conductance values versus frequency at different doses of electron are shown in Fig. 4. The density of interface states is calculated from the peak value of the curve using Eq. (3). The variation in the trap density with dose is shown in Fig. 5. The interface trap concentration observed before irradiation was 4 x 10^{13} eV^{-1} cm^{-2} and increases to 5.2 x 10^{13} eV^{-1} cm^{-2} after the electron irradiation. This is because as electron travels in the solar cell material, the energy dissipation of electron displaces the atoms in the lattice and hence the defects or trap centers are created. The dominating effect at high energy/high fluence electron irradiation is the introduction of majority carrier traps which primarily reduce the majority carrier concentration in the base region (Yamaguchi and Taylor, 1996). Because most of these defects are electrically active which influence the carrier concentration by trapping the charge carriers (Srivastava et al., 2006).

Fig. 6 shows the variation of interface trap time constant as a function of dose. A slight increase in the time constant is observed with the radiation dose. Hence the free carriers



Unirradiated
5 kGy
10 kGy
25 kGy
50 kGy
75 kGy
100 kGy
3.5x10^-6
3.0x10^-6
2.5x10^-6
2.0x10^-6
1.5x10^-6
1.0x10^-6
5.0x10^-7
0.0
G_p/ω
4.0x10^5
6.0x10^5
8.0x10^5
1.0x10^6
1.2x10^6
1.4x10^6
Frequency (Hz)

