

Effects of Layered Cadmium-Based Nanoparticles on Si Solar Cells

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Abstract — We deposit Cd-based nanoparticles on Si solar cells using the layer-by-layer method and measure their current-voltage and spectral response characteristics. The solar cells covered by the nanoparticles show higher conversion efficiencies due to the interference of the layered nanoparticles. We also observe features indicating the energy absorbance of the nanoparticles in the reflectance of cells.

I. INTRODUCTION

Characteristics of solar cells are sensitive to the optical properties of their surfaces such as anti-reflection films and textures. We previously synthesized nanoparticles of compound semiconductors such as CdTe [1], ZnSe [2][3] and ZnSe:Mn [4] and investigated their optical properties. We also deposited them on substrates using the layer-by-layer (LBL) method [5]. The energy transfer between nanoparticle layers was experimentally demonstrated [6]. On the assumption that the characteristics of solar cells might be modulated by forming layers of such nanoparticles on surfaces of their emitters, we previously coated the emitter surfaces of Si cells with CdTe nanoparticles and found that the conversion efficiency increased [7]. In this work, we examined effects of layered Cd-based nanoparticles on characteristics of Si cells with emphasis on their spectral response.

II. EXPERIMENTAL

We performed ion implantation of boron and phosphorous species to p-Si (100) substrates and annealing so as to form p⁺-base and n⁺-emitter layers. The contacts to the p⁺-base were formed by evaporating Al/Ni/Au multilayers and annealing. 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 their current-voltage (I-V) characteristics under the solar irradiance of AM1.5G/one sun as well as reflectance and quantum efficiency characteristics at room temperature.

We prepared CdS and CdTe nanoparticles by using the hydrothermal synthesis method. Diameters of the CdS and CdTe nanoparticles were 3.35 and 3.3 nm, respectively. The peaks of the photo absorption and photo emission spectra of the CdS nanoparticles were observed at 404.2 and 626.0 nm, respectively, at room temperature. Peaks appeared at 582.1 and 605 nm in the photo absorption and photo emission spectra of the CdTe nanoparticles.

Using the LBL method [5], we coated the surfaces of emitters of the Si cells with Cd-based nanoparticles. The LBL process is schematically shown in Fig. 1. As is shown in this figure, the surfaces of Si cells were alternately dipped by a solution of positively-charged poly diallyl-dimethyl ammonium-chloride (PDDA) and a solution of negatively-charged poly acrylic acid (PAA) and nanoparticles. The Si cells were rinsed by a water between dipping.

We prepared three types of CdS-coated Si cells ((b), (c)-, and (d)). By repeating the above process 10, 20, and 30 times, respectively. Another type of Si cells, (e), were prepared by coating them using CdTe nanoparticles 10 times. Uncoated Si cells are hereinafter referred to (a).

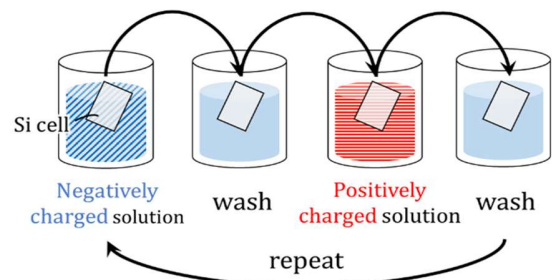


Fig. 1. Schematic drawing of Layer-by-Layer (LBL) method. Substrates were alternately dipped by solutions of positively charged and negatively charged molecules, between dipping, these were rinsed by a water.

III. RESULTS AND DISCUSSION

The I-V characteristics of cells of (a)-(d) are compared in Fig. 2. Parameters extracted from the respective curves are summarized in Table I. We obtained a larger short-circuit current (J_{SC}) and a higher conversion efficiency in (b)-(d). The highest J_{SC} and conversion efficiency were obtained for (c). The increase in J_{SC} and the conversion efficiency was also observed in the results of cells coated with CdTe nanoparticles [7]. We obtained, however, a lower fill factor (FF) and lower shunt resistance in the coated cells (b)-(d).

The degradation in R_{sh} and FF might be related to the partly-covered emitter metals by the nanoparticles and the possible formation of the leak path on the side walls of mesa.

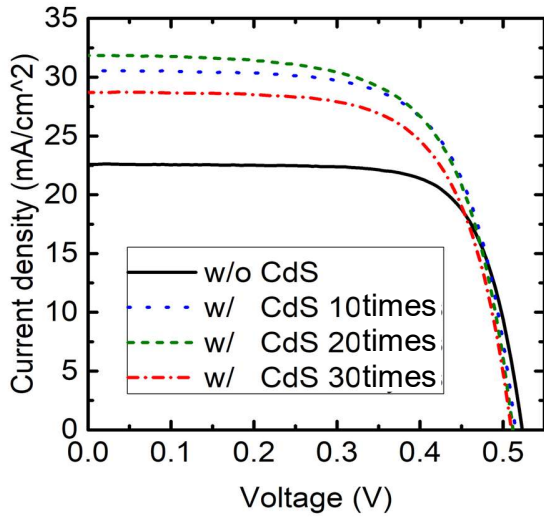


Fig. 2. I-V characteristics of Si cells (a)uncoated and after (b)10-,(c)20- and (d)30- times CdS nanoparticles coating process under the solar irradiance with the AM 1.5G / 1SUN.

