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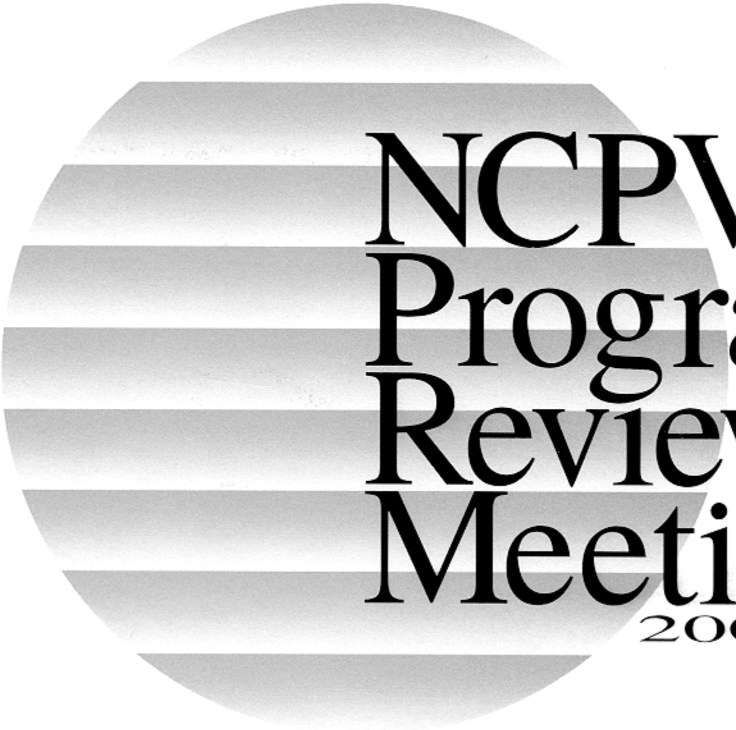

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Cross-Section AFM and EFM Examination of Thin-Film Solar Cells

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ABSTRACT

We demonstrated the feasibility of analyzing cross sections of thin-film CdTe/CdS and CIGS/CdS solar cells using atomic force microscopy (AFM). The AFM images were compared with images obtained with the scanning electron microscopy (SEM), and the correspondence was very good. We also used electrostatic force microscopy (EFM) [1] to image the distribution of the electrical potential on cross sections of CdTe/CdS solar cells biased at different conditions. We were able to follow the potential drop at the junction, and the changes in the depletion width for different bias values.

EXPERIMENTAL

We used the following structures in this work: glass/SnO_2/CdS/CdTe and glass/Mo/CIGS/CdS/ZnO. The CdTe was grown by close-spaced sublimation, the CdS by chemical-bath deposition, the SnO_2 by chemical-vapor deposition, the CIGS by physical evaporation of Cu, In, and Ga in Se vapor, and the Mo and ZnO by sputtering. We prepared the cross sections by scratching one side of the structure (in general, the film side) and applying a pressure on the other side until the structure broke. All the devices were still working during the EFM analysis.

The AFM and EFM analyses were performed in an Autoprobe CP Research system, from ThermoMicroscopes. We used doped Si tips for the AFM and EFM analyses, and Co coated tips for some of the EFM analysis.

We obtained the EFM images by applying ac and dc voltages between the tip and the sample surface, and then monitoring the electrostatic force induced on the tip. To each EFM image, a simultaneous topographic image was also generated. The electrostatic force between the tip and the sample is given by the equation:

$$F = -\frac{1}{2}\frac{\partial C}{\partial z}\left[(V_{dc}-V_s)^2+\frac{1}{2}V_{ac}^2\right]$$

$$-\frac{\partial C}{\partial z}(V_{dc}-V_s)V_{ac}\sin(\omega t)+\frac{1}{4}\frac{\partial C}{\partial z}V_{ac}^2\cos(2\omega t) \qquad (1)$$

where V_s is the the surface potencial, C the capacitance, and z the distance between the sample and the tip. V_{dc} is the dc bias, and V_{ac} and ω are the amplitude and frequency of the ac bias, respectively [2].

In this work we used a lock-in amplifier to analyze only the ω component (16 kHz) of the electrostatic force. The p-side of the device was grounded during analysis and the dc bias was applied to the n-side. From equation (1) we notice that the EFM images are a convolution of several parameters, and their interpretation is not always straightforward.

RESULTS AND DISCUSSION

Cross-Section AFM

In Figure 1, we observe the cross section of a CdTe/CdS solar cell. The CdS structure cannot be visually distinguished from the SnO_2 layer. The dynamic of the fracture in the CdTe film is such that the grain boundaries are not visible and several terraces, with different orientations, are formed. These features indicate intragranular fracture.