Fig. 4

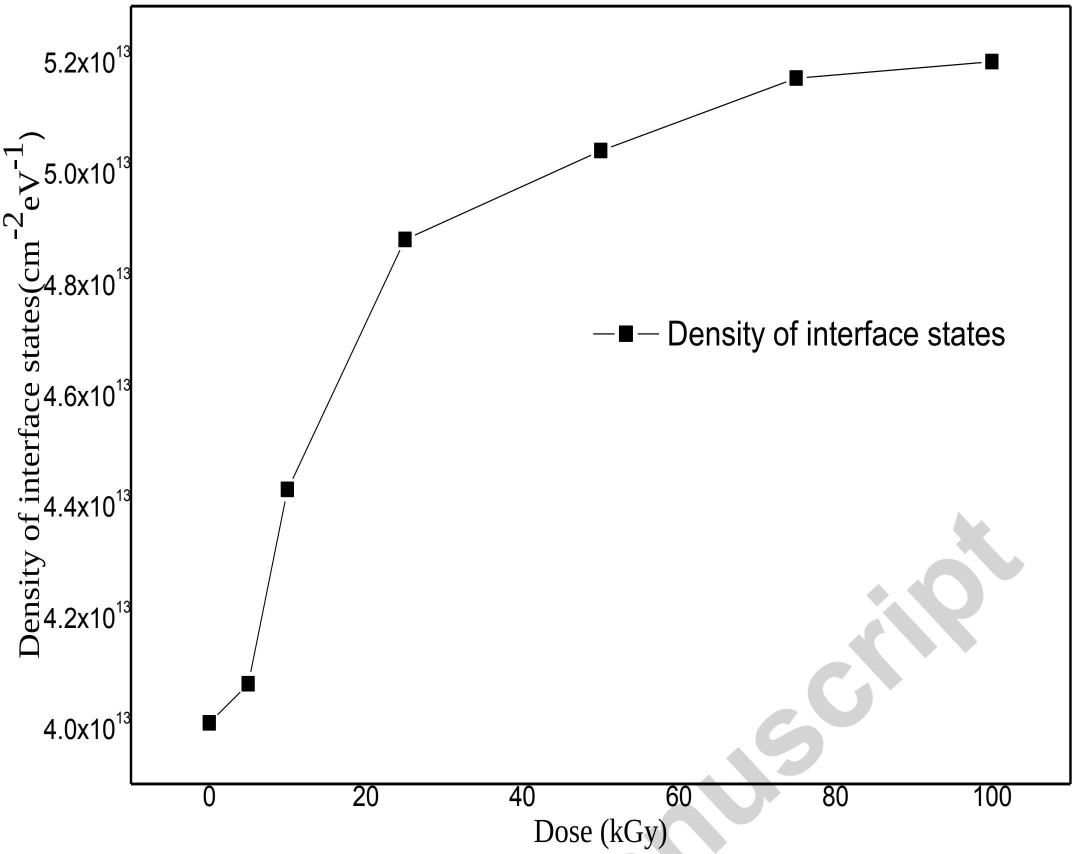
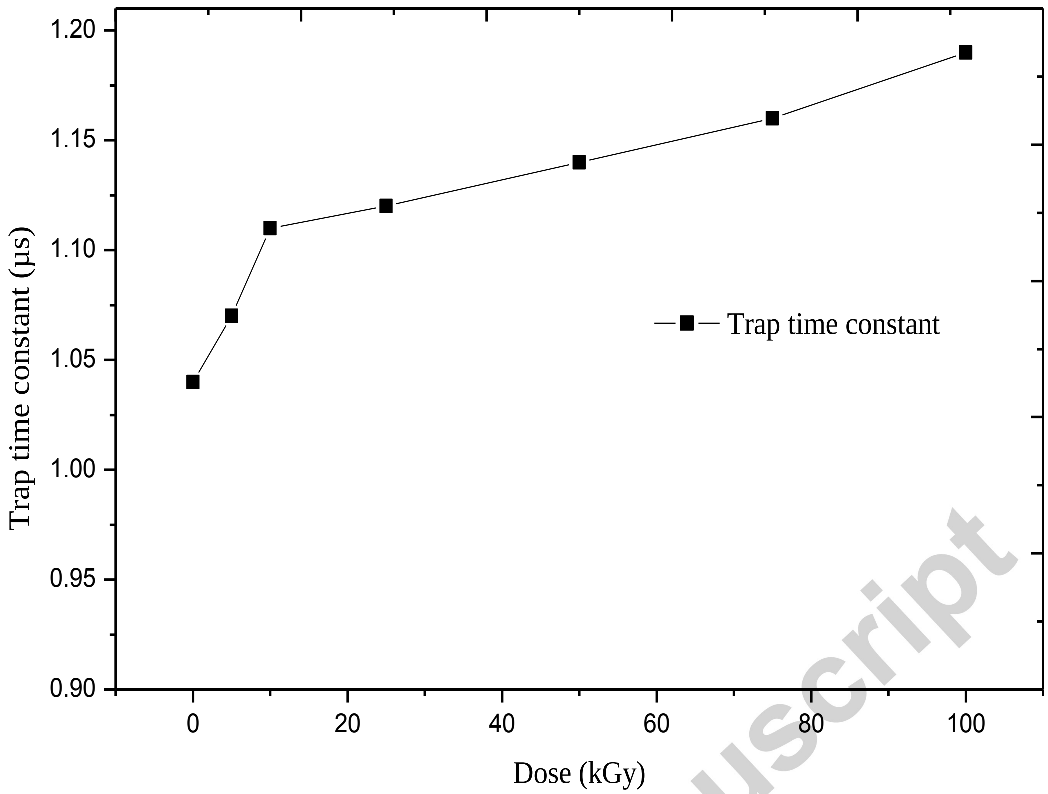

5.2x10^13
5.0x10^13
4.8x10^13
4.6x10^13
4.4x10^13
4.2x10^13
4.0x10^13
Density of interface states(cm^-2eV^-1)
Density of interface states
0
20
40
60
80
100
Dose (kGy)

Fig. 5



Trap time constant (µs)
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0
20
40
60
80
100
Dose (kGy)
Trap time constant

Fig. 6

available for conduction decrease with increasing radiation dose. This may be because the capture time for radiation induced defect levels are long enough in comparison with the charge transfer rate for the traps to efficiently trap the carriers.

3.3. Capacitance – Frequency measurements

The variation of capacitance with frequency for silicon solar cells measured under dark conditions at 1 V is shown in Fig. 7. It was found that the capacitance values decreases with increase of frequency. At lower frequencies the interface states can follow the applied ac signal and give up excess capacitance however at higher frequency interface states might not follow the ac signal. Hence at higher frequency the total capacitance of the device is not contributed by the interface state capacitance (Hussain et al., 2012).

Capacitance value decreases from 502 nF to 462 nF corresponding to the frequency variation of 100 kHz to 1 MHz, for the unirradiated sample. The corresponding decrease in the capacitance value for the device irradiated with electrons of dose 100 kGy is from 500 nF to 451 nF. The change in the capacitance values of irradiated and unirradiated samples is insignificant, indicating that electron irradiation has not contributed significantly to the concentration of deep level defects (Rao et al., 2010).

