Low Cost All-Dielectric Thin-Film Solar Cell Using Diffuse Medium Reflectors

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Abstract: Diffuse reflectors can be beneficial for solar cells, due to no plasmonic loss, higher reflectance, decent light scattering, and low cost. Experimental and theoretical works are presented here to demonstrate its feasibility for photovoltaics.

OCIS codes: (310.6845) Thin film devices and applications; (040.5350) Photovoltaic; (050.1940) Diffraction.

1. Introduction

Recently, diffuse reflectors also find promising application in solar cells[1-4]. Theoretically, diffuse reflectors can replace the conventional metallic solar cell back reflectors to provide higher reflectance due to no plasmonic absorption. The light trapping property is also enhanced by the embedded scatterers in the diffuse mirror. Compared to DBR, diffuse reflectors have the advantage of simpler processing. This is due to the fact that in experiment sol-gel processes or other wet chemical processes can be applied, to realize such reflectors with relative ease, and no lithography and etching are needed. This low cost and low temperature processing nature of diffuse medium reflectors is extremely processing for solar cells. For the analysis of diffuse reflectors, several numerical methods have been previously applied including Monte Carlo method, N-flux methods based on radiation transfer equations, and one-dimensional approximation based on semi-coherent optical modeling. All of these works provide insightful conclusion on the diffuse reflectors together with suggestion on the design considerations. Nevertheless, the analysis along the line of wave optics, in a three dimensional space, has not been examined to date. In this work the concept of diffuse medium backed solar cells is realized experimentally. The white paint diffuse reflector is applied to amorphous silicon solar cells, and the efficiency achieved is 9.44%.

2. The rigorous solutions of Maxwell's Equations for diffuse medium reflectors

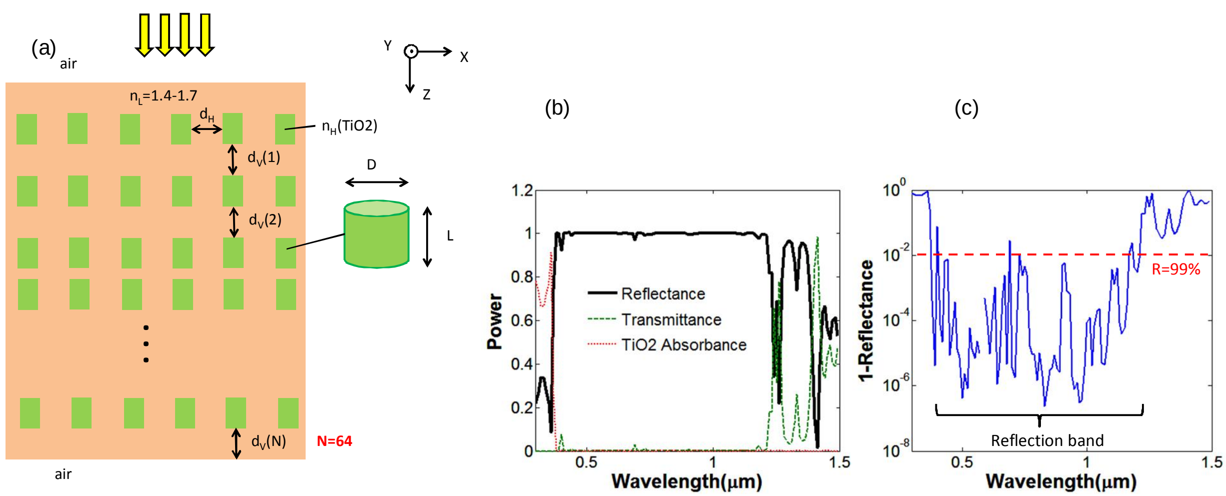

Fig. 1 (a) Illustration of the disordered TiO_2 diffuse reflector. The vertical spacing d_V is different between each layer of the TiO_2 scatterers. (b) The spectral reflectance and transmittance for the disordered TiO_2 diffuse reflector. (c) The semi-log plot of 1-Reflectance(R).