TABLE 2
PARAMETERS OF SI CELL CHARACTERISTICS.

	w/o	10 times	20 times	30 times
J_{sc} (mA/cm ²)	22.6	30.6	31.8	28.7
V_{oc} (V)	0.52	0.51	0.51	0.51
Fill Factor	0.74	0.68	0.66	0.67
R_s (Ω -cm)	2.73	2.17	1.90	1.94
R_{sh} (Ω -cm)	6150	4380	2330	4090
Conversion efficiency (%)	8.71	10.67	10.68	9.86

Figures 3 and 4 show the external quantum efficiency (EQE) and the reflectance spectra of (a)-(d) for a wavelength λ between 300 and 1100 nm. The internal quantum efficiency (IQE) extracted using the EQE and reflectance is shown in Fig. 5. In accordance with higher J_{sc} , the coated cells (b)-(d) revealed a markedly larger EQE. Although (b)-(d) had higher IQE for λ between about 400 and 1000 nm, the difference in the IQE spectra among cells was not as apparent as that in the EQE spectra.

These results imply that the deposited multilayers of polymers and nanoparticles acted as an optically thin film, i.e., the increases in J_{sc} and the conversion efficiency are mainly attributable to the changes in reflectance and EQE spectra due to the interference inside of the thin film. The non-uniformity in the thickness of layers of nanoparticles might be identified as the origin of the slight variation in the IQE.

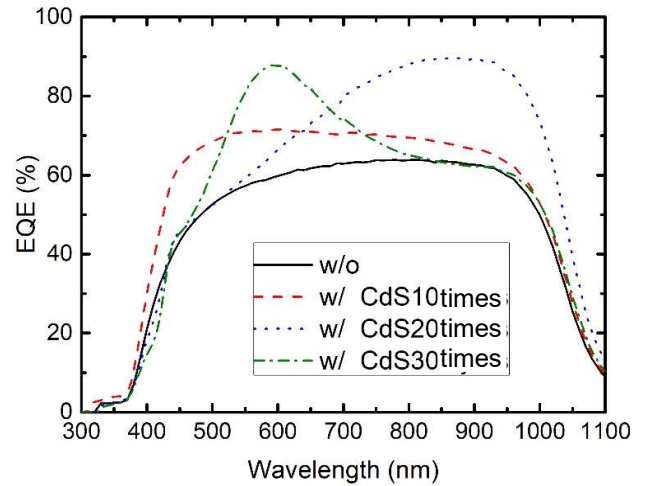


Fig. 3. EQE spectra of Si cells (a)uncoated and after (b)10-,(c)20-, and (d)30- times CdS nanoparticles coating process.

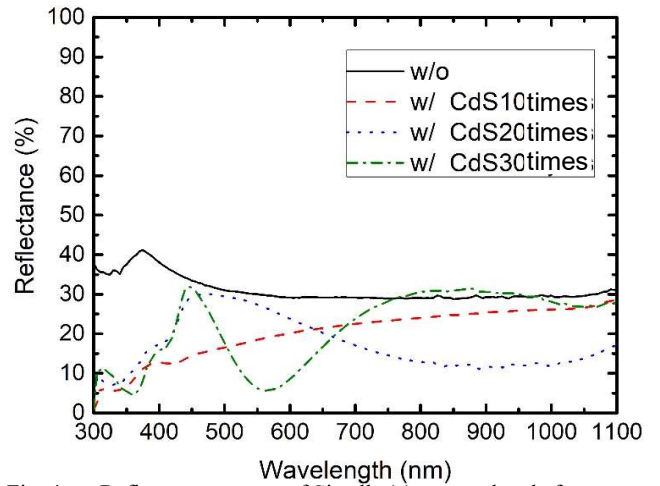


Fig. 4. Reflectance spectra of Si cells (a)uncoated and after (b)10-, (c)20-, and (d)30- times CdS nanoparticles coating process.

