Effects of layered CdTe nano particles on Si solar cells

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Abstract—**Layered CdTe nanoparticles were deposited on surfaces of n-on-p crystalline Si solar cells. Their short-circuit current and conversion efficiency were enhanced due to the nanoparticle deposition. Measurements of reflectance and external-quantum-efficiency spectra as well as atomic-force-microscope observations implied that the enhancements in cell performances were attributable to textured structures of the deposited nanoparticle layers.**

Keywords- CdTe nanoparticles; Si solar cells; textured sutracuture

I. INTRODUCTION

The performances of Si solar cells strongly depend on the optical properties of their surfaces [1]. Textured structures are formed on the surfaces of crystalline Si using several methods such as wet or dry etching [2] so as to increase the conversion efficiency. An efficiency as high as 24.7% was reported for passivated emitter, rear locally-diffused cells with the inverted-pyramid-structured surfaces [3]. Nanoparticles of compound semiconductors such as CdTe were previously synthesized and deposited using the layer-by-layer (LBL) method on substrates [4]. Furthermore the energy transfer between nanoparticle layers was experimentally demonstrated [5]. In this work, we examined effects of layered CdTe nanoparticles on n-on-p Si cells, which were deposited on their emitter surfaces.

II. EXPERIMENTS

Phosphorus and boron ions were implanted to surfaces and backsides of high-resistivity (0.94 Ω·cm) p-type Si (111) substrates, respectively. The implanted impurities were activated by an annealing at 900 ºC for 60 s in a N_2 gas ambient so as to form n^+-emitter and p^+-base layers. The contacts to the p^+-base layers were formed by evaporating Al/Ni/Au multilayers and annealing at 400 ºC for 60 s in a N_2 gas ambient. We fabricated n-on-p Si cells by forming emitter contacts by Ti/Au evaporation and dicing. The area of emitters was 2 mm by 2 mm. We measured current-voltage, reflectance, and spectral-response characteristics of cells at room temperature. The measurements were repeated after the surfaces of emitters were covered by CdTe nanoparticle layers using the LBL method. The nominal diameter of the nanoparticles was 3.3 nm. We also observed surfaces of cells before and after depositing CdTe nanoparticles by using the atomic force microscope (AFM).

III. RESULTS AND DISCUSSION

We measured current-voltage (I-V) characteristics of cells under the solar irradiance with the air mass 1.5G and one sun condition. Results for cells with uncoated surfaces and those for cells with surfaces covered by CdTe nanoparticle layers are compared in Fig. 1. Parameters extracted from the respective curves are summarized in Table I. We obtained a larger short-circuit current (J_{sc}), a higher open-circuit voltage (V_{oc}), and a higher efficiency in cells with surfaces covered by CdTe nanoparticles. We obtained, however, a lower shunt resistance (Rsh), a higher series resistance (Rs), and a lower fill factor (FF) in these cells.

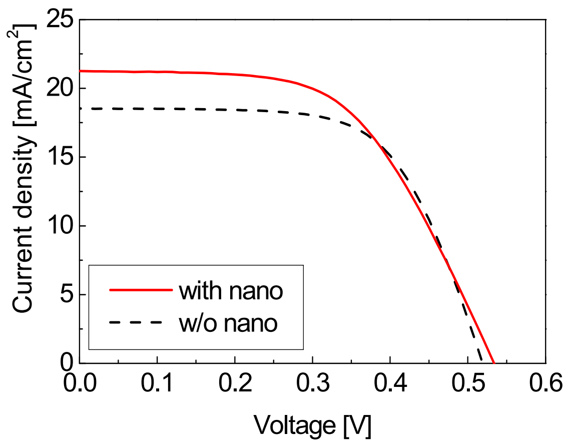

Fig. 1 I-V characteristics of Si cells with uncoated surfaces and surfaces covered by CdTe nanoparticles under the solar irradiance with the air mass 1.5G/one sun condition.

TABLE I. Parameters of Si cell characteristics.

	without CdTe nanoparticles	*with CdTe nanoparticles*
J_{sc} [mA/cm^2]	18.5	21.3
V_{oc} [V]	0.519	0.534
Rs [Ω·cm^2]	4.81	7.72
Rsh [Ω·cm^2]	14900	1980
Fill Factor [%]	64	56
Conversion efficiency [%]	6.16	6.36

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External quantum efficiency (EQE) and reflectance spectra of the two cells are shown for a wavelength λ between 300 and 1100nm in Figs. 2 and 3, respectively. As is shown in Fig. 2, the EQE for λ ≥ 460 nm was larger in cells with the coated surfaces. In addition, a peak was observed at 610 nm for these cells. AFM images of surfaces of the two cells are shown in Figs. 4(a) and 4(b). Values of the roughness average (Ra) for the respective surfaces are also shown. Ra increased from 0.2 to > 12 nm by depositing the CdTe nanoparticles.

