Estimating the performance of solar cells with luminescent down-shifting layers

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Abstract

One of the ways to improve the performance of solar cells is the inclusion of Luminescent Down Shifting (LDS) layers on the cell´s top, so that the available photon flux density can be increased at a wavelength range where the cell has a high internal quantum efficiency (IQE). In this work, we show a theoretical model to determine the cell illumination current density, considering the modified solar spectrum and the optical losses due to an LDS layer. It is shown that the LDS layer thickness must be optimized for minimizing the optical losses. Examples of application of this type of technology for CdTe thin film solar cells are described, showing that it is possible to increase their performance by more than 20%.

Introduction

The use of Luminescent Down Shifting (LDS) layers allows the modification of the photon flux density to be absorbed by the device, so that the modified spectrum is converted into electrical power with an improved efficiency.

Two configurations, LDS/glass /solar cell structure and glass/ LDS/Solar cell are compared for CdTe, and it is shown that in both cases the CdTe cell can improve its efficiency around 21% when using $Lu_3Al_5O_{12}:Ce^{3+}$ as an LDS layer.

Theoretical model

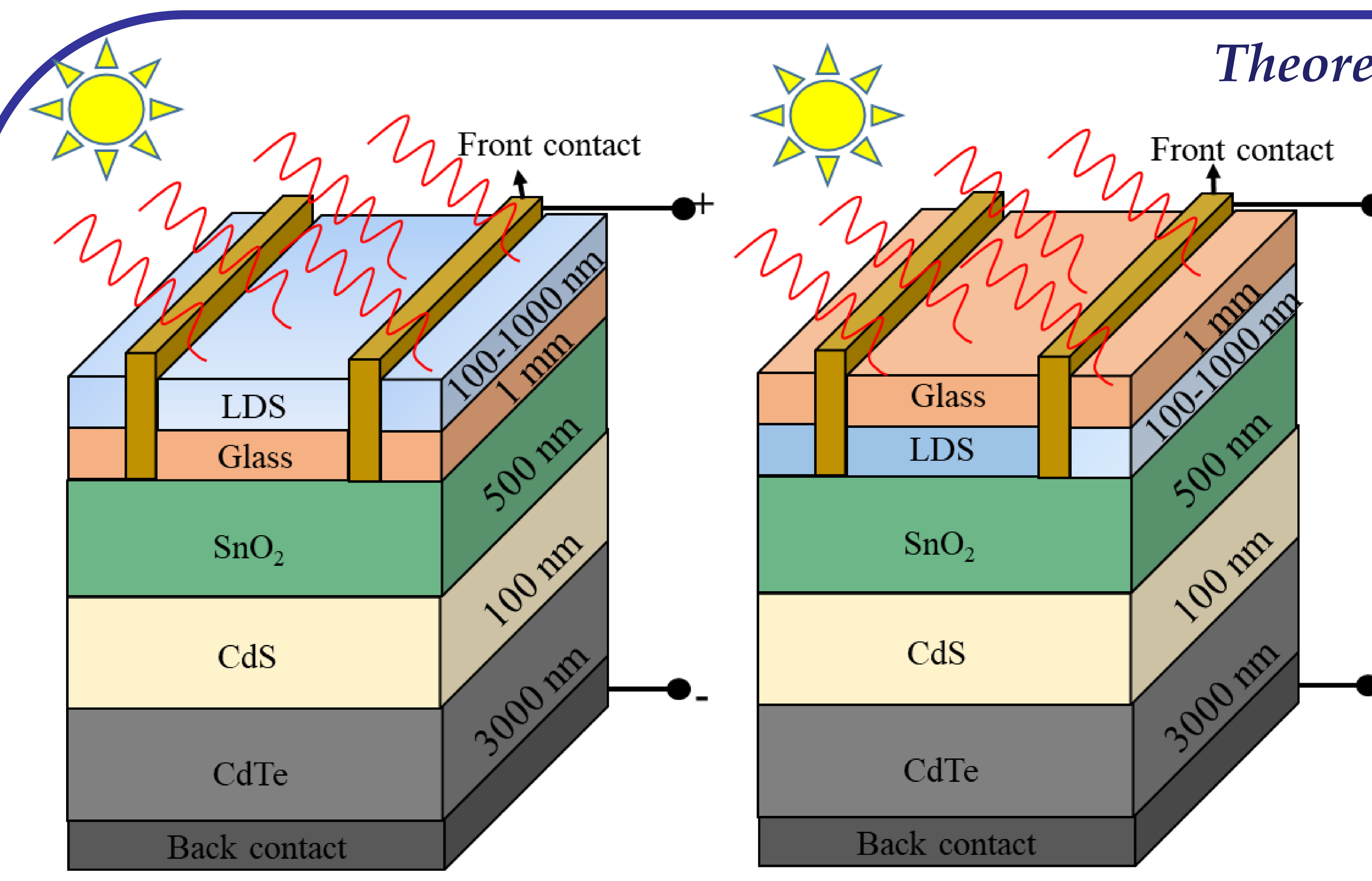

Figure 1. Structure for thin fil solar cell with an LDS layer a) on top the cover glass and b) below the cover glass.