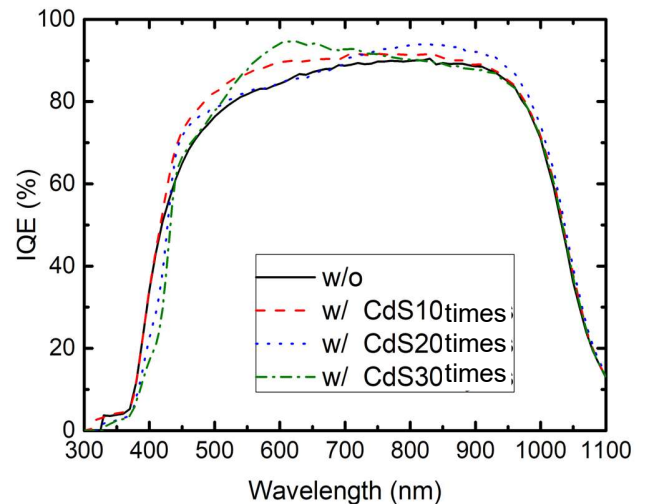


Fig. 5. IQE spectra of Si cells (a)uncoated, and after (b)10-, (c)20-, and (d)30- times CdS nanoparticles coating process.

Figures 6(a)-6(d) show the second derivatives of the reflectance with respect to λ between 340 and 500 nm for the respective cells. The reflectance was smoothed before differentiating. As is shown by arrows in these figures, we observed a peak at $\lambda \approx 420$ nm in the second derivative of the reflectance of (b)-(d) whilst such a peak was not seen in the EQE or IQE spectra.

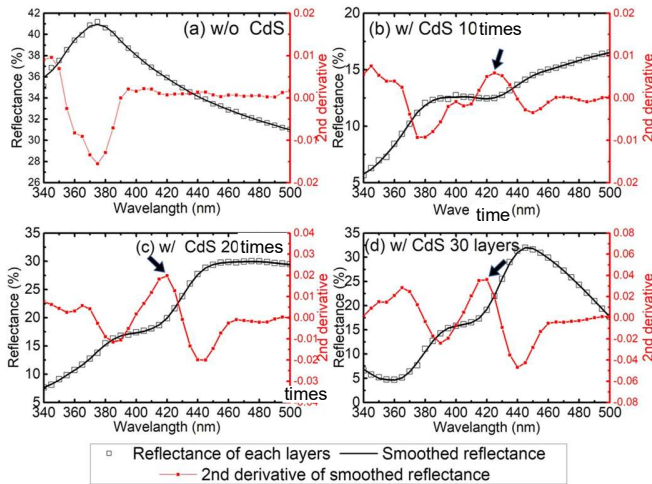


Fig. 6. Reflectance and the second order derivative of reflectance of cells (a) uncoated, and after (b) 10-, (c) 20-, and (d) 30-times CdS nanoparticles coating process.

Figure 7(a) shows a reflectance spectrum of cell (e) for λ between 300 and 1100 nm [7]. Figure 7(b) gives an enlarged view of the reflectance and its second derivative for λ between 300 and 800 nm. We find a peak at $\lambda \approx 580$ -590 nm in the second derivative of reflectance.

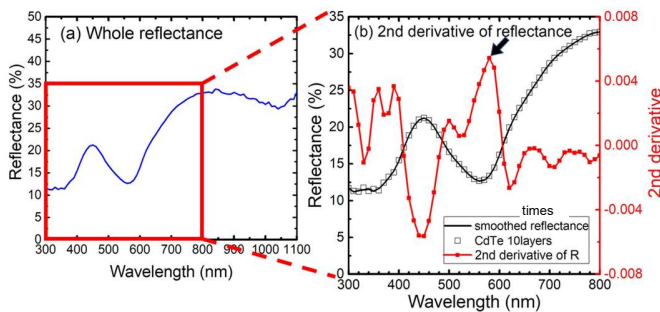


Fig. 7. Reflectance and second derivative of reflectance of cells after (e) 10 times CdTe nanoparticles coating process

It is notable that the position of peak, ≈ 420 and 580 - 590 nm for cells (b)-(d) and (e), was close to that in the absorbance spectrum of a solution of each nanoparticle (404.2 and 582.1 nm for the CdS and CdTe nanoparticles, respectively). The peak in the second derivative, which corresponds to the local minimum in the reflectance, is, consequently, attributable to the absorption of nanoparticles. We also find that the wavelength

for the peak observed for (b)-(d) was slightly larger than that for the peak of the CdS nanoparticle solution. The difference in the peak wavelengths might be due to the energy resonance between adjacent nanoparticles coating the cells.

The absorption and emission spectra of a solution of CdS nanoparticles predicted that in (b)-(d), the absorbed energy should be emitted at 626 nm and re-absorbed in Si cells, i.e., the transfer of energy from nanoparticles to Si cells should occur. This means that the quantum efficiency should be enhanced at 420 nm. Given that no peaks were observed in the second derivative of quantum efficiency spectra, the energy absorbed by the nanoparticles is assumed to be emitted through a non-radiative recombination process. Nanoparticles with higher efficiencies of the radiative recombination should be developed.

IV. CONCLUSION

The surfaces of Si solar cells were coated with CdS nanoparticles using the LBL method. It was found that J_{SC} and the conversion efficiency increased. The increase in J_{sc} was related to a lower reflectance due to the interference in the layered nanoparticles. The energy absorption by nanoparticles was observed in the reflectance spectra of coated cells.

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