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The Effects of Various Curvatures Characteristics on Stainless-Steel Substrates Using Back Correct Layer for CIS Films after RTP Selenization Process

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1. Introduction

Recently the highest efficiency of the CIGS-based thin film solar cells on soda lime glass substrates is 20.3% [1]. However, there are many disadvantages for CIGS-based solar cells on rigid substrates such as heavy weight and inflexibility. Flexible CIGS thin-film solar cells with their inherent properties of rollability, low weight, low thickness, are interesting candidates for mobile and space applications. High cell efficiency has reached so far on flexible substrate is 17.9% [2]. Among many flexible substrate types for CIGS-based solar cells, the coefficient of temperature expansion (CTE) value of stainless steel (S.S. ~11 μm/K) is close to CIGS material (11.2~11.4 μm/K) [3]. The CIGS-based cell with an efficiency of 17.7% has been fabricated on S.S. substrate [4]. Nevertheless, a major drawback of $FeInSe_2$ compound formation in CIGS film was due to Fe diffusion from S.S. substrates during selenization process [5]. The probability of defect recombination was increased due to a deep-level state of defect ($FeInSe_2$) [6]. Herz et al. reported that the concentration of metal impurity (Fe) in CIGS film was reduced by Al_2O_3 barrier layers between Mo film and S.S. substrate [7]. According to previous experiment, 1 μm-thick SiO_2 barrier layer was used by spray method which can achieve the same effect. There are many kinds of technology to prepare CIGS-based thin films, such as evaporation, sputtering and atomic layer deposition. Precursor-rapid thermal process (RTP) selenization two-step method is one of the best solutions for the industrial fabrication. Though, the cracking and spalling types can be easily observed on CIGS film which due to the high thermal rate of RTP system and various CTE values of materials on CIGS/Mo/barrier/substrate structure during selenization process. Hence, the effect of the thermal stress might have relationship with curvature property of CIGS-based structure device for each layer. Besides, the orientation and value of curvature on S.S. substrate was changed after de-convolution procedure in the manufacturer. Accordingly, the curvature characteristics controlling on S.S. substrate is important in the fabrication of CIGS films with selenization process. However, the orientation and value of curvature for CIGS-based structure that produced were not clearly identified in improved performance of photovoltaic characteristic on CIGS-based solar cell.

In this study, we controlled the curvature orientation of S.S. substrate with the various process pressures of ZnO thin film deposition. The effect of the orientation and value of curvature on S.S. substrates were investigated with CIS absorb layer after RTP selenization process.

2. Experimental

The solar cell with a structure of CIS/Mo/SiO2/S.S./ZnO was fabricated. The thickness and area of S.S. substrate is 200 μm and 5×5 cm^2, respectively. Firstly, 1 μm-thick SiO2 barrier layer was deposited on S.S. substrate using spray technique. Secondly, 1μm-thick Mo back contact layer was sputtered on SiO2/S.S. sample. Thirdly, 400 nm-thick ZnO films were coated on the back side of S.S. substrate by RF sputtering method. The stress properties of ZnO films were controlled with sputtering pressure at 2 mTorr and 10 mTorr, respectively. ZnO films were used to correct the orientation and value of curvature on Mo/SiO2/S.S. samples, which called "back correct layer". Finally, the CIS absorber layer was formed by sputtering precursor-RTP selenization two-step method on Mo film. The crystalline, orientation and curvature properties of various structure samples were analyzed by x-ray diffrac-tion (XRD) and α-Step measurement.

3. Results & Discussion

Fig. 1 shows the XRD patterns of (a) S.S. substrate (b) S.S./ZnO sample (2 mTorr) (c) S.S./ZnO sample (10 mTorr). According to JCPDS (Joint Committee on Powder Diffraction Standards), the main peaks of ZnO films were at 2θ=34.42° (002) and 2θ=62.86° (101). The formation of 2θ=44.8° was based on S.S. substrate. The a-axis strain value of ZnO films were calculated by equation (1) and (2) (see Table I).

$$\frac{1}{d^2} = \frac{4}{3}\left[\frac{h^2+hk+k^2}{a^2}\right] + \frac{l^2}{c^2} \qquad (1)$$

Where a is a-axis lattice constant, c is c-axis lattice constant, (hkl) is Miller index and d is plane distance.

$$\varepsilon_c = \frac{a_f - a_i}{a_i} \qquad (2)$$

Where ε_c is change of the strain, a_f is lattice constant by experiment and a_i is standard lattice constant.