3.4. Drive Level Capacitance Profiling

Drive-level capacitance profiling (DLCP) is a technique used for measuring the energetic and spatial distribution of defects in the band gap. The DLCP method examines the dependence of junction capacitance over a range of ac voltage amplitudes in addition to a range of dc bias, to obtain more information about the device response than is available from the C–V and admittance spectroscopy techniques (Heath et al., 2004).

DLCP results were obtained through the measurement of capacitance as a function of ac voltage at frequencies between 1 kHz and10 kHz and dc voltage from -0.2 V to -1 V at room temperature. The charge density and the approximate profile distance were calculated according to the following equations,

$$N_{dl} = -\frac{C_0^3}{2q\varepsilon A^2 C_1} \qquad (4)$$

Where C_1 and C_0 are based on a quadratic fit according to,

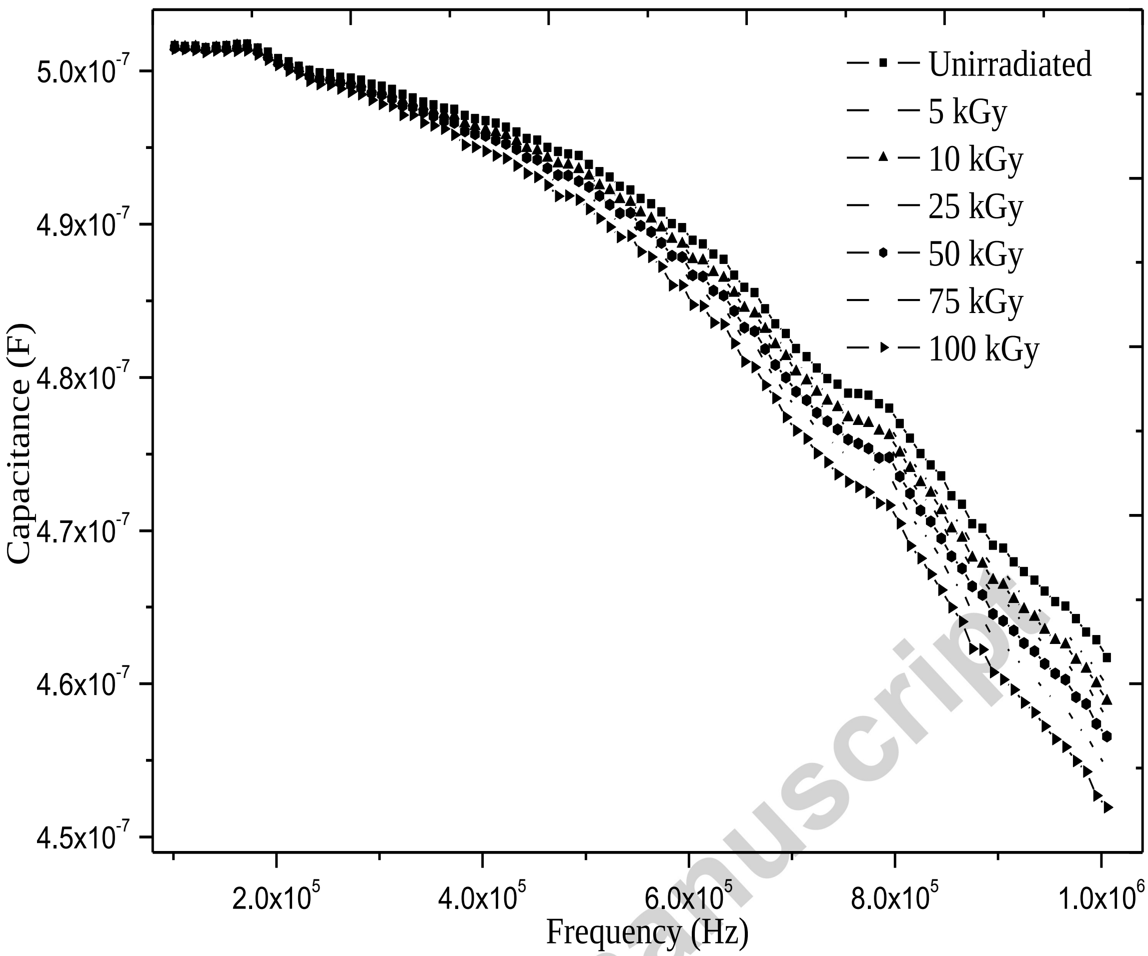

Unirradiated
5 kGy
10 kGy
25 kGy
50 kGy
75 kGy
100 kGy
Capacitance (F)
5.0x10^-7
4.9x10^-7
4.8x10^-7
4.7x10^-7
4.6x10^-7
4.5x10^-7
2.0x10^5
4.0x10^5
6.0x10^5
8.0x10^5
1.0x10^6
Frequency (Hz)

