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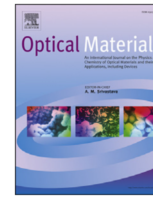

The role of hydrogenated amorphous silicon oxide buffer layer on improving the performance of hydrogenated amorphous silicon germanium single-junction solar cells

Jaran Sritharathikhun*, Sorapong Inthisang, Taweewat Krajangsang, Patipan Krudtad, Suttinan Jaroensathainchok, Aswin Hongsingtong, Amornrat Limmanee, Kobsak Sriprapha

Solar Energy Technology Laboratory (STL), NECTEC, National Science and Technology Development Agency (NSTDA), 112 Thailand Science Park, Thanon Phahonyothin Tambon Khlong Nueng, Amphoe Khong Luang, Pathum Thani 12120, Thailand

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A B S T R A C T

Hydrogenated amorphous silicon oxide (a-$Si_{1-x}O_x$:H) film was used as a buffer layer at the p-layer (μc-Si_{1-x}Ox:H)/i-layer (a-$Si_{1-x}Ge_x$:H) interface for a narrow band gap hydrogenated amorphous silicon germanium (a-$Si_{1-x}Ge_x$:H) single-junction solar cell. The a-$Si_{1-x}O_x$:H film was deposited by plasma enhanced chemical vapor deposition (PECVD) at 40 MHz in a same processing chamber as depositing the p-type layer. An optimization of the thickness of the a-$Si_{1-x}O_x$:H buffer layer and the CO_2/SiH_4 ratio was performed in the fabrication of the a-$Si_{1-x}Ge_x$:H single junction solar cells. By using the wide band gap a-$Si_{1-x}O_x$:H buffer layer with optimum thickness and CO_2/SiH_4 ratio, the solar cells showed an improvement in the open-circuit voltage (V_{oc}), fill factor (FF), and short circuit current density (J_{sc}), compared with the solar cells fabricated using the conventional a-Si:H buffer layer. The experimental results indicated the excellent potential of the wide-gap a-$Si_{1-x}O_x$:H buffer layers for narrow band gap a-$Si_{1-x}Ge_x$:H single junction solar cells.

1. Introduction

Recently, wide band gap hydrogenated amorphous silicon oxide (a-$Si_{1-x}O_x$:H) and hydrogenated microcrystalline silicon oxide (μc-$Si_{1-x}O_x$:H) materials have attracted much attention as promising materials for the fabrication of high performance Si-based thin film solar cells, wherein they are applied as p-, n- and i-layers instead of the conventional hydrogenated amorphous silicon (a-Si:H) and hydrogenated microcrystalline silicon (μc-Si:H) layers. Wide band gap p-type microcrystalline silicon oxide (p-μc-$Si_{1-x}O_x$:H) has been used as a window layer material because of its low light absorption and high conductivity [1]. On the other hand, intrinsic hydrogenated amorphous silicon oxide (i-a-$Si_{1-x}O_x$:H) has been used as the top cell of multi-junction solar cells for enhancing the spectral response in the short wavelength region [2–6]. In the case of silicon-based thin film solar cells, it is widely known that buffer layers play the role of controlling the quality of the interface between the p- and i- layers in order to increase both the open circuit voltage (V_{oc}) and the fill factor (FF). For this purpose, conventional intrinsic hydrogenated amorphous silicon (i-a-Si:H) has been used [7–11]. Some research groups have used i-a-$Si_{1-x}O_x$:H as buffer layers in a-Si:H solar cells in order to obtain a good compromise between a relatively high effective built-in potential (V_{bi}) and a relatively low recombination rate at the p/i interface [12–14]. Our group has previously reported a high efficiency of 9.4% for a hydrogenated amorphous silicon germanium (a-$Si_{1-x}Ge_x$:H) single junction solar cell by using the a-$Si_{1-x}Ge_x$:H VU-shape band gap profiling technique [15] and 11% for a-Si:H/a-$Si_{1-x}Ge_x$:H tandem solar cells using the conventional a-Si:H as a buffer layer for the interface between wide gap p-μc-$Si_{1-x}O_x$:H and narrow gap i-a-$Si_{1-x}Ge_x$:H [16]. However, there is still room for investigation of the a-$Si_{1-x}O_x$:H buffer layer in narrow band gap a-$Si_{1-x}Ge_x$:H solar cells as well as wide band gap a-Si:H and a-$Si_{1-x}O_x$:H solar cells. Moreover, the use of wide band gap a-$Si_{1-x}O_x$:H buffer layer between wide band gap p-μc-$Si_{1-x}O_x$:H and narrow band gap i- a-$Si_{1-x}Ge_x$:H, (resulting in a new device structure) needs to be

