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Reflection Spectra Simulation for Flat and Patterned Surfaces of CdTe Solar Elements

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The paper comprises the simulation of light total reflection from solar element multilayered structure. For CdTe solar cell the analysis of optical losses in two different types of solar cells with indium tin oxide and zinc oxide as transparent upper contact (with glass superstrate and without it) is performed. The effect of glass superstrate in the elements is discussed and spectral dependences for reflectance in plain layer structure are built. For textured surfaces of solar element layer the comparison of influence of different types of texture on total light reflection is carried out.

Keywords: Solar cell, CdTe, CdS, ITO, ZnO, Reflection.

PACS numbers: 68.55.jm, 84.60.Jt, 78.20.Ci, 78.40. – q,

1. INTRODUCTION

Photovoltaic devices play an important role in world energy supply, as sunlight is the primary source for mankind. To broaden the niche of solar elements (SE) in the market of energy supply devices the cost reducing and efficiency increase are mandatory. The cost reducing can be achieved by the decrease in thickness of SE active layer. But decrease of active layer thickness leads to decrease of its efficiency. Besides the positive features such as less recombination of electron-hole pairs and increased working stability, there is less light absorption and as a consequence – decrease in current density. Therefore optimization of SE construction, namely, determination of structure, shape of interfaces and layer thicknesses is urgent for compensation of the losses.

2. SIMULATION BACKGROUND

Numerical simulations of SE total reflection were carried out for two types of SE. In both elements buffer and active layers consisted of CdS and CdTe, respectively. As top contacts in the elements indium tin oxide (ITO) and ZnO were chosen. For simulation the following layer thicknesses were chosen. A layer of glass with 1.1 mm thickness was considered as superstrate for both types of SE. For ITO/CdS/CdTe SE the ITO layer was 25 nm, buffer layer of CdS was 100 nm and CdTe layer was 2 μm in thickness. For ZnO/CdS/CdTe SE the active and buffer layers were identical in thickness to layers in ITO/CdS/CdTe SE. Transparent conductive oxide ZnO was 270 nm in thickness. Refraction indexes and extinction coefficients for CdTe were taken from [1], for CdS from [2], for ITO from [3] and for ZnO from [4]. As glass superstrate was taken soda lime glass with typical dispersion law.

The simulations of reflection spectra are based on recurrence formulas $r_{0,j} = \dfrac{r_{0,1} + r_{1,j}\, e^{-2i\beta_1}}{1 + r_{0,1} r_{1,j}\, e^{-2i\beta_1}}$, and $t_{0,j} = \dfrac{t_{0,1} + t_{1,j}\, e^{-i\beta_1}}{1 + r_{0,1} r_{1,j}\, e^{-2i\beta_1}}$ for multilayered structure, where t and r are amplitude coefficient of reflection and transmission in relevant interfaces determined by Fresnel formulas, β is phase thickness of layer determined by formula $\beta = (2\pi/\lambda) n \cos\varphi$, where λ is wavelength, n is refraction index of relevant layer, φ is refraction angle in the layer. Indices from 0 to j are changed from top mediun to substrate. In the simulations only the case of normal light incidence was considered. As thickness of active layer was considered thick enough to avoid light transmission, results of simulation are presented only for reflection coefficients.

Modern technology supplies various methods of textured surface formation with different dimensions of texture element. The surface can be groove, caps or pyramid shape. In our calculations of total light reflection from textured surfaces we taken pyramid and inverted pyramid shape of texture element (previously the experimental and theoretical studies of CdTe SE with textured surfaces by our scientific group were performed for grooved elements of texture and presented in [5]) and consider the dimension of texture larger than incident light wavelength. Ray tracing in our calculations was performed for 100000 rays and matrix method of [6] was used.

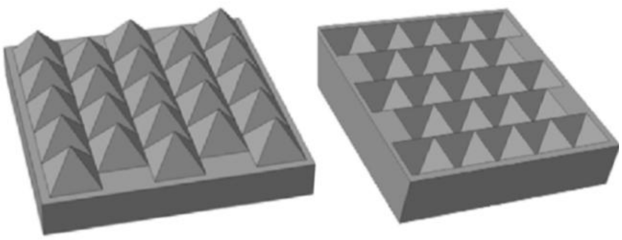

Fig. 1 – Model representation of pyramid and inverted pyramid surface patterning

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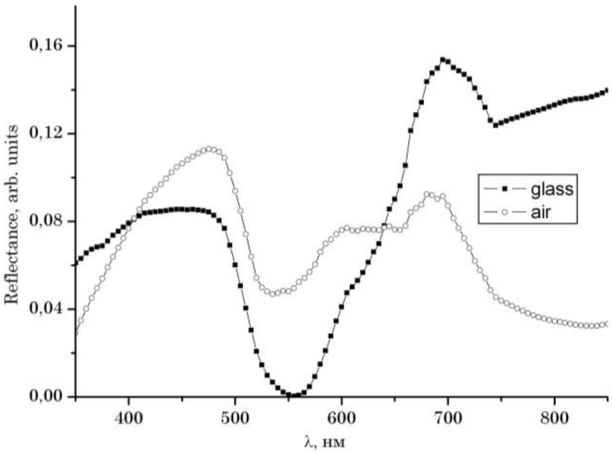
3. RESULS OF SIMULATIONS AND DISCUSSIONS

To study the reflection in SE the multilayer cell stack was simulated in the spectral range from 350 nm to 850 nm. For SE with ITO upper contact the positions of maxima and minima for both curves (see Fig. 2a) are practically unchanged when glass superstrate is replaced by air layer. In the working range of CdTe SE the average value of total light reflection is 0.102 for glass superstrate and 0.060 for air layer above conductive oxide. The results are caused by high level of light reflection from SE with glass superstrate in long wavelengths.



