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Effect of light trapping in an amorphous silicon solar cell

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ABSTRACT

Light trapping in amorphous silicon based solar cell has been investigated theoretically. The substrate for these cells can be textured, including pyramidally textured c-Si wafer, to improve capture of incident light. A thin silver layer, deposited on the substrate of an n–i–p cell, ultimately goes at the back of the cell structure and can act a back reflector to improve light trapping. The two physical solar cells we investigated had open circuit voltages (V_{oc}) of 0.87, 0.90 V, short circuit current densities (J_{sc}) of 14.2, 15.36 mA/cm^2 respectively. The first cell was investigated for the effect on its performance while having and not having light trapping scheme (LT), when thickness of the active layer (d_i) was changed in the range of 100 nm to 800 nm. In both the approaches, for having or not having LT, the short circuit current density increases with d_i while the V_{oc} and fill factor, decreases steadily. However, maximum cell efficiency can be obtained when $d_i = 400$ nm, and hence it was considered optimized thickness of the active layer, that was used for further investigation. With the introduction of light trapping to the second cell, it shows a further enhancement in J_{sc} and red response of the external quantum efficiency to 16.6 mA/cm^2 and by 11.1% respectively. Considering multiple passages of light inside the cell, we obtained an improvement in cell efficiency from 9.7% to 10.6%.

1. Introduction

The hydrogenated amorphous silicon solar cell is a popular photovoltaic device. When it is fabricated on a substrate with deposition of the layers in the order of n-type, i-type and p-type layers, the cell is called a n–i–p solar cell [1–3], while on a superstrate if the deposition sequence of the layers are p-, i-, n-type, it is called a p–i–n type solar cell. The advantage of the n–i–p type solar cell is that the cell can be fabricated with a pre-determined textured back reflector (BR). In the n–i–p structure, it is not only the feature of the BR being texturized, the whole cell surface can also be modulated by the feature of a highly texturized substrate [2,3]. Thus a great variation in the passage of light can be obtained in a n–i–p type cell structure. This variation in direction of passage of light inside the cell can lead to enhanced performance of the device.

The n–i–p cell structure is popular, because this structure is advantageous to implement improved light trapping with textured BR. An n–i–p single and tandem cell was reported in 2006 [4], where an improvement in diffused reflection at the BR is considered to have improved current density as well as cell efficiency. An n–i–p cell was also fabricated on Si nanowire that shows an improvement in external quantum efficiency (EQE) in both shorter as well as longer wavelength regions of the spectra [5]. Here, an increase in short circuit current density of the cell was as high as 26%. Investigation of light scattering at the BR shows that there is a significant correlation among surface roughness of the BR, light scattering, and improvement in red response of the EQE and efficiency [1], although an efficiency improvement from 8.1% to 8.5% was reported there.

Light trapping in a solar cell can generally be called as a method for effective use of incident light in photovoltaic energy generation, by reducing various loss mechanisms. It was suggested by Yablonovitch and Cody in 1982 [6] where effective enhancement of light intensity was reported with ray optical analysis. Since then various investigations show that the light trapping leads to an improved red response of the EQE as well as current density and cell efficiency [1–3,7–9]. Silver can act as a good back reflector. Recently, Ag nanoparticle was used as an effective plasmonic BR [10].

One of the limitations of the a-Si based single junction solar cell is lower EQE with narrow spectral width, which has a direct relation to short circuit current density (J_{sc}) of the cell. It is known that the EQE spectra can be improved further by the light trapping. The EQE spectra of amorphous silicon based solar cells are generally centered around 550 nm wavelength, with a maximum value around 0.8. The broader EQE spectra can contribute to higher current density.

P-type hydrogenated amorphous silicon oxide [2,3,11] and carbide [12,13] are two of the most interesting wide band gap window layers

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of a solar cell. The cells in Refs. [2,3] were fabricated with a p-type a-SiO:H, i-type a-Si:H and n-type a-Si:H, where the layers were not optimized, and hence the observed performance of the cell was low, although a systematic variation in J_{sc} and efficiency was observed. Here we report a similar investigation based on a theoretical analysis of an optimized baseline cell structure. This cell had higher initial efficiency and J_{sc} [13]. Additionally, we investigated the effect of optimum thickness of the i-layer. These cells were investigated both with light trapping and without light trapping. There has been some simulation studies on the n–i–p solar cell related to light trapping [14], however, a quantitative step by step investigation on the role of light trapping towards EQE and cell performance characteristics is not widely available.

This article is structured as follows. The experimental details give the cell deposition conditions. Theoretical analysis of the optimization of thickness of the active layer of the cell was discussed. A further improvement of the fill factor (FF) of the cell was made [13], but results are not given here. Then we analyzed possible improvement of the cell performance by introducing light trapping.