$$P(\lambda) = [1 - R(\lambda)] * T(\lambda) * \phi_s(\lambda) + \phi_M(\lambda) \quad (1)$$

$$\phi_M(\lambda) = \eta_{DS}(\lambda) * \beta_E(\lambda) * [1 - R(\lambda)] * \phi_s(\lambda) \quad (2)$$

$$P(\lambda) = [1 - R(\lambda)] * \phi_s(\lambda) * [T(\lambda) + \eta_{DS}(\lambda) * \beta_E(\lambda)] \quad (3)$$

$$P(\lambda) = [1 - R(\lambda)] * \phi_s(\lambda) * [T(\lambda) + \langle\eta_{DS}\rangle * \beta_E(\lambda)] \quad (4)$$

The available photon flux P(λ), can be written as in equations (1)-(4), where $\phi_s(\lambda)$ corresponds to the solar spectrum AM 1.5, R(λ) is the reflectance, T(λ) the transmittance, $\beta_E(\lambda)$ is the normalized emission spectrum by the LDS layer, and $\eta_{DS}(\lambda)$ is the efficiency with which this layer downshifts and emits photons in the proper direction for absorption by the solar cell.

$$J_L = q * \int_{\lambda_{min}}^{\lambda_g} P(\lambda) * \eta_{int}(\lambda) * d\lambda \quad (5)$$

In equation (5): q is the magnitude of the electron´s charge and $\eta_{int}(\lambda)$ is the cell´s internal quantum efficiency. The limits are the minimum wavelength (λ_{min}) for photons in the respective solar spectrum and the maximum wavelength (λ_g) to be absorbed by the absorber material in the device.