* Corresponding author.
E-mail address: jaran.sritharathikhun@nectec.or.th (J. Sritharathikhun).

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Table 1
Deposition condition for a-$Si_{1-x}O_x$:H films.

Parameters	Values
$SiH_4/H_2/CO_2$	1/10/0–0.6
Plasma frequency	40 MHz
Deposition temperature	180 °C
Deposition pressure	500 mTorr
Power density	42 mW/cm^2
Thickness	0.4 μm

investigated.

In this paper, we have applied a-$Si_{1-x}O_x$:H as a buffer layer in a-$Si_{1-x}Ge_x$:H single junction solar cells. The electrical, optical, and structural properties of the prepared a-$Si_{1-x}O_x$:H films were characterized. The study focused on the effects of variation in thickness of the a-$Si_{1-x}O_x$:H buffer layer and the carbon dioxide (CO_2) to the silane (SiH_4) ratio (during the thin film preparation) on the performance of the a-$Si_{1-x}Ge_x$:H single-junction solar cells. A comparison between solar cells containing the conventional a-Si:H buffer layer and those containing a-$Si_{1-x}O_x$:H buffer layer, developed in this study, was also carried out.

2. Experimental details

2.1. Deposition of the a-$Si_{1-x}O_x$:H films

The a-$Si_{1-x}O_x$:H films were prepared on soda lime glass and silicon substrate by high frequency plasma enhanced chemical vapor deposition (VHF-PECVD) at 40-MHz and substrate temperatures of approximately 180 °C in the chamber used for the deposition of p-layer. A gas mixture of silane (SiH_4), hydrogen (H_2), and CO_2 was used as the precursor. The base pressure in the deposition chamber was kept at about 2×10^{-6} Torr by using a turbo molecular pump backed up by a rotary pump. The deposition conditions for a-$Si_{1-x}O_x$:H films are summarized in Table 1.

The CO_2/SiH_4 ratio, during the preparation of a-$Si_{1-x}O_x$:H films, was varied between 0.0 and 0.6 to obtain films of varying thickness (maximum thickness = 0.4 μm). The E_{opt} of samples was measured by spectroscopic ellipsometry (SE) (J.A. Woollam, V-VASE series). The data was fitted and analyzed using the Tauc-Lorentz model [17].

2.2. Fabrication of a-$Si_{1-x}Ge_x$:H single junction solar cells

a-$Si_{1-x}Ge_x$:H single-junction solar cells were fabricated using the cluster type plasma enhanced chemical vapor deposition (PECVD) technique to obtain the following device structure: TCO coated glass (U-type, Asahi)/aluminum-doped zinc oxide (ZnO:Al)/p-μc-$Si_{1-x}O_x$:H (30 nm)/a-$Si_{1-x}O_x$:H buffer layer (0–9.8 nm)/a-$Si_{1-x}Ge_x$:H (300 nm)/n-type microcrystalline silicon (n-μc-Si:H) (30 nm)/ZnO:Al/Ag/Al, as shown in Fig. 1(a); the band diagram and the optical band gap of the p-i-n layer of the solar cells are shown in Fig. 1(b). For the deposition of p-μc-$Si_{1-x}O_x$:H layer, a-$Si_{1-x}O_x$:H buffer layer, and n-μc-Si:H layer, 40 MHz generator was used, while 27 MHz generator was employed for the i-a-$Si_{1-x}Ge_x$:H layer deposition. The a-$Si_{1-x}O_x$:H buffer layer was deposited in a same processing chamber as depositing the p-layer after p-layer deposition. In order to investigate the role of the buffer layer on the performance of the solar cells, a-$Si_{1-x}O_x$:H buffer layer of varying thickness (0–9.8 nm) and varying the CO_2/SiH_4 ratio in the range of 0.0–0.8, were used. The solar cells were isolated by laser scribing to an active area of 1.0×1.0 cm^2.

