

PARASITIC ABSORPTION LOSS BY SURFACE PLASMON POLARITON IN THIN FILM SOLAR CELLS

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ABSTRACT

We describe a method to determine the parasitic absorption loss arising from the excitation of surface plasmon-polaritons at the rough metallic back reflector in thin film solar cells. The developed calculations based on the dispersion relation can be used to estimate the surface plasmon-polariton effects on the current density of solar cells with different back reflectors. It is found that the refractive index of the dielectric medium adjacent to the metal reflector plays an important role in mitigating the parasitic absorption loss in the metal and doped layer.

1. INTRODUCTION

Light trapping is of great importance for the efficiency improvement of photovoltaics [1, 2]. The upper limit for the path length enhancement that can be obtained by using a texture structure is given by $4n^2$. However, the absorption enhancement achieved in real solar cells is still less than the ergodic limit. One of the main reasons is the pronounced parasitic absorption in the device, which leads to a more conservative limit for the absorption enhancement. Among the different absorption losses, the rough metallic back reflector of a solar cell was found to result in the parasitic absorption, which arises from the excitation of the surface plasmon polaritons (SPPs) [3].

SPP resonances have been intensively investigated to enhance light absorption in the material [4], but it is still debatable whether these light trapping schemes will be better than the tradition approach, it is because the parasitic absorption within the plasmonic material may be stronger than the absorption within the absorber layer itself. In this paper, we use the dispersion relation of SPPs to theoretically analyze the parasitic absorption loss arising from the excitation of SPPs at the rough metallic back reflector.

2. THEORY AND RESULTS

SPPs are excited when photons interact with a rough dielectric/metal interface, its dispersion relation is given by

$$k_x = k_0 \sqrt{\frac{\epsilon_m \epsilon_d}{\epsilon_m + \epsilon_d}} \quad (1)$$

In a two dimensional planar structure, the density of the guided modes per unit area per unit frequency can be obtained by using the dispersion relation

$$\rho_m = \frac{k_m}{2\pi} \left(\frac{dk_m}{d\omega} \right) \quad (2)$$

And the number occupied by the SPP mode is proportional to

$$N = \rho_{spp} / h \rho_{tot} \quad (3)$$

Where ρ_{spp} the density of the SPP mode, h is the thickness of the absorber layer and ρ_{tot} is the total density of the electromagnetic modes. From the point of view of energy conservation, the energy entering the SPP mode must exactly equal the energy escaping from it. In solar cells, the escaping channel includes the propagation mode along the interface, the evanescent mode inside the metal and dielectric, the outcoupling mode and the radiative mode. Energy stored in each mode is given by

$$r_m = \alpha v_g^m u_m \quad (4)$$

where α is the absorption coefficient, v_g^m is the group velocity of the mode and u_m is the energy density stored in the mode. By using the dispersion relation and eq. (4), the dissipation rate of the propagation mode, The rate of the energy dissipated in the doping layer, The rate of the radiative mode and out-coupling mode are given as follows:

$$\gamma_{spp} = 2 \text{Im}(k_x) \frac{k_x}{2\pi \rho_{spp}} \quad (5)$$

$$\gamma_d = \alpha_d \frac{c}{n_d} \Gamma_m \quad (6)$$

$$\gamma_{rad} = \alpha_{abs} \frac{c}{n_{abs}} \quad (7)$$

$$\gamma_{oc} = \frac{\rho_0 c}{4h\rho_{tot}} = \frac{c}{4hn_{abs}^3} \quad (8)$$

The fraction of the SPP mode that cannot be absorbed by the active layer is then

$$F = 1 - \frac{\gamma_{rad}}{\gamma_{spp} + \gamma_d + \gamma_{oc} + \gamma_{rad}} \quad (9)$$

and the energy loss factor arising from the excitation of the SPP mode is then

$$L_{spp} = \frac{\rho_{spp}}{h\rho_{tot}} \quad (10)$$

2.2 Results

We now consider the result in eq. (10) for the cases of crystalline and amorphous silicon solar cells. The calculated absorbance spectrum for a series of dielectric mediums is shown in Fig 1. Pronounced absorption losses are observed where n-Si and n-SiOx layers are used as the dielectric medium; however, when ZnO:Al is used, the absorption loss in the a-Si solar cells disappears. In other words, ZnO:Al can be used to mitigate the parasitic absorption loss resulting from the rough metallic back reflector in a-Si solar cells.

Plots of energy loss factor in Fig 2 shows that the loss is largely increased at the SPP resonant wavelength. The refractive index and extinction coefficient play important role in determining the intensity and resonant wavelength. By using a lossless ZnO:Al, the energy loss can almost be eliminated.

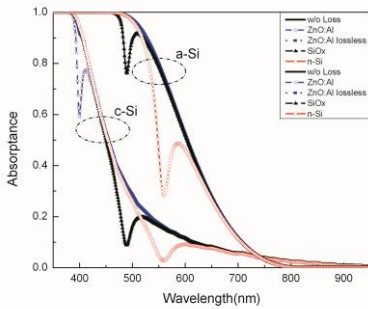


Fig 1 the absorbance spectra calculated with different dielectrics in 300nm c-Si and a-Si solar cells, the thickness of dielectric medium and metal is 30nm and 250nm.

The different behaviors of ZnO:Al in the c-Si and a-Si solar cells are mainly due to the higher refractive index and higher absorption coefficient of a-Si. As can be seen from eq. (3), a higher refractive index leads to a higher total density of the electromagnetic modes. On the other hand, the density of the SPP mode does not change, so the occupation number of the SPP mode decreases. A higher absorption coefficient will raise the

fraction of the energy of the SPPs absorbed by the active layer; therefore, the parasitic absorption loss decreases.

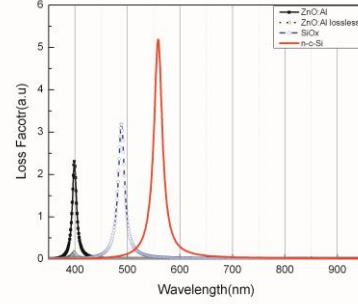


Fig 2 Energy loss factor from Eq. (12) with ZnO:Al, SiOx and n-Si as the dielectric medium, lossless ZnO:Al is also used to check the effect of the extinction coefficient.

We examine the results from the experiments and theoretical calculation for the a-Si solar cells. 300 nm p-i-n amorphous thin film solar cells with and without ZnO:Al as the dielectric medium between n-Si and Ag were measured with a Sun simulator. An improvement of 1.5-1.8 mA/cm² is achieved with ZnO:Al used between n-Si and Ag back conductor. The calculation using our developed method predict 1.3 mA/cm² gain with ZnO:Al, which is slightly lower than the experiment result, though the extra gain may come from other effects, such as preventing the diffusion of silver atoms into the silicon layer.

3. ACKNOWLEDGEMENT

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