Case study for CdTe solar cell

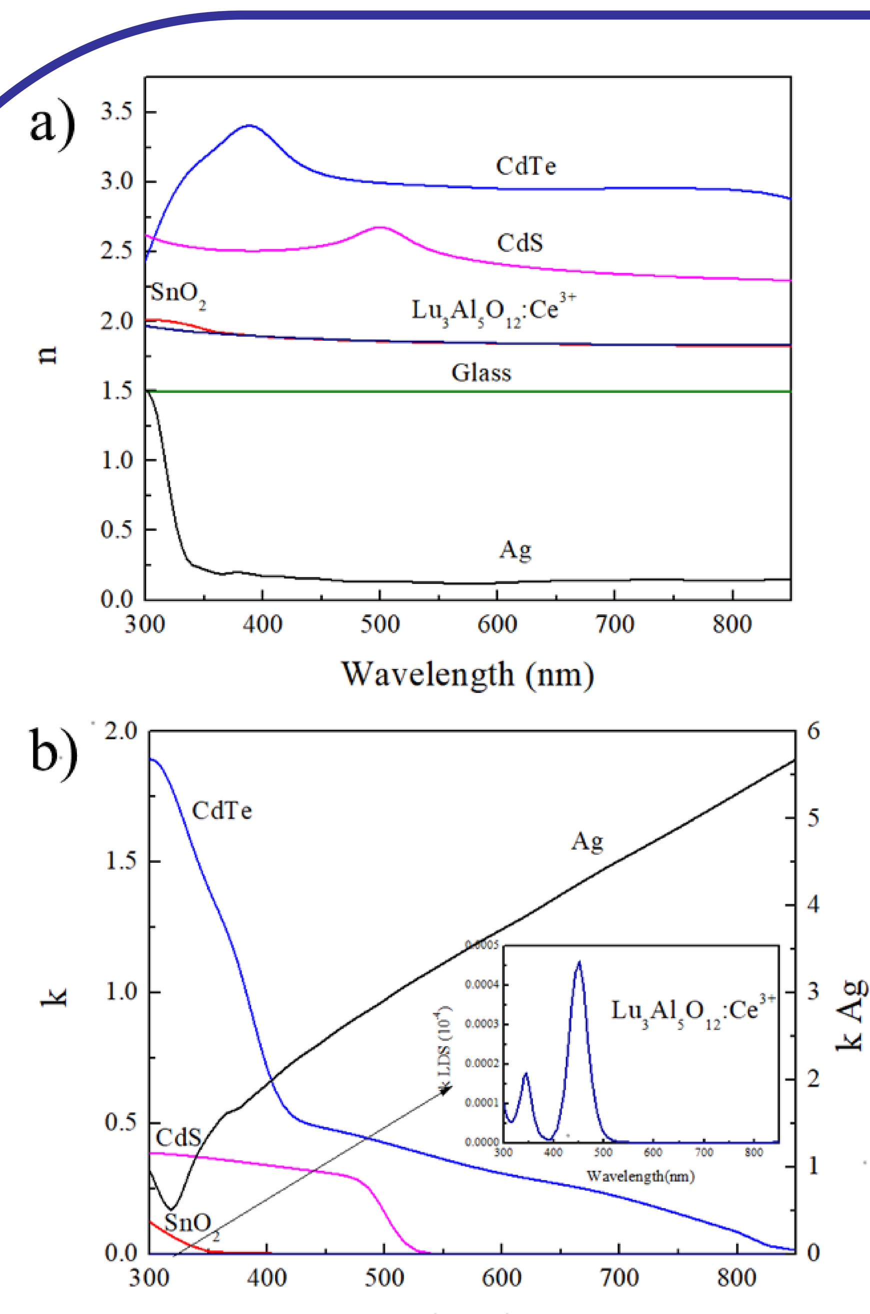

Figure 2. Refractive index and extinction coefficient of the different materials in a CdTe solar cell structure.

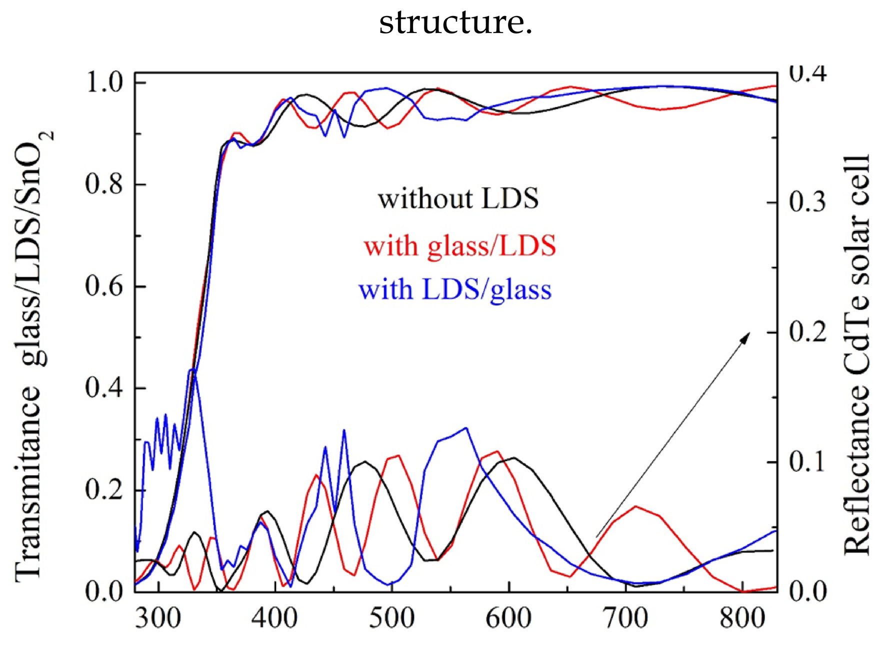

Figure 3. Calculated reflectance and transmittance spectra for the different structures using an optical matrix model

To determine the LDS optimum thickness, the reflectance and transmittance averages weighed on the solar spectrum were calculated, so that the product $(1 - \bar{R})*\bar{T}$ becomes maximum, for the respective configuration.

$$\bar{R} = \frac{\int_{\lambda min}^{\lambda material} R(\lambda)\phi_s(\lambda)\, d\lambda}{\int_{\lambda min}^{\lambda material} \phi_s(\lambda) d\lambda} \quad (6)$$

$$\bar{T} = \frac{\int_{\lambda min}^{\lambda material} T(\lambda)\phi_s(\lambda)\, d\lambda}{\int_{\lambda min}^{\lambda material} \phi_s(\lambda) d\lambda} \quad (7)$$