2. Experimental details

Our first cell was of p–i–n type, where the deposition sequence of the cell layers is p-, i-, and n-layers. In an n–i–p type cell the deposition sequence is reverse. We assume that the deposition sequence will have insignificant impact on the cell performance. Asymmetric wet etching of c-Si wafer can easily produce a pyramidally textured substrate, Fig. 1(a). A thin layer of silver (Ag), at the back of the cell, can create a back reflecting mirror, Fig. 1(b)–(e). Surface roughness of the deposited Ag layer can be altered based on temperature of the substrate on which it is deposited. Fig. 1(b) is for room temperature (25 °C), Fig. 1(c) is for 100 °C, Fig. 1(d) is for 200 °C while Fig. 1(e) is for 400 °C temperature. These are the scanning electron microscopic (SEM) images of pyramidal texture, showing various nanometric surface roughnesses.

The p–i–n structure of the deposited solar cell was: glass/TCO/p-a-SiC:H (15 nm)/i-a-SiC:H (5 nm)/i-a-Si:H (400 nm)/n-a-Si:H (10 nm)/n-μc-Si:H (20 nm)/Ag/Al, where TCO is transparent conducting oxide. Here p-a-SiC:H is p-type hydrogenated amorphous silicon carbide (a-SiC:H), i-a-SiC:H the intrinsic a-SiC:H buffer layer, i-a-Si:H the intrinsic type hydrogenated amorphous silicon (a-Si:H), n-a-Si:H the n-type a-Si:H, and n-μcSi:H the n-type microcrystalline silicon layer. We used 2% gas phase doing ratio for B_2H_6 and 3% doping for PH_3 as the p-type and n-type dopants respectively. The current density voltage (J–V) characteristic curve of the cell was measured under AM1.5G radiation with 100 mW/cm^2 light intensity, at a 25 °C temperature. The external quantum efficiency of the cell was measured with the instrument, model number

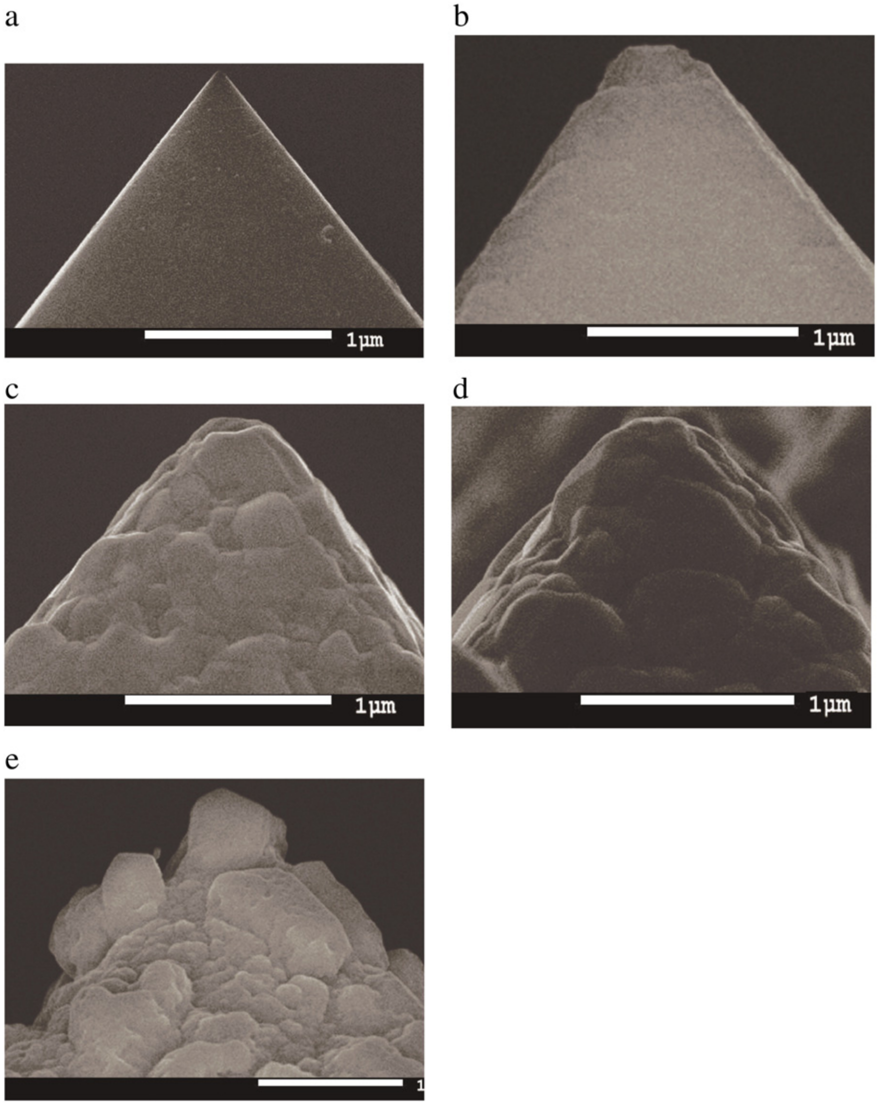

Fig. 1. (a) SEM surface image of pyramidal surface texture of c-Si. On Ag layer deposition, nanometric modification of its surface roughness was observed, with root mean square (rms) surface roughness of (b) 4.32 nm, (b) 24.5 nm, (c) 53.0 nm (d) 445.0 nm.