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Reflection loss minimization for a $ZnO/CdS/CuInSe_2$ photovoltaic cell

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Abstract. A photovoltaic cell, based on copper and indium selenide ($CuInSe_2$) thin layers, with a good efficiency can be achieved by simple, easy to implement and low cost techniques. The high refractive index materials used as absorbers in photovoltaic cells cause high reflection losses (about 30%). Thin CdS and ZnO films that are, respectively, the buffer layer and the window of the cell have lower indices and are naturally suited to antireflective applications. Also, a suitable choice of the film thickness leads to minimization of reflection losses, resulting in a significant improvement of the photovoltaic efficiency. The aim of this work is to provide easy solutions that reduce reflection losses to less than 4% while respecting technological constraints.

Keywords: reflectivity, optical index, thickness, photovoltaic efficiency.

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1. Introduction

The photovoltaic efficiency of thin film solar cells, based on $CuInSe_2$ vacuum deposited in laboratories, reached 17.5%, while Cu(In,Ga)As hold 19.9% record performance on Mo sheet [1-3] and 14.1% on plastic sheet. The industry offers flexible cells on Mo with efficiencies of 6 to 11% [2]. Deposition techniques with low cost, used in our laboratory (chemical bath, electrodeposition and ultrasonic spray pyrolysis), are expected to return conversion efficiencies around 10%. These can be significantly improved, if the reflection losses are reduced. Indeed, thin films (CdS and ZnO) that constitute, respectively, the buffer layer and the window of the cell have indices lower than those of $CuInSe_2$. They are thus naturally adapted to antireflection applications. It is there important to determine the optimal thickness that minimizes reflection losses, while remaining objective regarding technological limitations. Conventional material for antireflection coatings for this kind of solar cells is MgF_2 chosen for its low refractive index [4]. In this work, we propose to apply an antireflection coating made of porous silica chemically stable, mechanically resistant, good dielectric and with low refractive index above the metal grid to avoid heaviness of the technological process.

2. Quality criterion

To evaluate the performance of the proposed antireflection solutions, we chose like quality criterion the effective reflectivity R_{eff} weighted by $\Phi(\lambda)$ in the standard AM1.5 solar spectrum [5]. The lower the effective reflectivity is, the less one has losses by reflection in the solar cell.

$$R_{eff} = \frac{\int_{\lambda_1}^{\lambda_2} R(\lambda)\Phi(\lambda)\,d\lambda}{\int_{\lambda_1}^{\lambda_2} \Phi(\lambda)\,d\lambda}. \qquad (1)$$

Calculation covers the spectral range located between 300 and 1100 nm, representing practically the whole solar spectrum.

For the studied solar cell represented in Fig. 1 and which is a thin-film structure, the spectral reflectance $R(\lambda)$ is calculated by applying the theory of stratified media in its simple matrix form [6]. In our case we consider normal incidence and calculation will be held using Eq. (2):

$$\begin{bmatrix} E_i \\ E_r \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 1 & \frac{-1}{n_0} \\ 1 & \frac{1}{n_0} \end{bmatrix} \prod_{j=1}^{N} \begin{bmatrix} \cos\delta_j & -\tilde{n}_j^{-1}\sin\delta_j \\ -\tilde{n}_j\sin\delta_j & \cos\delta_j \end{bmatrix} \begin{bmatrix} E_s \\ n_s E_s \end{bmatrix}. \quad (2)$$

E_i, E_r and E_s are, respectively, the incident, reflected and transmitted electric fields associated to the solar radiation. $\tilde{n}_j(\lambda)$ and d_j represent, respectively, the complex indices and the thicknesses of each layer. δ_j is the phase shift of the electromagnetic wave due to the jth strate and it is given by relation (3):

$$\delta_j = \frac{2\pi}{\lambda} \tilde{n}_j d_j . \quad (3)$$

Then, the reflectance R for each wavelength λ is calculated using Eq. (4):

$$R(\lambda) = \left[\frac{E_r}{E_i}\right]\left[\frac{E_r}{E_i}\right]^* . \quad (4)$$

Introducing experimental values of optical indices determined by ellipsometric measurements on the used materials [7], it will be a question, thereafter, of finding suitable optical parameters for our stratified structure leading to the lowest possible effective reflectivity.

3. $CuInSe_2$ reflectance

The $CuInSe_2$ (or CIS) absorber of the thin films cell requires a thickness about a few microns [1]. From the optical viewpoint, this thickness completely covers glass and its molybdenum metallization. The spectral reflectivity obtained on a CIS/Mo/glass structure is the same one as that obtained on a simple substrate of $CuInSe_2$ (Fig. 2). The losses by reflections are estimated in the considered wavelength range at 26.5%.

