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Role of a-Si:H buffer layer at the p/i interface and band gap profiling of the absorption layer on enhancing cell parameters in hydrogenated amorphous silicon germanium solar cells

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ABSTRACT

Separate influences of a hydrogenated amorphous silicon (a-Si:H) buffer layer at the p/i interface and staircase band gap profiling of entire absorption layer on cell parameters, such as open-circuit voltage (V_{oc}), short-circuit current density (J_{sc}) and fill factor (FF), of hydrogenated amorphous silicon germanium (a-SiGe:H) thin film solar cells are discussed. An added thin a-Si:H buffer layer at the p/i interface can mainly improve V_{oc} and J_{sc} while the staircase band gap profiling can enhance FF. Consequently, a combination of the buffer layer and band gap profiling can lead to significantly enhance V_{oc}, J_{sc} and especially FF. A significant performance-improvement of the a-SiGe:H solar cell from 8.3% up to 9.8% was recorded by this combination. Role of the buffer layer and band gap profiling process was examined by empirical results and simulations.

1. Introduction

The most essentially persistent pursuit in thin film silicon solar cells for competitive photovoltaic applications have focused on further enhancing the performance and stability [1]. All efforts have tended to multi-junction designs, in which the highest performance has been obtained for triple-junction designs [2,3]. In these structures, hydrogenated amorphous silicon germanium (a-SiGe:H) thin film solar cells mainly play a role as middle sub-cells, along with hydrogenated amorphous silicon (a-Si:H) top cells and microcrystalline silicon (μc-Si:H) bottom cells. Further efficiency enhancement of these structures is supposed to further improving the quality of individual single junction thin film solar cells. In a-SiGe:H thin film solar cells, it has been well-known that an efficiency improvement can be caused by using different buffer layers (BLs) at the p/i or i/n interface and appropriate band gap profiling (BGP), the so-called band gap grading [4–7]. However, there have been different observations about effect of BLs and BGP on cell performance. D. Lundszien et al. showed that the complex band-gap grading technique can be replaced simply by using appropriately thin a-Si:H buffer layers at both interfaces [8,9]. In other aspects, B. Samanta et al. indicated that the light-induced degradation was faster in cells with buffer layers at the p/i interface; and they also proposed that for the absolutely highest stabilized efficiency of the double-junction cell, the buffer layer at the interface should be set at the top cell only [10]. Moreover, S. Guha et al. [11] and V. Dalal et al. [12] showed opposite observations

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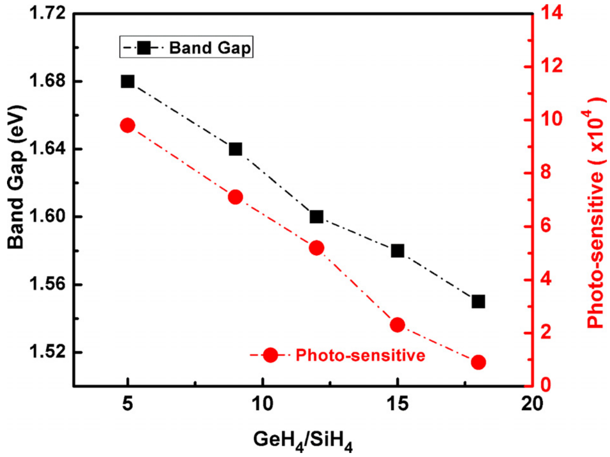

Fig. 1. Opto-electrical properties of single a-SiGe:H layers with various GeH_4/SiH_4 gas ratios.

about effect of the reverse profiling on fill factor parameter. As a result, effect of BLs and BGP on cell parameters of a-SiGe:H solar cells is still debates.

In this work, we experimented separately an a-Si:H buffer at the i/n interface and BGP of narrow-gap a-SiGe:H solar cells, and showed separate roles of the buffer and BGP on the a-SiGe:H cell parameters. In addition, a combination of both BL and BGP in a-SiGe:H cell structure is proposed as a favorable design for further cell efficiency enhancement.

