

A Theoretical Study of CdTe Flat-film Thickness Impact on AM1.5G Solar Absorption

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Abstract

The impact of CdTe flat layer thickness on AM1.5G solar absorption is theoretically investigated in this paper. It is found that CdTe with a thickness down to 500 nm can achieve an ultimate efficiency (UE) of 31.9%, which is far greater than the counterpart of Si thin film (only 23.7% for a thickness of 10 μm). UE of CdTe tends to saturate with the thickness of more than 500 nm. For 550 nm thickness CdTe, 5% of thickness variation results in only about 0.1% UE change.

Keywords: CdTe; Solar Absorption

1 INTRODUCTION

CdTe emerges as an important material candidate for 2nd-generation thin-film solar cell application due to its excellent device performance [1-3]. However, the supply of the CdTe raw materials remains a great challenge for the ultra-large-scale power output [4]. The reduction of the CdTe thickness in the solar cell device is considered as a straightforward way to reduce the materials consumption as well as the corresponding cost. On the other hand, with the decrease of CdTe thickness, the light absorption properties shall be compromised, which would adversely affect the final power conversion efficiency. Various methods to enhance the thin-film light trapping property have been developed, such as surface texturing [5-7] or anti-reflection layer coating [8], which would eventually increase the complexity of the device fabrication and thus the cost of the device. Exploration of the flat film (i.e. without any addition of light trapping schemes) light absorption properties is meaningful, and it is interesting to investigate what's the minimum thickness requirement to achieve reasonable good light absorption, and what's the thickness variation impact on light absorption properties. For large-scale industry production, the thickness variation during thin film flat layer deposition becomes an important concern [9]. In this paper, such a study is presented on the CdTe flat film.

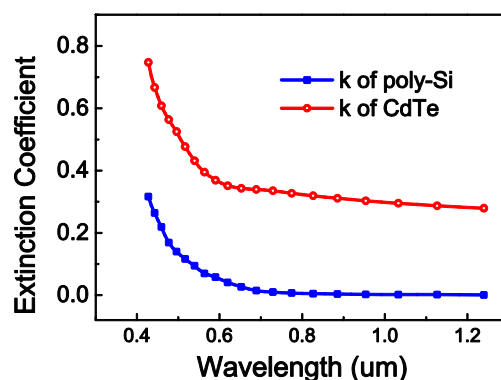


FIG. 1 COMPARISON OF EXTINCTION COEFFICIENT (K) OF CdTe AND POLY-SILICON. CDTE HAS HIGHER K VALUE THROUGHOUT THE SPECTRUM.

As can be seen from Fig. 1 [10-12], CdTe has superior K property than Si. Additionally, CdTe has a direct energy gap

value of 1.44 eV (in comparison, Si has an indirect energy gap value of 1.12 eV). Both would predict that CdTe flat film can achieve excellent light absorption properties as compared to Si counterpart even for an ultra-thin thickness. Indeed, our study has found that CdTe with a thickness down to 500 nm can achieve an ultimate efficiency (UE) of 31.9%, which is far greater than the counterpart of Si thin film (only 23.7% for a thickness of 10 μm). UE of CdTe also tends to saturate with the thickness more than 500 nm.

2 MODEL

The optical simulations are carried out by employing the HFSS software. The absorption efficiency is derived from the energy flux distribution of the incident light solved by finite element method. The material property is set up by relative permittivity and dielectric loss tangent according to frequency. These values are derived from permittivity (n) and extinction coefficient (k) of the material. A repeating boundary condition is used to achieve the infinite flat cell simulation. The top and bottom surfaces are bounded to the Perfectly Matched Layer (PML). The wavelength of incident light (normal to the flat surface) varies from 300 to 1200 nm.

The ultimate efficiency of the solar cells is derived from Equation (1):

$$UE = \frac{\int_{E_g}^{+\infty} \frac{I(E)\alpha(E)E_g}{E} dE}{\int_{-\infty}^{+\infty} I(E) dE} \quad (1)$$

Where $I(E)$ is the intensity spectrum of the incident light at AM1.5G and $\alpha(E)$ is the absorption spectrum of the evaluated cell, and E_g is the specific band gap.