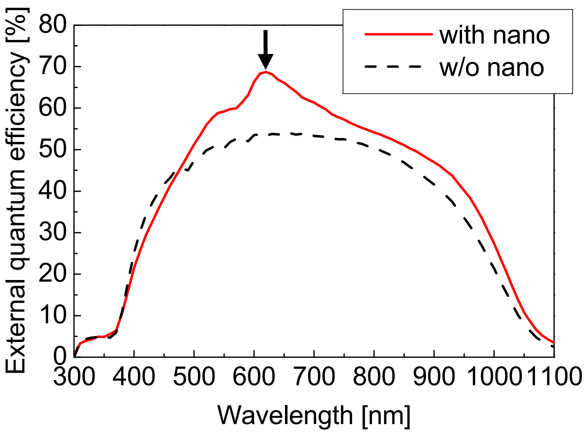

Fig. 2 EQE spectra of Si cells.

The larger EQE in cells with CdTe nanoparticles deposited [Fig.2] is attributable to the smaller reflectance as is shown in Fig. 3. The minimum at 570 nm in the reflectance spectrum of these cells, which is assumed to be related to the absorption edge of the nanoparticles (nominally 590 nm), is likely to bring about the peak in the EQE at 610 nm. The increases in J_{sc}, V_{oc}, hence the efficiency are attributable to the changes in reflectance and EQE spectra due to the nanoparticles. The degradation in Rs, Rsh and FF might be related to the partly-covered emitter contacts by the nanoparticles and the possible formation of the leak path on the side walls of mesa.

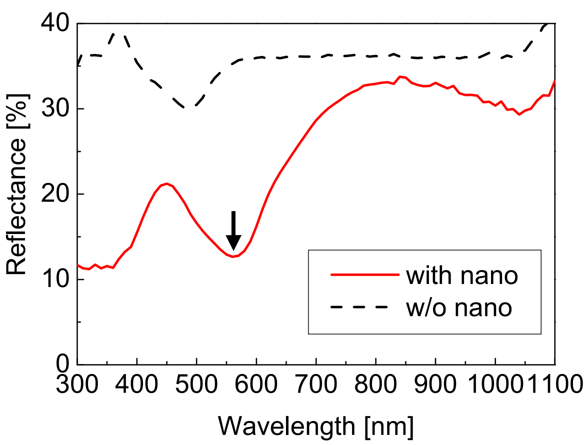

Fig. 3 Reflectance spectra of Si cells.

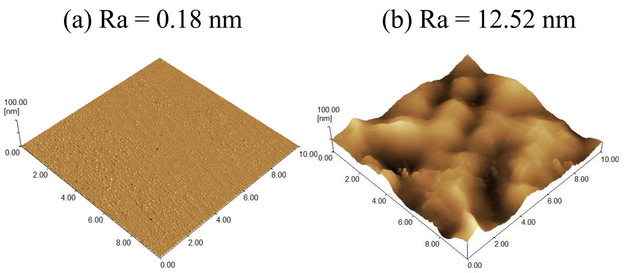

Fig. 4 AFM images of Si cells with (a) uncoated surfaces and (b) surfaces covered by CdTe nanoparticles. Values of the roughness average are also shown.

Given that Ra of the surfaces of emitters drastically increased by depositing the CdTe nanoparticles, the increase in EQE is likely to be effects similar to those of texture structures, which are conventionally formed during the process for cell fabrication [2]. The results that we obtained, consequently, suggests that characteristics of cells could be enhanced by coating their surfaces with nanoparticles in a kind of add-on process.

IV. Conclusion

The surfaces of Si solar cells were coated with CdTe nanoparticles using the LBL process. It was found that J_{sc} and the conversion efficiency increased by depositing CdTe nanoparticle layers on the emitter surfaces. The increase in J_{sc} was related to changes in the reflectance and EQE. These results as well as the AFM observation of the cell surfaces suggest that textured surfaces, which should play a role of enhancing the solar cell performances, are achieved after the device process is completed.

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