2. Experiment

Plasma enhanced chemical vapor deposition (PECVD) cluster system with multi-chamber at the 13.56 MHz RF power source was used for cell fabrication. The single junction a-SiGe:H thin film solar cells in the p-i-n superstrate configuration were fabricated on the commercial FTO coated glass. An aluminum-doped zinc oxide (AZO) thin layer of 30 nm was coated on the FTO surface by sputtering system to protect the FTO electrode layer under bombardment of hydrogen plasma during preparation. Double p-type layers were used including a hydrogenated microcrystalline silicon oxide (p-μc-SiO_x:H) and an amorphous silicon oxide (p-a-SiO_x:H), which directly contacts with the front FTO electrode and intrinsic layer, respectively. N-type layers were hydrogenated microcrystalline silicon (n-μc-Si:H) layers. Intrinsic a-SiGe:H layers (i-a-SiGe:H) were deposited by adding germane (GeH_4) gas, beside silane (SiH_4) and hydrogen (H_2) reactant gases. Band gap profiling of the i-a-SiGe:H layers was implemented by controlling the band gap of the intrinsic layers, i.e. controlling [GeH_4/SiH_4] gas ratios, as equal staircase profiles of five steps during deposition. The band gap of the graded i-a-SiGe:H layers was gradually increased from 1.55 eV at the p-side to 1.68 eV at the n-side. The total film thickness of the i-a-SiGe:H layers was 300 nm.

Optical properties of the i-a-SiGe:H layers with and without band gap grading were examined by Fourier transform infrared spectroscopic (FT-IR) and spectroscopic ellipsometry (VASE®, J. A. Woollam). Electrical properties such as dark- and photo-conductivity of the i-a-SiGe:H layers (300 nm) with various optical band gap, as shown in Fig. 1, were examined in an aluminum co-planar electrode configuration using a programmable Keithley 617 electrometer. The current density-voltage (J-V) curve characteristics of the cells were tested in both standard dark and illumination conditions using AM 1.5 illumination. The band diagrams were simulated from the amorphous semiconductor analysis (ASA) simulation program.

3. Results and discussion

Apart from the optimization of the p- and n-type doped layers, which were published elsewhere by our group [13,14], quality of absorption a-SiGe:H layer is one of the important factors, which can affect strongly cell performance. Fig. 1 shows optoelectronic properties of the single a-SiGe:H layers with various optical band gaps, i. e. different Ge contents. It shows that the photosensitive, ratio of photo-conductivity to dark-conductivity, of these layers is in orders of 10^4. Such ranges of the photosensitive are already in the acceptable values, characterizing the appropriate quality of the photon-absorption layers in thin film cell structures [15,16]. The structural schemata of the p-i-n a-SiGe:H solar cells with varying a-Si:H BLs at the p/i interface and BGP process of entire absorption layer are shown in Fig. 2. In these diagrams, cell A has a constant band gap absorption layer of 1.55 eV without any buffers at the p/i interface while cell B has an a-Si:H buffer of 15 nm at the p/i interface. Cell C has the staircase BGP while at cell D, an a-Si:H buffer layer at the p/i interface is combined to the staircase BGP. The J-V curves under 1 sun illumination of the cells are shown in Fig. 3. Cell parameters including open circuit voltage (V_{oc}), short circuit current (J_{sc}), fill factor (FF) and efficiency (E_{ff}), extracted from the J-V curve data, are presented in Table 1. The results show that the V_{oc} and J_{sc} of cell B and D, compared with that of cell A and C respectively, can be significantly increased by adding the a-Si:H BL at the p/i interface. In comparison between cells with and without band gap profiling, it can be seen that cells with band gap profiling, such as cell C and D, show higher FF than ones without profiling, cell A and B. In