Fig. 7

$dQ/dV = C_0 + C_1 dV + C_2 (dV)^2 + ...$ (5)

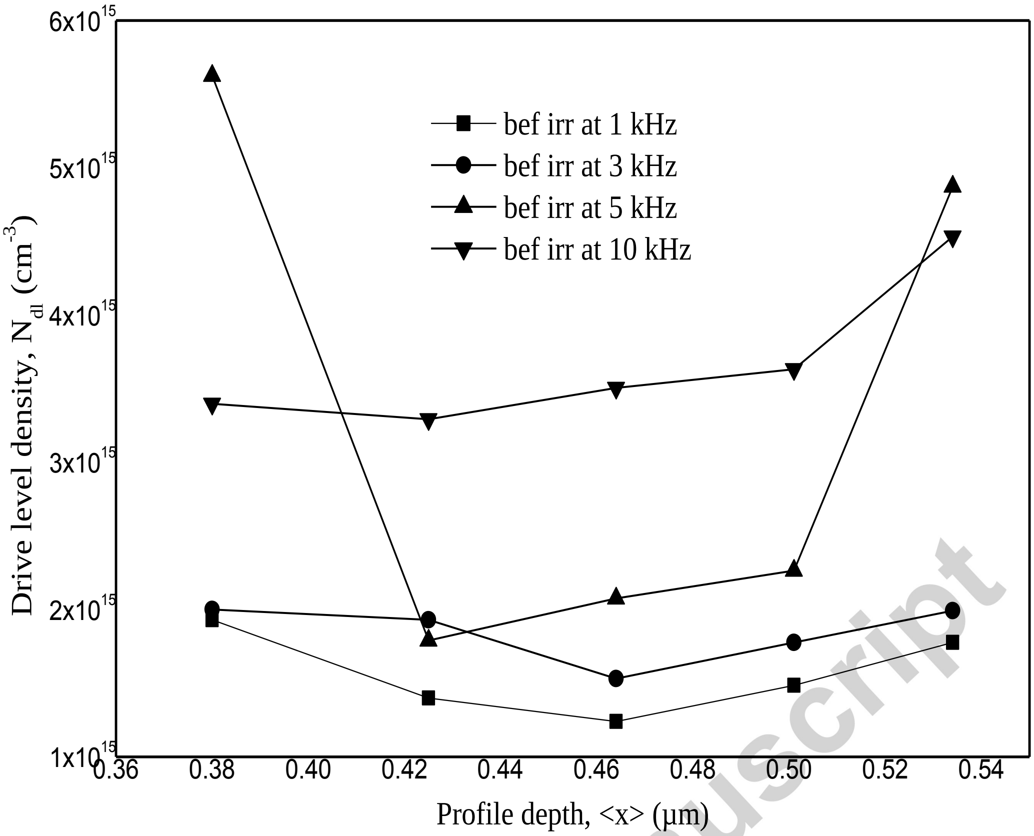
$$\langle \times \rangle = \frac{\varepsilon A}{C_0} \quad (6)$$

Where N_{dl} is the drive level density, <x> is the profile distance and A is area of the solar cell (Heath et al., 2004; Lei et al., 2011).

The variation of drive level density with profile depth at different frequency for an unirradiated silicon solar cell is shown in Fig. 8. It is observed that the responses of defect levels are increasing with the frequency. At 5 kHz and 10 kHz profile, non uniform distribution of defects is observed. A small amount of deeper defects may be observed at 10 kHz profile. But it is found that the deeper defect density appears to be less than 1 x 10^{15} cm^{-3} for the silicon solar cell before irradiation. An approximately uniform distribution of defect levels was observed in the lower frequency profiles and the responding state densities are in the range 1 x 10^{15} cm^{-3} to 2 x 10^{15} cm^{-3} with small frequency dependence. The defects follows the AC signal, i.e, it can change its charge states according to the variation of the band bending, if the AC signal frequency is lower than a characteristic frequency which depends on temperature and other intrinsic properties of the material. This periodic variation of the charge in the defect can contribute to the total differential capacitance of the device (Biccari, 2009). By analyzing the total capacitance, defect densities can be obtained at different frequency.

