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Thesis Title - INVESTIGATION OF INTRINSIC AMORPHOUS SILICON PASSIVATION LAYERS FOR SILICON HETEROJUNCTION SOLAR CELLS FABRICATION

ABSTRACT

A feasible way to tackle the growing energy demand is to harvest solar energy efficiently to produce electricity via photovoltaic devices (also known as solar cells). Crystalline silicon-based solar cells are the leading technology in fulfilling the demand in the photovoltaic industry due to stability and reliability in fabrication processes. Silicon heterojunction (SHJ) based solar cell technology is one of the options apart from other silicon solar cell technologies due to the relatively higher power conversion efficiency.

This thesis addresses the strategies to improve the SHJ solar cell power conversion efficiency by investigating the hydrogenated intrinsic amorphous (i-a-Si:H) buffer layer grown by the plasma-enhanced chemical vapor deposition technique. The primary purpose of the i-a-Si:H is to passivate the c-Si surface's dangling bonds, lowering the defect density at the a-Si:H/c-Si interface. As a result, it has now been widely acknowledged that optimizing the i-a-Si:H passivating layers is the key to producing high-performance SHJ solar cells. The microstructure of the i-a-Si:H layer is directly linked to its deposition conditions and is mainly responsible for the passivation quality of the c-Si wafer in the minimization of minority carrier recombination.

With this motivation, we have first explored the effect of the total flow rate variation (30–80 sccm) of precursor gases on the passivation of the i-a-Si:H/c-Si interface during the PECVD deposition of i-a-Si:H layer using SiH_4/H_2 (equal ratio) plasma. However, a window of intermediate gas flow rates has been identified to achieve relatively good quality surface passivation. At an intermediate gas flow rate, a maximum effective minority carrier lifetime

(τ_{eff}) above 1 ms, implied open-circuit voltage (iVoc) of 710 mV, and low interface defect density (D_{it}) of 3.5×10^9 cm^{-2}eV^{-1} is achieved. Besides, the precursor gasses (SiH_4:H_2) discharge emission characteristics and the a-Si:H film characteristics (hydrogen concentration, film density, optical band gap, and refractive index) are also investigated. The front-junction silicon heterojunction solar cells with flow rate variation are fabricated on n-type textured silicon wafers, and ~17% conversion efficiency and open-circuit voltage (V_{oc}) close to 690 mV is achieved at an optimized gas flow rate. Thus, this work on a variation of gas flow rate provided insight regarding the correlation of the transient plasma instability, SiH_4 depletion, secondary reactions in the plasma, and flux of radicals towards the substrate for the film growth for a good level of surface passivation.

Furthermore, the surface passivation recovery by post-deposition annealing of a-Si:H/c-Si/a-Si:H in a vacuum and at different pressure conditions of annealing have been investigated. It is noticed that there has been a gradual improvement in the effective minority carrier lifetimes (MCL) and lowering of interface defect density (D_{it}) with an increase in the annealing pressure when compared to vacuum annealing. Ambient annealing at atmospheric pressure (760 Torr), the lifetime drastically enhances from 456 µs to 1057 µs with the lowest D_{it} of 8.1×10^9 eV^{-1}cm^{-2} compared to the as-deposited and vacuum annealed conditions of 1.77×10^{10} eV^{-1}cm^{-2} and 2.50×10^{10} eV^{-1}cm^{-2}, respectively. This MCL's value variation can be related to the inter-diffusion of atomic hydrogen within the a-Si matrix and reorganization of the strained bonds leading to the structural improvement, which is supported by the spectroscopic ellipsometry as well as Fourier Transfer Infrared Spectroscopy analysis. During the initial growth conditions of the film, as-deposited films seem to be dominated by non-equilibrium local network structure at the interface whereas the annealed films may be equilibrated by decreasing the built-in strain of bulk a-Si:H network and saturating the silicon atom orbitals.

To further improve the crystalline silicon surface passivation by minimizing the interface defect density at the a-Si/c-Si interface, a stack of i-a-Si:H passivation layers deposited at two different temperatures is investigated. The microstructure factor (R*) of the PECVD-grown intrinsic amorphous silicon (i-a-Si:H) layer plays a crucial role in crystalline silicon (c-Si) surface passivation and charge carrier transport in silicon heterojunction solar cells have been studied. The initial i_1-a-Si:H layer at ~150 ºC with a high R*, whereas the second i_2-a-Si:H layer at 230 ºC with a low R* is deposited on the c-Si as a stack. Ex-situ ellipsometry analysis of i-a-Si:H layers provided information about the thin a-Si:H film's void fraction as a result of changes in the $Si-H_2$ and Si-H bonding environment, which is crucial for atomic H migration towards the i-a-Si:H/c-Si interface. Later, the low- and high-temperature i-a-Si:H layer stack in combination improved the cell precursor passivation to ~2.1 ms with an implied V_{oc} of ~714 mV. The device's power conversion efficiency increased to about 19.06 % by implementing the optimized thickness (2 nm + 8 nm) of the i-a-Si:H stack (with 40 % void fraction in the i_1-a-Si:H layer).