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Effect of conductive layer thickness on light energy capture of thin-film photovoltaic cells

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ABSTRACT

We study the effects of the tunneling evanescent wave, the incident angle and the conductive layer thickness on light energy capture for thin-film polymer solar cells in theory. It is shown that as the thicknesses of conductive layer decrease from 75 nm to 30 nm, the results show that the absorption increases from 58.53% to 67.75% of incoming light at 480 nm and the average optical absorption of the evanescent wave increases from 0.1319% to 0.2083% of incoming light, respectively. The research results indicate that the conducting layer thickness reduction can increase the optical capture of the active layer.

1. Introduction

It is shown that solar energy is one of the most promising clean renewable energy resources for the future [1]. The enhanced light capturing in an active layer is very important to a higher efficiency of thin-film photovoltaic (PV) cells [2,3]. Considering the factor of bulk recombination, some researchers [4–6] had explored the thickness effect of the active layer and had found that the thickness of active layers must be smaller than the minority carrier or exciton diffusion length. While, other researchers improve the power conversion efficiency by changing structure of the solar cells or alternative methods [7–9].

A multilayer thin film structure PV cell comprises alternating layers of absorbent material wherein the alternating layers have different indices of refraction with respect to each other. The total internal reflection exists at the interface between each layer due to the difference in index of refraction when incident light comes from optically denser medium through optically thinner medium. Therefore, the tunneling evanescent waves maybe occurring in organic solar cell. Based on the research of Green [10], the tunneling evanescent waves can enhance the absorption of active materials in photovoltaic cells. To enhance light capturing in an active layer, we should consider angular response [5,11,12] and the tunneling effect of evanescent waves. In this paper, we provide a theoretical model which contains the effects of the incident angle factor, the conductive layer thickness and the tunneling evanescent waves on the capture energy of an active layer. The flat thin-film PV cell involved in this paper and associated parameter values are illustrated in Fig. 1 [11].

2. Light energy capture tunneling evanescent wave model of cell

The photoactive layer in the cell sandwiched between PEDOT:PSS and Al cathode consists of an interpenetrating network of poly-[2-(3,7-dimethylo-ctyloxy)-5-methyloxy]-*para*-phenylene-vinylene (MDMO-PPV) and 1-(3-methoxycarbonyl) propyl-1-phenyl [6,6]C_{61} (PCBM) with a mixing ratio of usually 1:4 by weight. Because indium tin oxide (ITO) has the attribute of high transmittance in the visible region and good electrical conductivity, ITO thin films coated on glass substrates have been widely used for the electrode of solar cells. The transparent ITO is used as anode of the model which is between PEDOT:PSS and Glass (see Fig. 1). On account of the high absorption of the aluminum electrode for electrons, we suppose that it is a complete absorption electrode. A complex index $N_i(\lambda) = n_i(\lambda) - j \cdot k_i(\lambda)$ accommodates each layer's absorption, where $n_i(\lambda)$ is known as the refractive index of i layer, $k_i(\lambda)$ is known as the extinction coefficient

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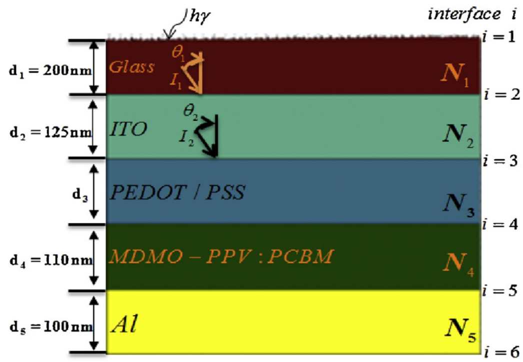

Fig. 1. Schematic structure of the modeled multilayer flat device.

of i layer, and λ is vacuum wavelength of light. Properties of related geometries are well known [13]. The absorption coefficient of thin film is given by $\alpha_i(\lambda) = 4\pi k_i(\lambda)/\lambda$ [14].

The amplitude reflection and transmission coefficients for multiple coherent reflections at the interface of i are denoted by [15]

$$r_{i,s} = \frac{\sqrt{(a_{i-1} - a_i' \cos\varphi_i)^2 + (a_i' \sin\varphi_i)^2}}{\sqrt{(a_{i-1} + a_i' \cos\varphi_i)^2 + (a_i' \sin\varphi_i)^2}} \exp[-j(o_{i,-} + o_{i,+})] \tag{1}$$

$$t_i(s) = \frac{2a_{i-1}}{\sqrt{(a_{i-1} + a_i' \cos\varphi_i)^2 + (a_i' \sin\varphi_i)^2}} \exp(-jo_{i,+}) \tag{2}$$