After the electron irradiation, the profiles are non-uniform throughout the active region of the solar cell; reflects in the activation of the defects as the frequency level of the measurement is changed. The DLCP profile for an electron irradiated silicon solar cell at 300 K and 5 kHz is shown in Fig.9. A slight increase in the defect density at profile distance 0.38 µm is observed after the electron irradiation for 5 kHz frequency. This indicates that the shallow level defects are formed upon irradiation which suggests that the majority of the responding defect states are shallow donor-like states, sited within about 0.38 µm of the junction. Similar results were reported by George Hugger for the nc-Si:H absorber layer a shallower defect of energy 0.4 eV that is unusually contained within 0.3 µm of the p/i interface (Hugger, 2011).

Fig. 10 shows the DLCP profile for an electron irradiated solar cell at frequency 10 kHz. It is observed that the deep level defects increases with the radiation dose indicating



Drive level density, N_{dl} (cm^{-3})
6x10^{15}
5x10^{15}
4x10^{15}
3x10^{15}
2x10^{15}
1x10^{15}
bef irr at 1 kHz
bef irr at 3 kHz
bef irr at 5 kHz
bef irr at 10 kHz
0.36
0.38
0.40
0.42
0.44
0.46
0.48
0.50
0.52
0.54
Profile depth, <x> (μm)