3 RESULTS AND DISCUSSION

The evaluated model is based on pure Si and CdTe materials without any additional light trapping schemes. Fig. 2 shows the relationship between UE and thickness. For both Si and CdTe, UE and thickness have a positive correlation. For Si film, its UE increases to 9.8% at thickness of 500 nm, and then increases gradually to 23.7% as thickness rises to 10 μm . As a common sense, light transmittance would be reduced with the increase of the layer thickness [13, 14]. However, for CdTe, the UE tends to saturate at 31.9% once the layer thickness reaches 500 nm.

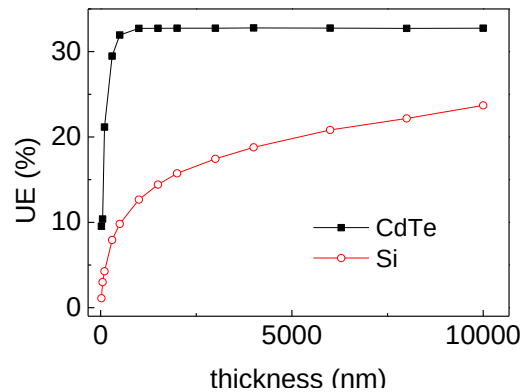


FIG. 2 RELATIONSHIP BETWEEN UE AND THICKNESS FOR SI-BASED (BLACK) AND CdTe-BASED (RED) THIN-FILM SOLAR CELL. THE UE CONVERGES AS THE THICKNESS INCREASES FOR BOTH MATERIALS. CdTe HAS A MUCH HIGHER CONVERGENT RATE.

For CdTe film, when the thickness is small, i.e. less than 500 nm, significant transmission exists only in long wavelength range, as can be seen from fig.3 (a). Transmission shall reduce with the increase of thickness, and it would become negligible when the thickness is larger than 500 nm. This can be explained by the large k value of CdTe (Fig. 1), which leads to a rather short absorption depth. Reflectance of CdTe flat film doesn't vary much when the cell thickness is greater than 500 nm as well (Fig. 3(b)). When the film thickness is less than 500 nm, reflection oscillation at long wavelength region might be correlated with the interference from the photons reaching top surface and bottom surface of the film. With the increase of the thickness, long wavelength photons reaching the bottom surface would be considerably reduced owing to the suppressed transmission (Fig.3 (a)), thus the reflection

oscillation would also become smaller. As a result, absorption saturation is observed in CdTe layer when the thickness is larger than 500 nm, as shown in Fig. 3(c).

