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Theoretical investigation of transparent front surface field layer on the performance of heterojunction silicon solar cell

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ABSTRACT

In order to couple more light in absorber layer of a silicon heterojunction (SHJ) solar cell, higher optical transparency of the front layer is desirable. In that respect we investigated indium tin oxide (ITO) as a front surface field (FSF) layer in a rear emitter SHJ solar cell. We used numerical simulation starting from an experimentally obtained real solar cell. In the experimental cell the n-type nanocrystalline silicon (n-ncSi:H) was used as the FSF, where the power conversion efficiency (PCE) of the reference cell was 21.84%. Our investigation shows that if 20 nm thick ITO is used as the FSF, the PCE of the device can be 25.67%, while with an 80 nm thick ITO as FSF, the PCE can be 23.8%. This improvement in the device efficiency primarily comes with the increase in current density in the solar cell due to an increased intensity of light in the absorber layer.

1. Introduction

Solar cell is a semiconductor device that can convert light energy to electrical energy. Improved coupling of incident light into its absorber layer is a preferable approach because it can result in more photon being available to the absorber layer to generate electricity. Among a large number of investigations that reported to have successfully applied the light coupling mechanism, few are [1–4]. Wide band gap silicon oxide is one of the materials that can be useful in this respect [3,5]. Using textured front surface [6,7], anti-reflection coating, optically matched layers for reduction in reflection [3], light trapping etc few of the schemes generally used in this respect. Thinner doped layer [8] at the front surface is also preferable because it can reduce parasitic absorption loss of light [9,10].

Silicon heterojunction (SHJ) solar cell is one of the most popular devices. Its power conversion efficiency (PCE) is relatively high, for example 26.3% efficiency was reported in 2016 [11], and its fabrication process is relatively simple. When wide band gap nano-crystalline silicon oxide layer is used instead of nano-crystalline silicon at the front surface, its power conversion efficiency (PCE) can be improved from 21.84% to 22.34% [3,4]. In a solar cell the conversion of incident light energy to electrical energy, takes place based on the intensity of light entering the absorber layer. Therefore, it can be expected that the presence of more transparent layers at the front side of the absorber layer can make a device more efficient. Wide band gap indium tin oxide (ITO) can be used as a front surface field layer. ITO is a versatile material, it has higher optical gap and its work function can be tuned in a wide range, from 4.3 to 5.1 eV [12], 6.1eV [13], 4.4–4.5eV [14], 4.3eV [14] and 4.1eV [15] etc. However, there is not much information available to use the ITO as a front surface field (FSF) layer. Therefore we used AFORS-HET [16] simulation to investigate the effect of using the ITO as a FSF in a SHJ solar cell.

Here we start our investigation with an experimentally measured solar cell and then replace the FSF layer with the ITO layer. The Cell-A of reference [3] is used, in which the FSF layer was n-type nano-crystalline silicon (n-ncSi:H). The details of the real solar cell can be found in Ref. [3].

2. Theoretical

When light is incident on a solar cell, it is expected that more light is absorbed in the active region or in the absorber layer. Due to this optical absorption, high density electron-hole pairs are generated. The number density of electron-hole pairs (N_{eh}) is proportional to intensity of light absorbed by the active layer (I_a). If I_0 is the intensity of incident light then I_a can be derived as in the following. If R_{ITO} is effective reflectivity at the front side of the solar cell, then intensity of light transmitting through the front ITO surface is $I_0\ (1\text{-}R_{ITO})$. This light have to travel

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