where

$$a_{i-1} = \frac{[(n_{i-1}^2 - k_{i-1}^2 - n_0^2 \sin^2\theta_0)^2 + (2n_{i-1}k_{i-1})^2]^{1/4}}{(n_{i-1}^2 + k_{i-1}^2)^{1/2}}$$

$$a_i' = \frac{[(n_{i-1}n_i + k_{i-1}k_i)^2 + (n_{i-1}k_i - n_ik_{i-1})^2]^{1/2}}{n_{i-1}^2 + k_{i-1}^2} \frac{[(n_i^2 - k_i^2 - n_0^2 \sin^2\theta_0)^2 + (2n_ik_i)^2]^{1/4}}{(n_i^2 + k_i^2)^{1/2}}, \quad \varphi_i = \phi_i' - \frac{\phi_i}{2} - \mu_{i-1,i} - \phi_{i-1}' + \frac{\phi_{i-1}}{2},$$

$$\varphi_{i-1}' = \phi_{i-1}' - \frac{\phi_{i-1}}{2} - \mu_{i-1,i} - \phi_i' + \frac{\phi_i}{2}, \quad \phi_i = \arctan\frac{2n_ik_i}{n_i^2 - k_i^2 - n_0^2 \sin^2\theta_0}, \quad \phi_i' = \arctan\frac{k_i}{n_i}, \quad o_{i,-} = -\arctan\frac{a_i' \sin\varphi_i}{a_{i-1} - a_i' \cos\varphi_i},$$

$$o_{i,+} = \arctan\frac{a_i' \sin\varphi_i}{a_{i-1} + a_i' \cos\varphi_i}, \quad o_{i-1,+}' = \arctan\frac{a_{i-1}' \sin\varphi_{i-1}'}{a_i + a_{i-1}' \cos\varphi_{i-1}'}, \quad o_{i-1,-}' = -\arctan\frac{a_{i-1}' \sin\varphi_{i-1}'}{a_i - a_{i-1}' \cos\varphi_{i-1}'}.$$

For a single boundary between linear, isotropic and homogeneous mediums, when a scattered ray travels from one medium with index $N_i(\lambda)$ to a second medium with index $N_{i+1}(\lambda)$, the amplitude reflection and transmission coefficients at the interface of i are governed by the Fresnel's law for s and p polarizations (perpendicular to and in the plane of incidence, respectively), which are denoted by $r_{i,l}$ and $t_{i,l}$, respectively ($l = p$ *or* s).

$$r_{i,p} = \frac{\sqrt{(a_i - a_{i-1}' \cos\varphi_{i-1}')^2 + (a_{i-1}' \sin\varphi_{i-1}')^2}}{\sqrt{(a_i + a' \cos\varphi_{i-1}')^2 + (a_{i-1}' \sin\varphi_{i-1}')^2}} \exp[-j(o_{i-1,-}' + o_{i-1,+}')] \tag{3}$$

$$t_{i,p} = \frac{2a_i}{\sqrt{(a_i + a_{i-1}' \cos\varphi_{i-1}')^2 + (a_{i-1}' \sin\varphi_{i-1}')^2}} \exp(-jo_{i-1,+}') \tag{4}$$

The reflectance and transmittance of a thin film are given by

$$\rho_m \cdot \rho_m^* = \frac{1}{2}(\rho_{ms} \cdot \rho_{ms}^* + \rho_{mp} \cdot \rho_{mp}^*), \quad \tau_m \cdot \tau_m^* = \frac{1}{2}(\tau_{ms} \cdot \tau_{ms}^* + \tau_{mp} \cdot \tau_{mp}^*) \tag{5}$$

where

$$\rho_{i,p} = \frac{\ddot{Q}_i \exp[-j\ddot{\Theta}_i] + \ddot{Q}_{i+1} \exp[-j\ddot{\Theta}_{i+1}']}{1 + \ddot{Q}_i \dddot{Q}_{i+1} \exp(-j\ddot{\Theta}_i)} \tag{6}$$

$$\rho_{i,s} = \frac{\sqrt{(\tilde{Q}_i \cos\tilde{\Theta}_i + \tilde{Q}_{i+1} \cos\tilde{\Theta}_{i+1}')^2 + (\tilde{Q}_i \sin\tilde{\Theta}_i + \tilde{Q}_{i+1} \sin\tilde{\Theta}_{i+1}')^2} \exp[-j(\Xi_i - \tilde{\Xi}_i)]}{\sqrt{(1 + \tilde{Q}_i\tilde{Q}_{i+1} \cos\Theta_i)^2 + (\tilde{Q}_i\tilde{Q}_{i+1} \sin\Theta_i)^2}} \tag{7}$$