Fig. 8

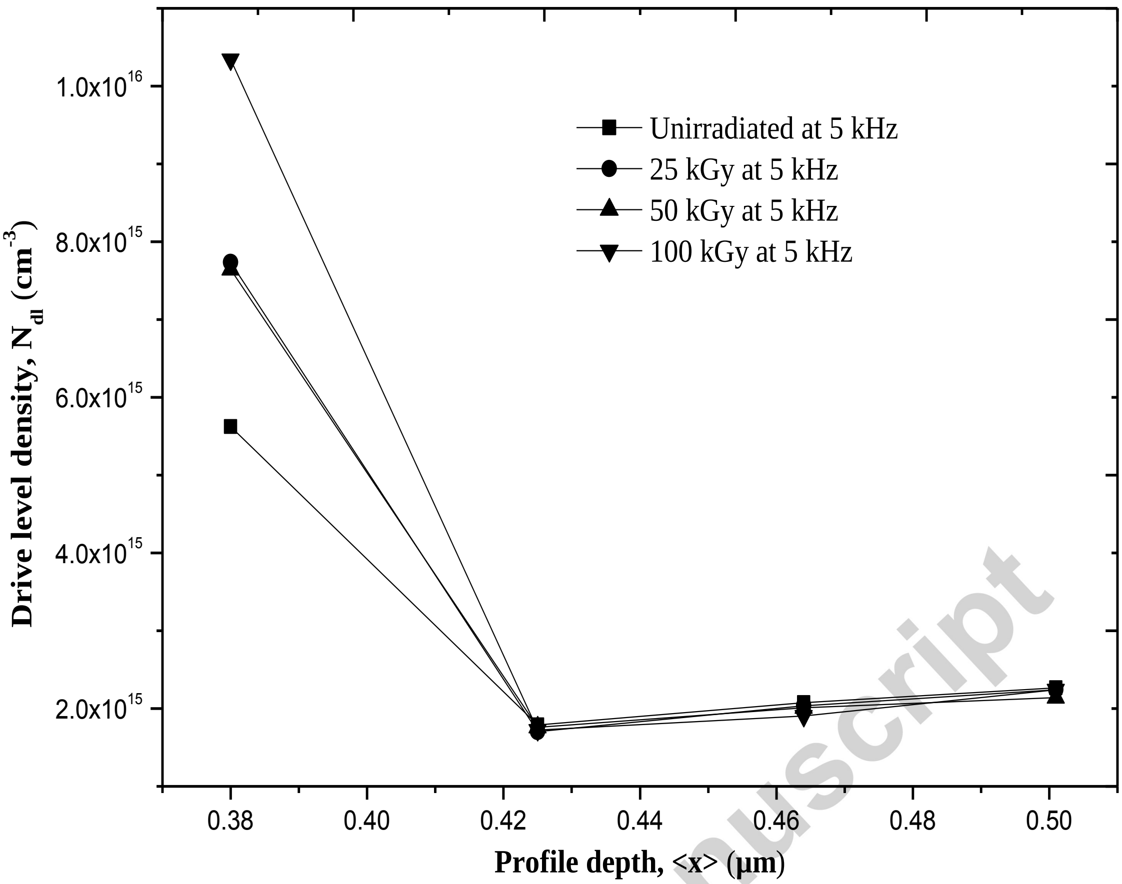
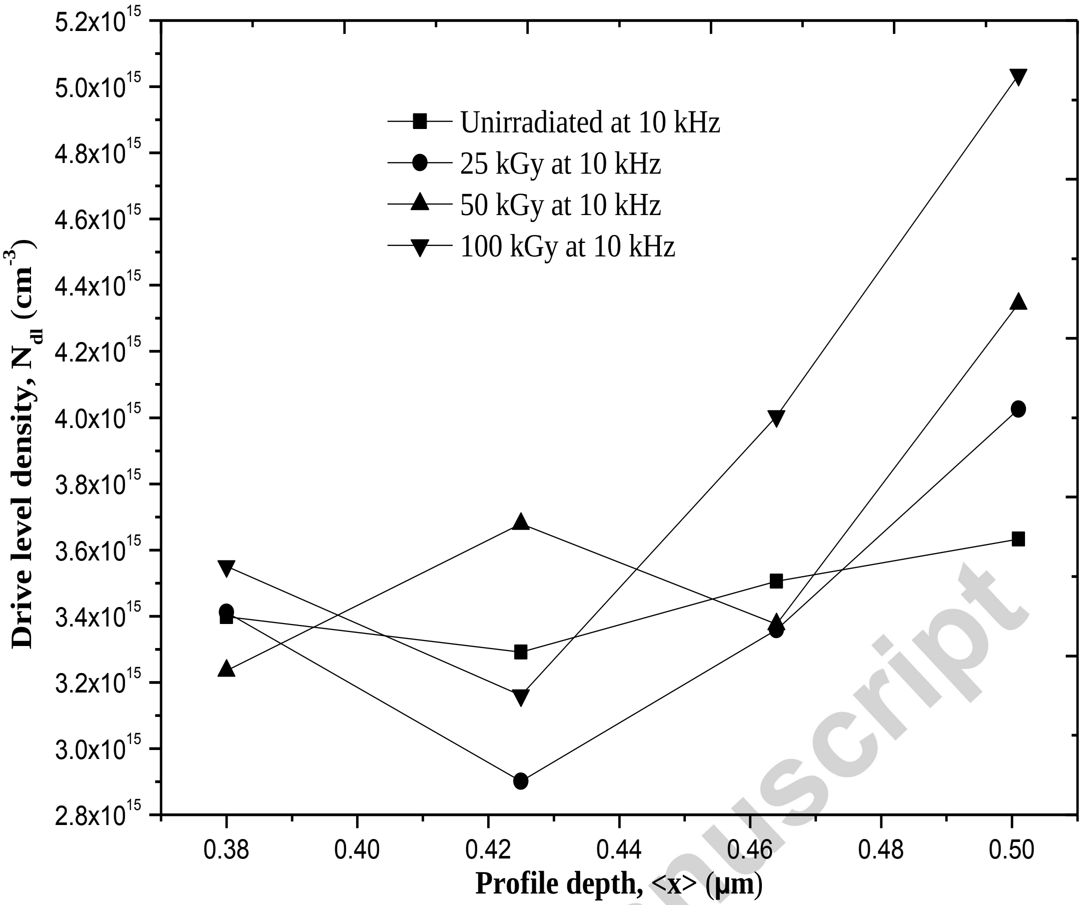

1.0x10^16
8.0x10^15
6.0x10^15
4.0x10^15
2.0x10^15
Drive level density, N_dl (cm^-3)
Unirradiated at 5 kHz
25 kGy at 5 kHz
50 kGy at 5 kHz
100 kGy at 5 kHz
0.38
0.40
0.42
0.44
0.46
0.48
0.50
Profile depth, <x> (µm)