4. Reflectance of $ZnO/CdS/CuInSe_2$ structure

By depositing the buffer layer (50 nm of CdS) on $CuInSe_2$ absorber, on the one hand, the heterojunction of the solar cell is carried out and, on the other hand, the reflection losses are reduced to 13% (Fig. 3). This antireflection effect is observed because the refractive index of CdS is lower than that of $CuInSe_2$. In addition, a thin CdS film allows to collect photo-generated carriers and provide a good conversion efficiency.

By adding a layer of 300-nm ZnO transparent and conductive (TCO), which plays the dual role of window and conductive grid, reflection losses become 11.5% (Fig. 4). This is because the refractive index of ZnO is lower than that of CdS. It remains that these losses are significant, and they can still be reduced.

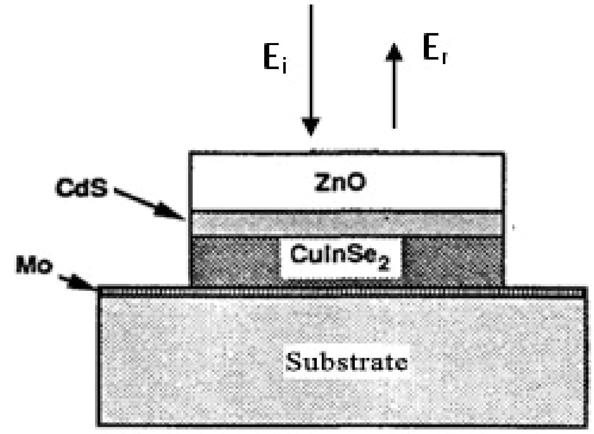

Fig. 1. Thin-film structure solar cell.

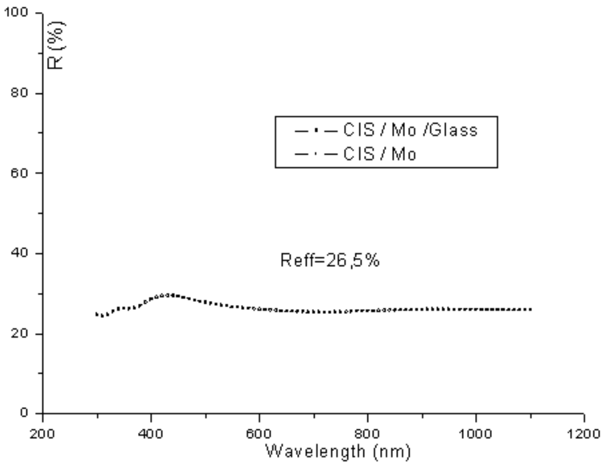

Fig. 2. Reflectance of $CuInSe_2$/Mo/glass.

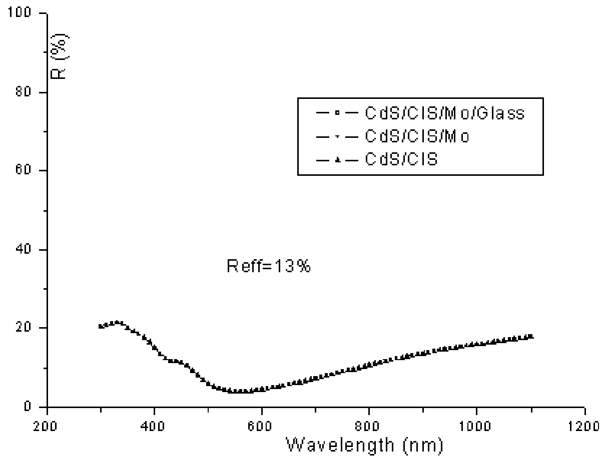

Fig. 3. Reflectance of $CdS/CuInSe_2$/Mo/glass.

5. Proposed solution

In order to reduce the reflection losses, without weighing down the technological process, we propose to add a thin layer of porous silica with low refraction index on the surface of the photovoltaic cell, after deposition of the metal grids. Searching for optimal thicknesses (objective technologically) suggests us the following solution:

100nmSiO_2/260nmZnO/50nmCdS/$CuInSe_2$.

This structure would make it possible to reduce the losses by reflection to less than 4%.

