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Improved radiation resistant properties of electron irradiated c-Si solar cells

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HIGHLIGHTS

- c-Si solar cells were fabricated and subjected to 9 MeV electron radiation.
- I-V measurements of pre and post irradiated and annealed solar cells.
- Capacitance and conductance characteristics were done before and after irradiation.
- Increase in density of interface states and trap time constant after irradiation.
- FSP solar cell showed lower degradation and higher efficiency recovery ratios.

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ABSTRACT

This work investigates the radiation tolerance of c-Si solar cells under electron energy of 9 MeV with fluence of 5.09 × 1016 cm.$^{-2}$ The solar cells were fabricated and characterized before and after electron irradiation through current-voltage (*I-V*), capacitance-voltage (*C-V*), and frequency dependent conductance (G_p) measurements. The results revealed that all the output parameters such as short circuit current (I_{sc}), open circuit voltage (V_{oc}), series resistance (R_s), and efficiency (η) were degraded after electron irradiation. Capacitance-Voltage measurements show that there is a slight decrease in the base carrier concentration (N_D), while a small increase in depletion layer width (W_D) was due to an increase in the base carrier concentration. Enhancements in the density of interface states (N_{ss}), and trap time constant (τ) have been observed after electron irradiation. The results has revealed that back surface field (BSF) solar cell with front surface passivation (FSP) presented lowest efficiency degradation ratio of 11.3% as compared to 15.3% of the solar cell without FSP. The subsequent annealing of irradiated Si solar cell devices revealed that the Si solar cell with FSP demonstrated high efficiency recovery ratio of 94% as compared to non-FSP solar cell.

1. Introduction

Solar cells are highly sensitive to radiation environment, especially in the presence of charged particles (electrons/protons etc.) (HU, 2006). Radiation of this type are abundantly available in space that cannot be avoided and are widely used to study ionization/displacement damage effects in the devices (Srour et al., 2003). Lattice defects in semiconductor devices are the outcome of exposure to these types of high-energy radiation. Such defects are responsible for decreasing the output power of the solar cells (Yamaguchi, 2001; Ali et al., 2013). Additional energy levels in the band gap are the ultimate result of the changes caused by charged particles in the lattice periodicity. These new energy levels or defect centres vary the electrical characteristics of solar cells (Sathyanarayana Bhat et al., 2015).

These radiation induced defect centres reduce the base carrier concentration, increase the series resistance and broaden the depletion layer width (Sathyanarayana Bhat et al., 2014). Usually, one to two displacements with an introductory rate of the order of 1 cm^{-1} are produced due to electrons in the range of 0.1 to several MeV (Corbett, 1966). On the average, a fluence of 10^{16} cm^{-2} is important to create a homogeneous distribution of displacements with 10^{16} cm^{-3} concentrations (Bourgoin and De Angelis, 2001). Capacitance-voltage (*C-V)* curves provide the important information about the carrier concentration, built-in voltage and the depletion layer widths of the solar cells (Rao et al., 2009). One of the most reliable and commonly adopted interface trap density (N_{ss}) extraction technique is the conductance method which is used to

