INVESTIGATION OF CHARGE CARRIER TRANSPORT BEHAVIOUR IN SILICON HETEROJUNCTION SOLAR CELLS

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ABSTRACT

To establish the silicon heterojunction solar cells' technology in near future for harvesting the abundant solar energy, there is a strong need to develop a deeper understanding of the internal device operation mechanisms by optimizing the device process conditions for augmenting the device power conversion efficiency.

With this motivation in the thesis work, we have analyzed a-Si:H(p)/a-Si:H(i)/c-Si(n) heterojunction silicon solar cell having the S-shape current density-voltage characteristics with low fill factor and open-circuit voltage, using quantum efficiency (QE) characterization technique under forward/reverse voltage and different light (blue, infrared, and white) bias conditions. The curvature of the S-shape is sensitive to excitation light intensities due to modification in junction barrier potential (variation in quasi-Fermi levels splitting). With forward bias voltage alone near/above S-shape region, the cell's QE is uniformly reduced due to a reduction in junction field and dominance of barrier for collection of holes. However, with blue and white light at bias

voltages close to S-shape characteristics, a uniform improvement of QE in the broad wavelength region is observed due to defects saturation at the junction interface and photoconductivity in the a-Si layers. With white light and voltage bias, the cell's QE is anomalously improved and even crossed the QE response at no voltage/light bias conditions in the blue region due to defects saturation in a-Si:H layers. Whereas, under infrared light and voltage bias conditions, defect saturation is not displayed in the QE due to carrier generation in a deeper region of the cell after crossing unabsorbed photons from the front region.

Furthermore, to explore the effect of the device process conditions, we have investigated a-Si:H/c-Si heterojunction silicon solar cells, which are fabricated by Infra-Red (IR) radiative or resistive pre-heating of silicon wafers before the a-Si:H layers deposition. The cells with IR radiative or resistive pre-heating have led to without S-shape (WoS) or with S-shape (WS) in their light current density-voltage (J-V) characteristics, respectively. The Suns-Voc analysis has shown no front/back metal contact barrier for the minority carriers in both the cells. The light- and voltage-bias dependent quantum efficiency of the WS cell has shown the hindrance of carrier collection at the a-Si:H/c-Si interface due to the band-offset, while, more defective a-Si:H layers are observed in the WoS cell. The WS and WoS cells' temperature-dependent dark J-V characteristics have revealed that the carrier transport is through tunnel assisted recombination and tunnelling, respectively. The IR pre-heating of wafers has resulted in the reduction of the bandgap of a-Si:H and facilitated for minimizing the band-offset at the interface, whereas; the resistive heating has shown the relatively better a-Si:H/c-Si interface passivation due to the optimum hydrogen presence in the a-Si:H layer.

To further understand the charge transport in different cases, the heterojunction silicon solar cells displaying two different open-circuit voltages and having S-shape light current density-voltage characteristics are analyzed by observing a change in quantum efficiency (QE) with voltage and light bias conditions. With forward bias voltage close to (and beyond) the S-shape region, the QE is reduced uniformly in the entire region due to dominance of barrier over junction field for collection of holes. Under white light and the voltage bias; an improvement of QE is observed due to saturation of defects at the interface and an enhancement of photoconductivity of the amorphous Si layers. The cell with a small open-circuit voltage showed considerable improvement in QE from the interfacial region (e.g. in the short and long wavelength region), in contrast, the response in the bulk region (intermediate wavelength region) remains flat.

Also, the S-shape in light current density–voltage (J-V) characteristics of MoO_x hole-selective contact (Ag/ITO/MoO_x/c-Si(n)/LiF_x/Al) solar cell in comparison to a-Si/c-Si SHJ cell (Ag/ITO/a-Si:H(p+)/a-Si:H(i)/c-Si(n)/a-Si:H(i)/a-Si:H(n+)/ITO/Ag) are studied. The cells are analyzed by the Suns-V_{OC}, and quantum efficiency with voltage- and light-bias measurements. The MoO_x cell has shown turn-around in the Suns-V_{OC} graph, whereas a linear behaviour has been observed from the SHJ cell. Quantum efficiency analysis has revealed the poor performance of the MoO_x cell from the backside; for this cell, the minority carrier diffusion lengths also are estimated. The S-shape in light J-V graph of MoO_x cell is due to carrier extraction barrier for trap assisted tunneling at the MoO_x/c-Si interface by the insufficient number of traps, which also is reflected as turn-around in the Suns-V_{oc} characteristics. Whereas; the S-shape in the J-V graph of SHJ cell is due to the minority charge carrier barrier from the band-offset at the a-Si/c-Si junction.

We also have investigated the Ni_xO based carrier-selective contact (CSC) silicon solar cells' carrier transport mechanisms without and with the SiO_x passivation interlayer having the device configuration of Ag/ITO/Ni_xO/n-Si/LiF_x/Al. For this purpose, we have adopted temperature-dependent dark current density-voltage (J-V) and photo-induced capacitance-voltage (C-V) characterization techniques. With the SiO_x interlayer, the thermionic (Schottky) emission at the high-forward bias voltage region (>0.4 V) and the carrier tunnelling at the low-forward bias voltage region (<0.4 V) have determined the carrier transport in the CSC cell. Whereas, without the SiO_x layer at the Ni_xO/c-Si interface, the carrier recombination has observed due to relatively large interface/surface defect states, which has reflected with the smaller activation energy for saturation current and strong temperature-dependent ideality factors in high-forward bias voltage region. The C-V analysis of the cell without SiO_x has confirmed the inability to hold the excess photo-generated charge carriers because of the poor interface quality in comparison to the cell with the SiO_x layer. The Ni_xO/c-Si junction with the SiO_x layer has led to the higher built-in voltage and open-circuit voltage representing the better interface passivation quality by suppressing some of the interface/surface defect states.