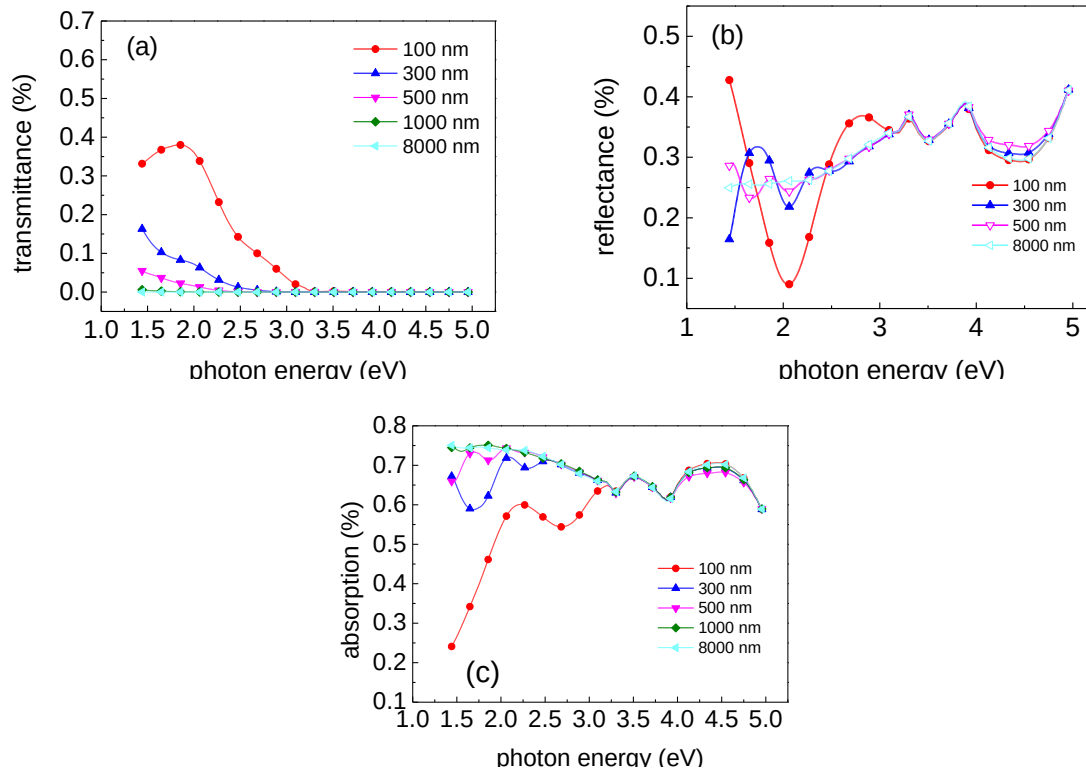


FIG. 3 TRANSMITTANCE (A), REFLECTANCE (B) AND ABSORPTION(C) OF CdTe-BASED FLAT FILM SOLAR CELL DUE TO DIFFERENT THICKNESS. THE TRANSMITTANCE IN RED LIGHT REGION REDUCES RAPIDLY TO THE BOTTOM WHEN THE THICKNESS INCREASES TO 500NM. OSCILLATION IN RED LIGHT REGION APPEARS WHEN THICKNESS IS LESS THAN 500NM.

CdTe UE enhancement factor with respect to Si is defined as:

$$En(t) = \frac{UE_{CdTe}(t) - UE_{Si}(t)}{UE_{Si}(t)} \times 100\% \quad (2)$$

Where UE_{CdTe}/UE_{Si} is the ultimate efficiency of the CdTe/Si at the same thickness t . By using Equation 2, one can estimate how efficient CdTe absorbs light as compared to Si film under the same thickness or in what a way to determine CdTe thickness in the solar device can be considered as relatively economical when combining with Fig. 2. As can be seen from Fig. 4, the enhancement decreases with the increase of the thickness. The high enhancement in the thickness ranging from 20 nm to 500 nm results from the relatively low UE of Si. With thickness of 500 nm, CdTe achieves a very high UE of 31.9% and has an impressive enhancement factor of about 220%.

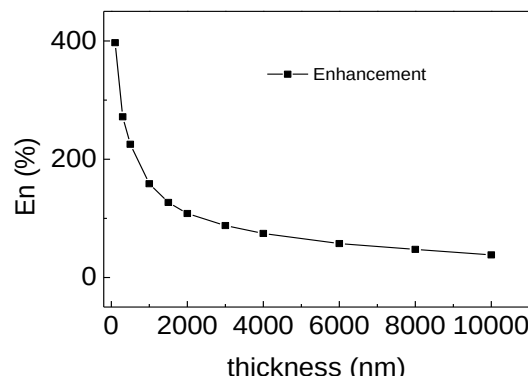


FIG. 4 CdTe UE ENHANCEMENT WITH RESPECT TO Si

Which is defined as:

$$En(t) = \frac{UE_{CdTe}(t) - UE_{Si}(t)}{UE_{Si}(t)} \times 100\%$$

Where UE_{CdTe}/UE_{Si} is the ultimate efficiency of the CdTe/Si and t is the corresponding thickness.

For practical large-scale film deposition (usually the area is more than $1m^2$), film uniformity such as thickness variation should be taken into consideration seriously as it determines the cell efficiency uniformity (largely due to the light absorption capability variation) and thus the final module efficiency. In our calculation, the thickness variation of 5% in 550 nm thickness CdTe film is considered to reveal its impact on light absorption. The calculation yields a difference of only about 0.1%. It is far more stable than its counterpart Si which has a yield UE uncertainty of about 3.1%. The fast UE-thickness saturation rate of CdTe accounts for its good product uniformity, which renders the stability of possible ultrathin CdTe flat film solar cell product.

4 CONCLUSIONS

With UE of 31.9% and thickness down to 500 nm, CdTe flat film solar cell could potentially provide an impressive performance without any surface texturing or other light trapping schemes. Thickness variation having impact on light absorption properties is negligible when the layer is thicker than 550 nm. This work can be treated as a guideline to future ultra-thin CdTe thin-film solar cell design.

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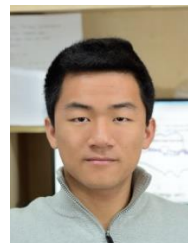
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