The photovoltaic (PV) parameters of single junction solar cells were investigated under standard test conditions (STC) at AM 1.5, 100 mW/cm^2, 25 °C using the light source and filter of a solar simulator (Wacom, model WXS-155S-L2). The external quantum efficiency (EQE) of the solar cells was characterized using a quantum efficiency measurement system (PV Measurement, QEW7).

3. Results and discussions

3.1. Effect of the CO_2/SiH_4 ratio on the electrical and optical properties of the a-$Si_{1-x}O_x$:H films

Fig. 2 shows the dark (σ_d) and photo conductivity (σ_{ph}) of the a-$Si_{1-x}O_x$:H films deposited using various CO_2/SiH_4 ratios in chambers

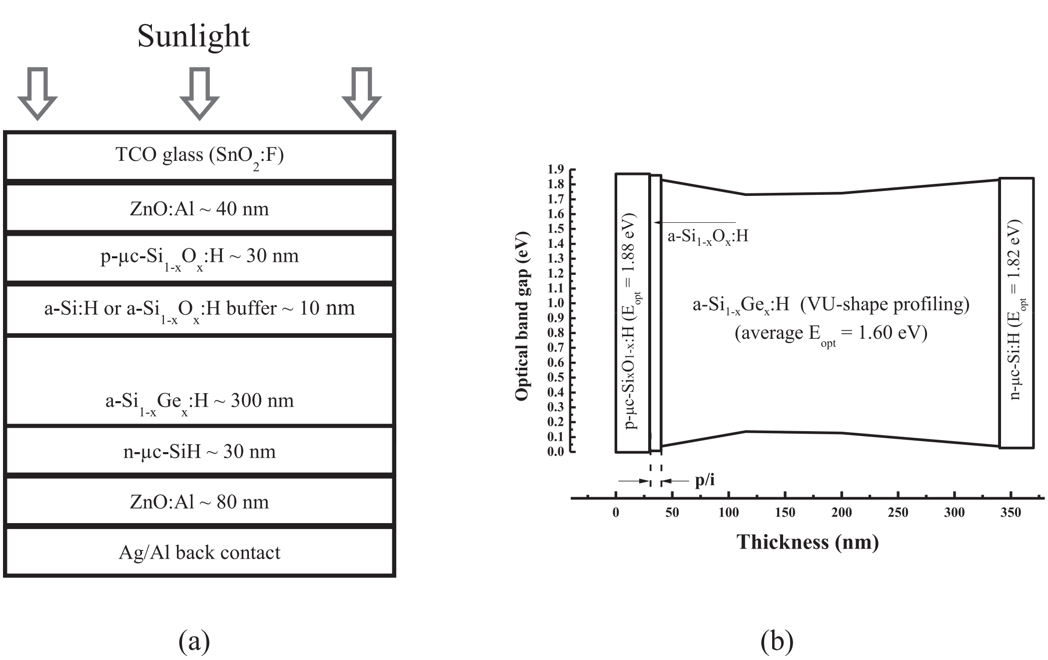

Fig. 1. (a). Schematic structure of the a-$Si_{1-x}Ge_x$:H single junction solar cell. (b). Schematic band diagram of the p-i-n layer of the a-$Si_{1-x}Ge_x$:H single junction solar cell.

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