Fig. 9



Unirradiated at 10 kHz
25 kGy at 10 kHz
50 kGy at 10 kHz
100 kGy at 10 kHz
Drive level density, N_{dl} (cm^{-3})
Profile depth, <x> (μm)
5.2x10^{15}
5.0x10^{15}
4.8x10^{15}
4.6x10^{15}
4.4x10^{15}
4.2x10^{15}
4.0x10^{15}
3.8x10^{15}
3.6x10^{15}
3.4x10^{15}
3.2x10^{15}
3.0x10^{15}
2.8x10^{15}
0.38
0.40
0.42
0.44
0.46
0.48
0.50

Fig. 10

the displacement of silicon atoms from their crystal lattice by introducing vacancies. The distributions of vacancies are not being uniform, because the vacancies from secondary displacements will lie relatively close to the associated primary vacancy. Hence the profiles are non-uniform after the irradiation (Tada et al., 1982). Therefore, from this study we can conclude that the radiation induced displacement damage is not uniform throughout the active region of silicon solar cell and response of the defects depends on the measurement frequency.

4. Conclusions

The effect of 8 MeV electron irradiation on the silicon solar cells parameters such as the carrier concentration, depletion layer width, the density of interface states and the trap time constant has been studied systematically by using C – V, C – F, G – F and DLCP measurements and the following conclusions were drawn.

- Capacitance – voltage measurements indicate that there is a slight decrease in the carrier concentration and small increase in depletion layer width due to electron irradiation. The built in potential remains the same for all doses. Hence radiation induced defects influence on the carrier concentration by trapping the charge carriers.
- The values of the density of interface states and the interface trap time constant is found to increase with increasing electron dose because of displacement damage induced in silicon solar cell due to electron irradiation.
- The variation of capacitance with frequency shows that electron irradiation has not contributed considerably to the increase of deep level defects.
- The DLCP studies of silicon solar cell gave responding state densities in the range 10^{15} cm^{-3} to 10^{16} cm^{-3}. The displacement damage formed due to electron is not uniform throughout the active region of c-Si solar cell. The response of these defects depends on measurement frequency.

5. Acknowledgement

The authors thank the Staff of Microtron Centre, Mangalore University, for their help during irradiation and Solar Panel Division, ISRO Satellite Centre for providing the samples. The authors thank the encouragement and support given by the Management of M. S Ramaiah University of Applied Sciences, Bangalore and Mangalore Institute of Technology and Engineering, Moodbidri.

References

Bhat, P.S., Rao, A., Krishnan, S., Sanjeev, G., Puthanveettil, S.E., 2014. A study on the variation of c-Si solar cell parameters under 8MeV electron irradiation. Sol. Energy Mater. Sol. Cells. 120, 191–196.

Biccari, F., 2009, Defects and Doping in Cu2O. Ph.D. Thesis. Sapienza – University of Rome, December 2009.

Bourgoin, J.C., Angelis, N.D., 2001. Radiation induced defects in solar cell materials. Sol. Energy Mater. Sol. Cells. 66, 467-477.

Cakar, M., Yldrm, N., Dogan, H., Turut, A., 2007. The conductance and capacitance–frequency characteristics of Au/pyronine-B/p-type Si/Al contacts. Appl. Surf. Sci. 253, 3464.

Cohen, J.D., 2005. Subcontract Report, NREL/SR-520-38676.

Corbett, J.W., 1966. Solid State Physics, Academic Press, New York.

Ganesh, Prashanth, K.C., Nagesh, Y.N., GnanaPrakash, A.P., Umakanth, D., Pattabi, M., Siddappa, K., Salkalachen, S., Roy, A., 1999. Modification of power diode characteristics using bremsstrahlung radiation from Microtron. Radiat. Phys. Chem. 55, 461–464.

Heath, J.T., Cohen, J.D., Shafarman, W.N., 2004. Bulk and metastable defects in CIGS thin films using drive level capacitance profiling. J. Appl. Phys. 95(3), 1000–1010.

Hisamatsu, T., Kawasaki, O., Matsuda, S., Tsukamoto, K., 1998. Photoluminescence study of silicon solar cells irradiated with large fluence electrons or protons. Radiat. Phys. Chem. 53, 25.