The S.S./ZnO samples were observed that the reverse strains (tensile-strained and compressive-strained) and the opposite orientation of curvature (-1.29 m^{-1} and 0.05 m^{-1}) in two different working pressures (2 mTorr and 10 mTorr). Fig. 2 show a clearly orientation of curvature on S.S./ZnO samples, it could be due to a lattice strain change as a result of opposite curvature orientations from compressive/tensile-strained. After coating Mo/SiO_2 on S.S. substrate, the value of curvature was increased from -6.56 m^{-1} to 0.042 m^{-1}. Finally, ZnO films were deposited on the back side of S.S. substrates with different sputtering pressure at 2 mTorr and 10 mTorr, the values of curvature were -30.41 m^{-1} and 7.18 m^{-1}, respectively. It has shown the same opposite orientations of curvature trend with structure of S.S./ZnO. The ZnO films were used as back correct layer for the purpose of correcting curvature properties on S.S. substrates. It can be processed in different strain with the various process pressures. This phenomenon would be applied and used to control the orientation and value of curvature on S.S. substrates. The lattice constant, curvature and ZnO films process pressure were listed in Table I. The curvature of Mo/SiO_2/S.S. structure was controlled by ZnO thin film.

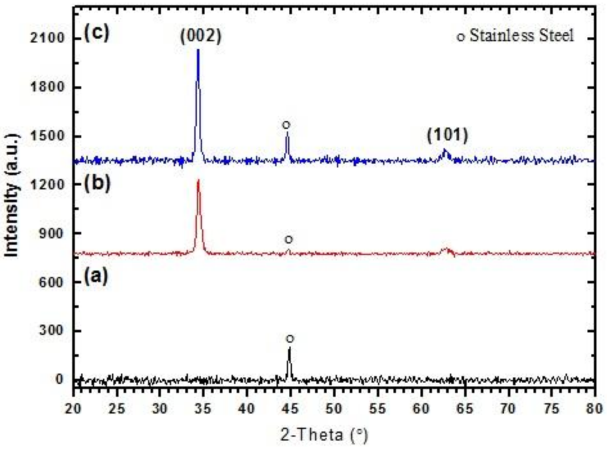

Fig. 1 XRD patterns of (a) S.S. substrate (b) S.S./ZnO sample (2 mTorr) (c) S.S./ZnO sample (10 mTorr).

Fig. 2 Photograph patterns of S.S./ZnO samples with different sputtering pressures (a) 2 mTorr and (b) 10 mTorr.

Table I Strain and curvature properties analyzed with different sputtering pressure of ZnO films on various structures.

Sample ID	ZnO Pressure	a-axis strain	Curv.* [m^{-1}]
S.S.	-	-	-6.56
S.S./ZnO	2 mTorr	0.357%	-1.29
S.S./ZnO	10 mTorr	-0.359%	0.05
Mo/SiO_2/S.S.	-	-	0.042
Mo/SiO_2/S.S./ZnO	2 mTorr	-	-30.41
Mo/SiO_2/S.S./ZnO	10 mTorr	-	7.18

* The values from α-Step measurement

4. Conclusion

According to above-mentioned experiment, we successfully produce opposite curvature orientations of ZnO layer on S.S. substrate in different process pressures (2 mTorr and 10 mTorr). In the future work, we will produce CIS films using 2-stage RTP selenization process on the Mo/SS/ZnO samples and investigate the effects of inter-relationship in terms of such as likely the curvature orientation of S.S. substrate, the quality of CIS thin films and residual stress on CIS samples. Finally, we will control the curvature value of S.S. substrate by back correct layer with film thickness and sputtering pressure parameters. The results can be optimized to achieve the better CIS solar cells on flexible S.S. substrate.

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