The simulation is also carried out in three-dimensional space, and thus the Fig. 1 is still the cross-sectional view of a disordered diffuse reflector. The vertical spacing d_V is now separately adjusted to simulate the disorder in the distribution of TiO_2 scatterers. Firstly, an optimized geometry will be discussed where the vertical spacing is selected by genetic algorithm. Since in some diffuse reflectors fabricated by sol-gel or other solution processes, the disorder may not be of well-controlled nature, a randomly distributed TiO_2 diffuse reflector will be discussed later. In the case of a randomly distributed TiO_2, the disorder, $d_V(1)$, $d_V(2)$, é $d_V(N)$ is random, and only d_H, D, and L can be optimized. Promisingly, it is found that even if the distribution of TiO_2 is random, the wide band reflection can still be achieved, and the spectral reflectance is only slightly degraded from the optimized disordered TiO_2 mirror. Polarization is still not important for the simulation in this section since the boundary condition is periodic in the x- and y-direction and the TiO_2 scatterers are cylindrical in shape. The reason for choosing cylindrical scatterers is stated in the first paragraph of section 2. In real diffuse reflectors, the disorder can exist in all of the three directions, but simulation of a three dimensional disordered array will be computationally unmanageable based on our literature review. Simulating one dimensional disorder(z-direction) in three dimension already captures the physics in the diffuse reflectors and can compare the distinct feature between the ordered and the disordered TiO_2 reflectors while the disorder in three directions is expected to further enhance the performance of the diffuse reflector. In Fig. 1, $d_V(1)$, $d_V(2)$, é . $d_V(N)$ is the vertical spacing between TiO_2 scatterers. Due to the fact that the disorder exists in the vertical direction, the d_V is now an array of length 64, and each element is denoted by $d_V(1)$, $d_V(2)$, é $d_V(N)$. d_H is the horizontal spacing between TiO_2 scatterers. The diameter of cylindrical TiO_2 scatterers is D and its length is L. The disorder is introduced in the z-direction. Similar to the previous study, the number of TiO_2 layers actually depends on the thickness of the real diffuse reflector, the length and the diameter of TiO2 cylindrical scatters, and the vertical spacing between them. . N=64 is still used for the simulation here to compare with the result in the previous section.

3. Experimental realization of amorphous silicon thin-film silicon solar cells with diffuse medium reflectors

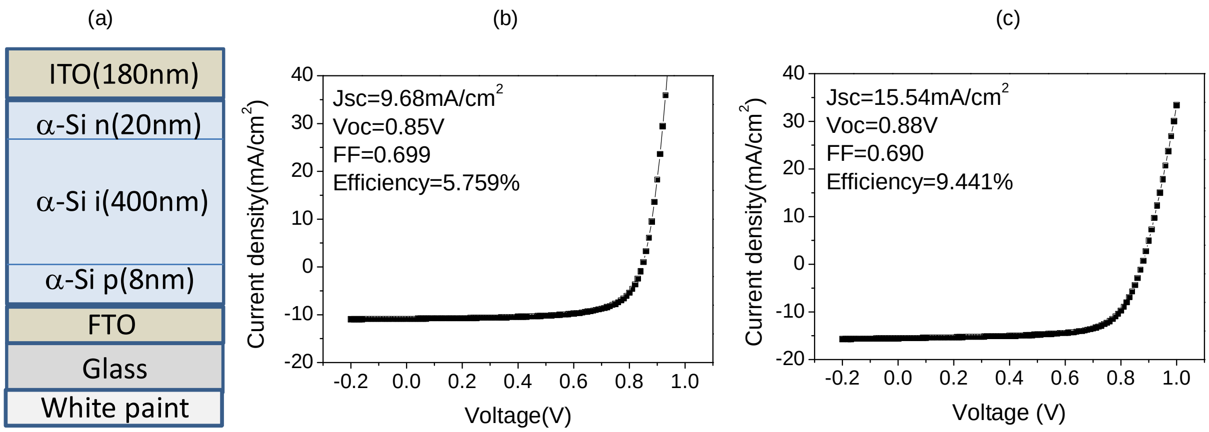

Fig. 2 (a) The illustration of amorphous silicon solar cells. The light comes from the indium tin oxide(ITO) side. (b) The J-V without a white-paint back reflector. (c) The J-V with a white-paint back reflector, the white paint is pasted on the glass substrate.

Fluorine-doped tin oxide(FTO) coated glass is cleaned by firstly acetone. Afterward, the p-i-n amorphous silicon film is deposited on FTO glass and the thickness of p, i, and n layers are 8nm, 400nm and 20nm, respectively. The p-i-n silicon film is deposited by very high frequency plasma-enhanced chemical vapor deposition (VHF-PECVD). The indium tin oxide(ITO) thickness is 180nm and is deposited by sputtering. A shadow mask is placed on top of α-Si:H during ITO deposition to form the patterned ITO electrodes. Finally, Reactive ion etching (RIE) is employed to etch the portion of silicon film which is not covered by ITO, and therefore the contact to the FTO coated glass is possible. In, Fig. 2, J-V curve is measured for devices before and after the white paint is applied to the backside of the FTO glass substrate for the same sample. The amorphous silicon solar cell sample in this study is degraded in air and under illumination for six months and the measurement is conducted without annealing. The efficiency of this sample is around 9% as fabricated six month ago, and it degrades to 5.8% currently. After applying the white paint reflector, the efficiency is increased to 9.4%. It should be pointed out that white reflectors is promising for solar cells, due to its zero plasmonic loss, low cost, low temperature process, and high throughput. From initial experimental verification, it is shown that the concept of diffuse medium reflectors can indeed be applied to photovoltaics, and by wave optics design and optimization, it is believed that its reflectance and haze parameters will be continuously improved in the future.

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