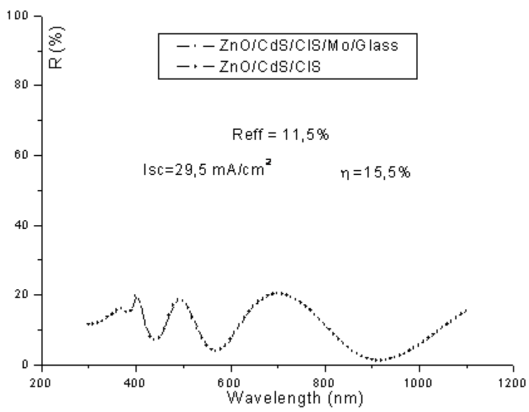

Fig. 4. Reflectance of ZnO/CdS/$CuInSe_2$/Mo/glass.

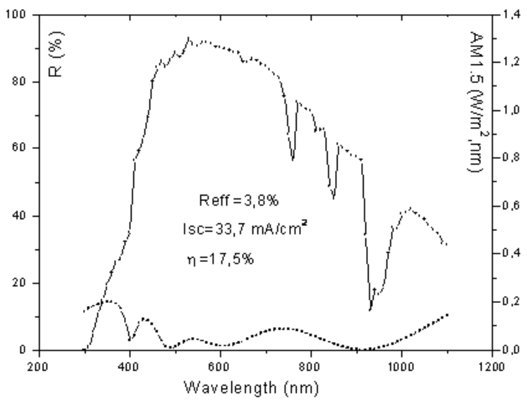

Fig. 5. Optimized reflectance of SiO_2/ZnO/CdS/$CuInSe_2$/Mo/glass.

By introducing these results into a simulator of solar cell, minimization of the losses by reflection improves the photocurrent (or I_{sc}, the short circuit current) by more than 30%. The energetic conversion efficiency η is then increased by more than 15% (see calculated values of I_{sc} and η indicated in Figs 4 and 5. With a similar solar cell but using MgF_2 as antireflection coating, J. Abushama et al. found a yield of 15% [8].

6. Conclusion

Control of thin film deposition and optimization of the choice of materials and thicknesses make it possible to reduce reflection losses of photovoltaic cells. In the case of $CuInSe_2$ thin films based cells, these losses can be reduced to less than 4% resulting in more than 15% improved photovoltaic efficiency. Thus, the addition of a porous silica layer, dielectric with low refractive index, allows besides a clear reduction in the losses by reflection, to ensure protection with respect to the ambient conditions without for that weighing down the technological process.

References

1. T.M. Razykov, C.S. Ferekides, D. Morel, E. Stefanakos, H.S. Ullal, H.M. Upadhyaya, Solar energy, Solar photovoltaic electricity: Current status and future prospects // *Solar Energy*, **85**(8), p. 1580-1608 (2011).
2. I. Repins, M.A. Contreras, B. Egaas, C. DeHart, J. Scharf, C.L. Perkins, B. To, R. Noufi, 19.9%-efficient ZnO/CdS/$CuInGaSe_2$ solar cell with 81.2% fill factor // *Progr. Photovolt.: Res. Appl.* **16**(3), p. 235-239 (2008).
3. J.A.M. AbuShama, S. Johnston, T. Moriarty, G. Teeter, K. Ramanathan, and R. Noufi, Properties of ZnO/CdS/$CuInSe_2$ solar cells with improved performance // *Progr. Photovolt.: Res. Appl.* **12**(39), p. 39-45 (2004).
4. N. Dahan, Z. Jehl, T. Hildebrandt, J.-J. Greffet, F. Guillemoles, Optical approaches to improve the photocurrent generation in Cu(In,Ga)Se_2 solar cells with absorber thicknesses down to 0.5μm // *J. Appl. Phys*. **112** (2012).
5. L. Remache, L. Fourmond, E. Mahdjoub, A. Dupuis, J. Lemiti, Design of porous silicon/PECVD SiO_x antireflection coatings for silicon solar cells // *Materials Science & Engineering B,* **176**(1), January 15, p. 45-48 (2011).
6. M. Born, and E. Wolf, *Principles of Optics: Electromagnetic Theory of Propagation, Interference and Diffraction of Light*. Oxford, Pergamon Press, 1964.
7. A. Mahdjoub, L. Hadjeris, L. Herissi, M. Benbouzid, N. Attaf, M.S. Aida, T. Easwarakhanthan, B. Assouar and J. Bougdira, Ellipsometric investigation on optical properties of ZnO thin films prepared by spray pyrolysis // *Intern. Conf. on Optics* (*ICO'08*), Setif, Algeria, November 8-10 (2008).
8. J. AbuShama, R. Noufi, S. Johnston, S. Ward, and X. Wu // *31th IEEE Photovoltaics Specialists Conference and Exhibition*, Lake Buena Vista, Florida, January 3-7 (2005).