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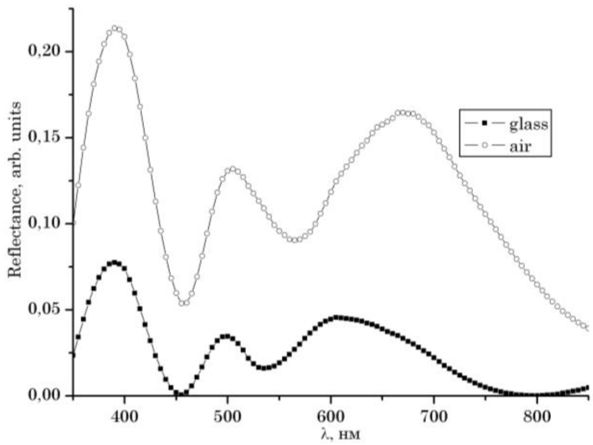
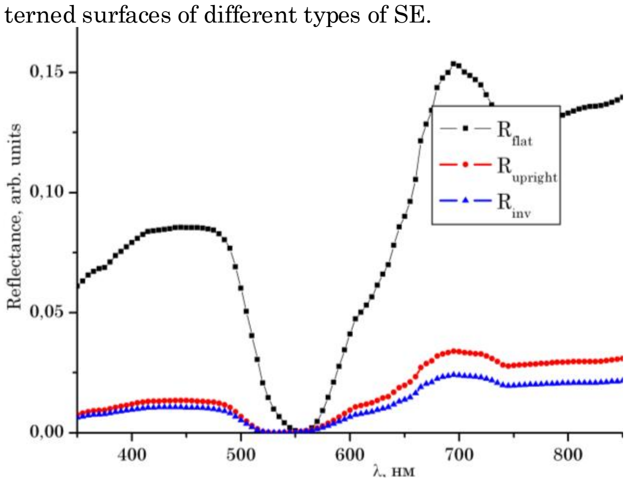


b

Fig. 2 – Total reflection for ITO/CdS/CdTe (a), and ZnO/CdS/CdTe (b) solar elements without superstrate and with glass superstrate

Curves for ZnO/CdS/CdTe SE (see Fig. 2b) have distinct interference nature caused by ZnO layer thickness. The spectral positions of extremums are slightly shifted in long wavelength region when glass superstrate is replaced by air layer. But in contrast to ITO case the calculated spectra for SE with ZnO contact layer show different behaviour when glass superstrate is replaced by air layer. Air layer leads to more pronounced oscillations and the curve is completely shifted up. The average value of total light reflection in working range of SE for glass superstrate case is 0.020. For SE with air layer above the conductive oxide the average value of reflection increase to 0.110. As a result the following finding can be made. In SE with thin layer of ITO as transparent conductive oxide the additional glass superstrate increases optical losses in SE twofold. In contrast, additional glass layer above the ZnO contact layer decreases the average value of total reflection in SE five times.

Now let us consider the simulation results for patterned surfaces of different types of SE.



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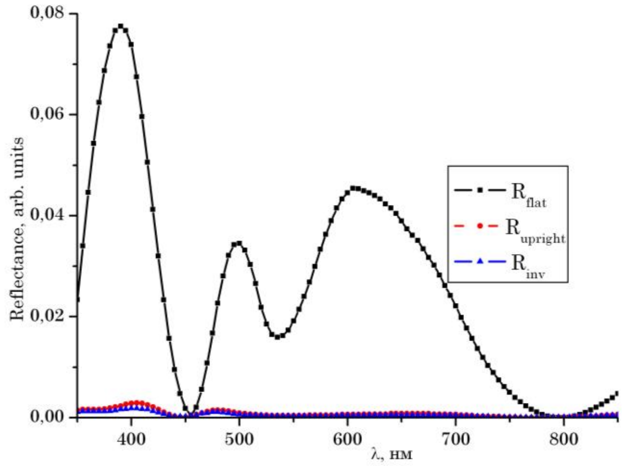

b

Fig. 3 – Total reflection for ITO/CdS/CdTe (a), and ZnO/CdS/CdTe (b) solar elements with flat surfaces of layers and with pyramid and inverted pyramid surfaces

For both types of SE the total reflection from textured structures was calculated. Surface texturing leads to substantial decrease of total reflection. For structure ZnO/CdS/CdTe texturing causes damping the interference oscillation practically to zero. For ITO/CdS/CdTe structure the texturing does not change the shape of curves but significantly decreases optical losses. There is no great difference between upright and inverted pyramid shape of texture. Therefore the type of texture can be selected by researchers from the technological aspects (for example, etching method is more convenient for inverted pyramid or cap patterning, cylinder and pyramid – by epitaxial growth and so on).

4. CONCLUSIONS

Simulation analysis for two types of CdTe SE with plain interfaces shows that glass superstrate above the SE essentially increases light propagation to SE active layer by means of reflection decrease for ZnO/CdS/CdTe SE. For ITO/CdS/CdTe SE glass superstrate increases total reflection twofold. Therefore for the latter structure the top glass superstrate only increases optical losses.

Surface patterning substantially decrease optical losses in SE and even though inverted pyramid patterning is characterized by less reflection than right pyramid texture elements there is the difference between total reflection of the two structures small enough to be not essential for SE efficiency rise by particular patterning.

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