Hugger, P.G., 2011. Structural and electronic properties of hydrogenated nanocrystalline silicon employed in thin film photovoltaic's. Ph.D Thesis, University of Oregon.

Hussain, I., Soomro, M.Y., Bano, N., Nur, O., Willander, M., 2012. Interface trap characterization and electrical properties of Au-ZnO nanorod Schottky diodes by conductance and capacitance methods, J. Appl. Phys. 112.

Kawasuso, A., Hasegawa, M., Suezaki, M., Yamaguchi, S., Sumino, K., 1995. Charge State Dependences of Positron Trapping Rates Associated with Divacancies and Vacancy-Phosphorus Pairs in Si. Jpn. J. Appl. Phys. 34, 2197-2206.

Lei, B., Hou, W.W., Li, S., Yang, W., Chung, C., Yang, Y., 2011. Cadmium ion soaking treatment for solution processed $CuInS_x Se_{2-x}$ solar cells and its effect on defect properties. Sol. Energy Mater. Sol. Cells. 95(8), 2384–2389.

Nicollian, E.H., Brews, J.R., 1982. Metal Oxide Semiconductor Physics and Technology, Wiley, New York.

Ohshima, T., Morita, Y., Nashiyama, I., Kawasaki, O., Hisamatsu, T., Nakao, T., Wakow, Y., Matsuda, S., 1996. Mechanism of anomalous degradation of silicon solar cells subjected to high-fluence irradiation. IEEE transactions on nuclear science, 43(6), 2990-2997.

Rao, A., Krishnan, S., Sanjeev, G., Siddappa, K., 2010. Temperature and 8 MeV electron irradiation effects on GaAs solar cells. Pramana. 74(6), 995–1008.

Rao, A., Krishnan, S., Sanjeev, G., Siddappa, K., 2009. Effect of 8 MeV Electrons on Au/n-Si Schottky diodes. Int. J. Pure. Appl. Phys. 5(1), 55.

Schroder, D., 1998. Semiconductor Material and Device Characterization, second ed. Wiley, Toronto.

Siddappa, K., Ganesh, Ramamurthy, S.S., Soni, H.C., Srivastava, P., Sheth, Y., Hemnani, 1998. Variable energy microtron for R & D work. Radiat. Phys. Chem. 51, 441–442.

Srivastava, P.C., Pandey, S.P., Asokan, K., 2006. A study on swift heavy ion irradiated crystalline Si-solar cell, Nucl. Instrum. Methods B. 244(1), 166–170.

Sze, S.M., 1981. Physics of Semiconductor Devices, second ed. Wiley Interscience, New York.

Tada, H.Y., Carter, J.R., Anspaugh, B.E., Downing, R.G., 1982. Solar cell radiation handbook, third ed. JPL Publication.

Wei, C.K., 2010. Impact of interface states on sub-threshold response of III-V MOSFETs, MOS HEMTs and tunnel FETs. M.S Thesis, Pennsylvania State University, 27-28.

Figure captions

Fig. 1. C-V Characteristics under dark condition at various doses of 8 MeV electron.

Fig. 2. Plot of $1/C^2$ versus Voltage for an electron irradiated Silicon solar cell.

Fig. 3. Carrier concentration of the silicon solar cell as a function of dose.

Fig. 4. G_p/ω versus frequency characteristics of silicon solar cell for different doses.

Fig. 5. The variation of interface state density with 8 MeV electron dose.

Fig. 6. The variation of trap time constant as a function of 8 MeV electron dose.

Fig. 7. Variation of capacitance with frequency at -1 V for silicon solar cell irradiated with different doses of 8 MeV electron.

Fig. 8. The DLCP profile for silicon solar cell at different frequencies before irradiation.

Fig. 9. The DLCP profile for an electron irradiated silicon solar cell at room temperature and 5 kHz.

Fig. 10. The DLCP profile for an electron irradiated silicon solar cell at frequency 10 kHz.

Highlights

- Space grade Si solar cells were subjected to 8 MeV electron radiation
- Capacitance and conductance measurements were done before and after irradiation
- Density of interface states and the interface trap time constant is found to increase with increasing electron dose
- The displacement damage formed due to electron is not uniform throughout the active region of c-Si solar cell.