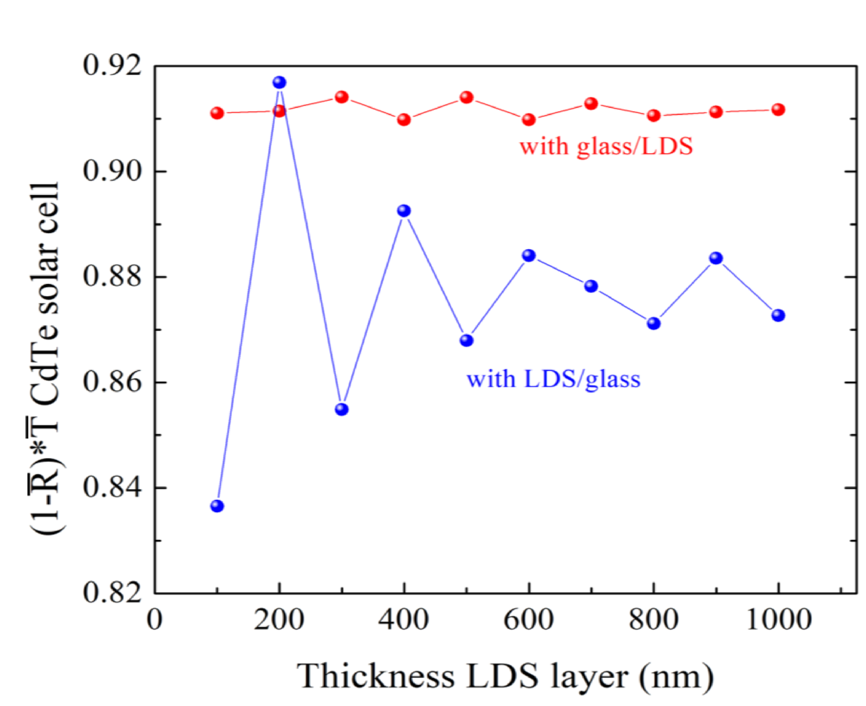

Figure 4. . Graphs for $(1 - \bar{R}) * \bar{T}$ as a function of the $Lu_3Al_5O_{12}:Ce^{3+}$ layer thickness

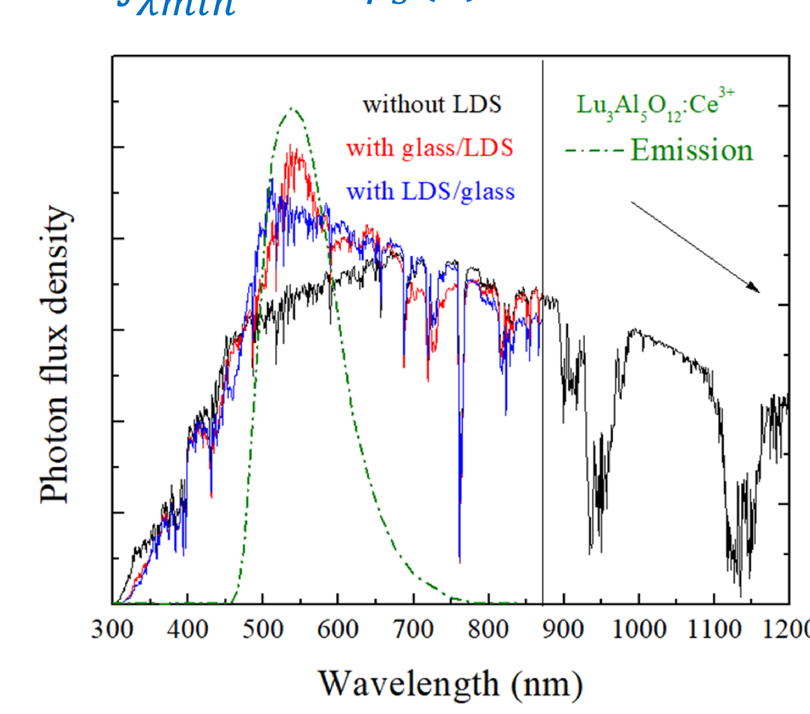

Figure 5. . Normalized LDS layer emission spectrum and photon density as a function of wavelength for CdTe solar cell.

Table 1. Photocurrent and efficiency results of CdTe solar cell with and without $Lu_3Al_5O_{12}:Ce^{3+}$

STRUCTURE	CURRENT DENSITY (mA/cm²)
glass/SnO_2/CdS/CdTe/Ag	23.8
glass/LDS/SnO_2/CdS/CdTe/Ag	28.8
LDS/glass/SnO_2/CdS/CdTe/Ag	29.0

The photocurrent density was determined using expression (5) with λ_{min}= 280 nm and λ_g = 815 nm for CdTe. A significant change in the photocurrent density is obtained for the cells with the LDS layers, in both configurations.

Conclusions

A new model for calculating the photocurrent density of solar cells with LDS layers on top was developed. The model includes the modified photon spectrum, together with the spectral transmittance and reflectance changes associated to the presence of the LDS layer itself. The model was applied to calculate the modified photocurrent density of CdTe solar cells with a $Lu_3Al_5O_{12}:Ce^{3+}$ LDS layer. It was shown that a photocurrent density and efficiency increase, around 21%, can be expected, so that it could be an alternative approach for improving this kind of solar cells in the future.

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