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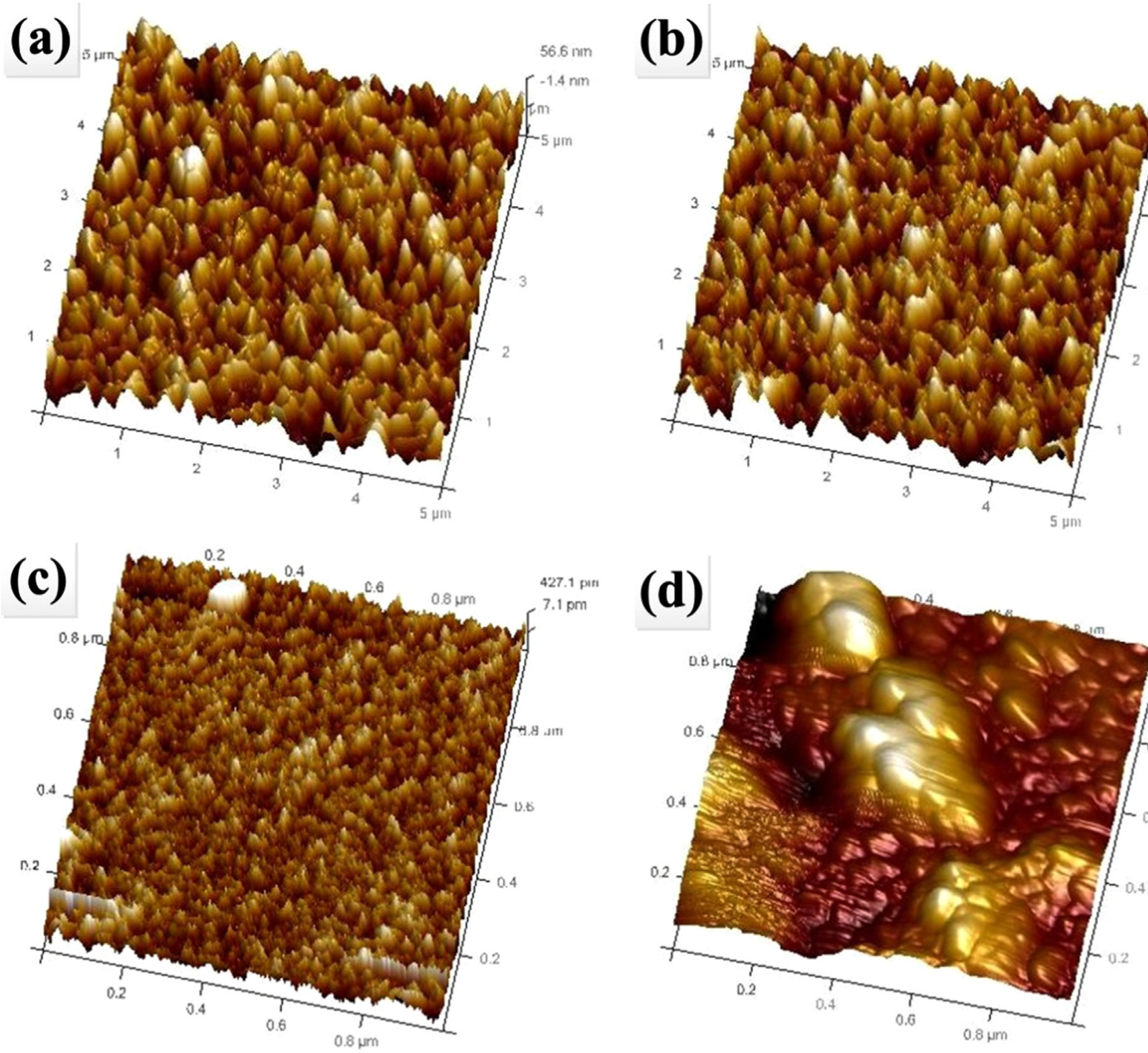

Fig. 1. AFM images of (a) SiO_2 as AR coating for solar cell with FSP, (b) SiO_2 as AR coating for solar cell without FSP, (c) as grown silicon and (d) Al alloying BSF.

evaluate the passivation of interfaces (Nicollian and Brews, 1982). This technique involves the measurement of an equivalent parallel conductance of the solar cell as a function of frequency. This method involves the loss mechanism produced by the capture and emission of carriers from the interface traps and can be used to extract the interface state density (Kao et al., 2010).

The initial efficiency of irradiated solar cell can be restored by annealing the solar cell for various time duration depending on the radiation fluence and radiation resistant properties of solar cell (Khan et al., 2002a; Kuendig and Shah, 2002). Annealing process involves the passivation of the irradiation induced defects of the solar cell with the annealing temperatures ranging from room temperature to 475 °C (Kawasuso et al., 1995; Yamaguchi et al., 1984).

In the present research work radiation tolerance of silicon cells was characterized using 9 MeV electron irradiation of 5.09×10^{16} e/cm^2. Changes in the electrical performance, *C–V* and frequency dependent conductance measurements as well as recovery of the solar cells under thermal annealing are presented in this paper.

2. Experimental techniques

The solar cells were fabricated using boron-doped p-type (100) oriented Si wafers with a size of 2×2 cm^2 and thickness of 100 μm. After RCA clean the p-n junction was realized by performing the thermal diffusion of the phosphorous atoms in a quartz tube furnace at 1000 °C. Phosphosilicate glass (PSG) formed in the diffusion process was then removed by using 1:50 HF: H_2O. The samples were then rinsed with deionized (DI) water of high purity ($\rho > 18.2$ MΩcm). Back surface field (BSF) was formed by 3 μm thick layer of high-purity aluminum (99.999%). Aluminum layer was thermally evaporated on the entire back surface and then annealed at 850 °C, followed by SiO_2 antireflection coatings. One sample was thermally passivized on the front surface while the other remained un-passivized. The refractive index, thickness, and reflectance of the films were measured using an optical reflectometer (Filmetrics F20) employing white light in a frequency range of 3×10^{14}–7.5×10^{14} Hz (using combinations of different wavelengths ranging from 400 nm to 1000 nm). The surface morphology was characterized using an atomic force microscope (Dimension Edge, Bruker). After making the contacts metallization and annealing, the photocurrent measurements before and after electron irradiation were made using a simulator (Leios IV SolarCT) under AM0 and white light illumination conditions. The *I–V* measurements were obtained immediately after the electron irradiation. Capacitance voltage (*C-V*) and dark *I-V* characteristics