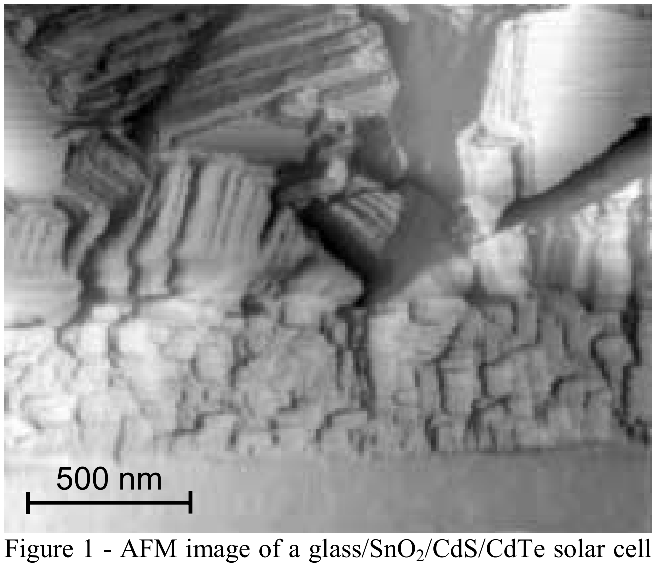

Figure 1 - AFM image of a glass/SnO_2/CdS/CdTe solar cell cross section.

The cross section of a CIGS/CdS solar cell is seen in Figure 2. Contrary to the CdTe case, the CIGS grains are easily distinguishable and present a regular form, which indicates that, in this case, the fracture process was intergranular. In Figure 2 we can also distinguish the columnar character of the Mo bi-layer.

We have also analyzed the cross-section structures with SEM. We were able to locate the same areas in the AFM

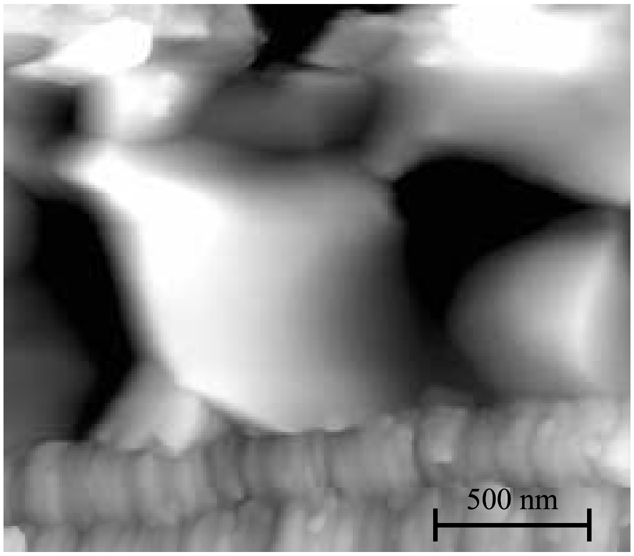

Figure 2 - AFM image of a glass/Mo/CIGS/CdS/ZnO solar cell cross section. The large grains belong to the CIGS film.

and SEM. The images were comparable, although we could, in general, obtain better resolution with the AFM.

Electrostatic-Force Microscopy

Figure 3 shows topographic and EFM images of a CdTe/CdS solar cell cross section. By convention, we use positive values for forward bias and negative values for reverse bias. The EFM signal shows that there is a sudden drop in electric potential at the CdTe/CdS junction. By comparing the topographic and EFM images, we notice that the drop in the EFM signal is located at the CdTe/CdS interface, indicating the presence of a heterojunction. As expected, the EFM contrast is inverted when we invert the polarization of the applied dc bias (Figures 3(b) and 3(c)). Figure 3(d) shows several line scans for the same device, with different applied bias. For direct bias, the signal drop is relatively sharp. As we polarize the junction in reverse bias condition, the signal change gets less abrupt and extends well into the CdTe layer. These results are associated with an increase in the depletion-region width as the reverse bias increases.

CONCLUSIONS

We showed the potential of the AFM for studying cross sections of polycrystalline semiconductor structures. The AFM provides better resolution than the SEM, and allows for real 3-dimensional manipulation and calculations in the images. EFM was applied to a CdTe/CdS solar cell and was able to map the drop in potential in the junction for different bias conditions. The results indicate that the CdTe/CdS solar cell is formed by a heterojunction between CdTe and CdS.

REFERENCES

[1] Y. Martin, D.W. Abraham, and H.K. Wickramasinghe, Appl. Phys. Lett. 52, 1103 (1988).
[2] Q. Xu and J.W.P. Hsu, J. Appl. Phys. 85, 2465 (1999).

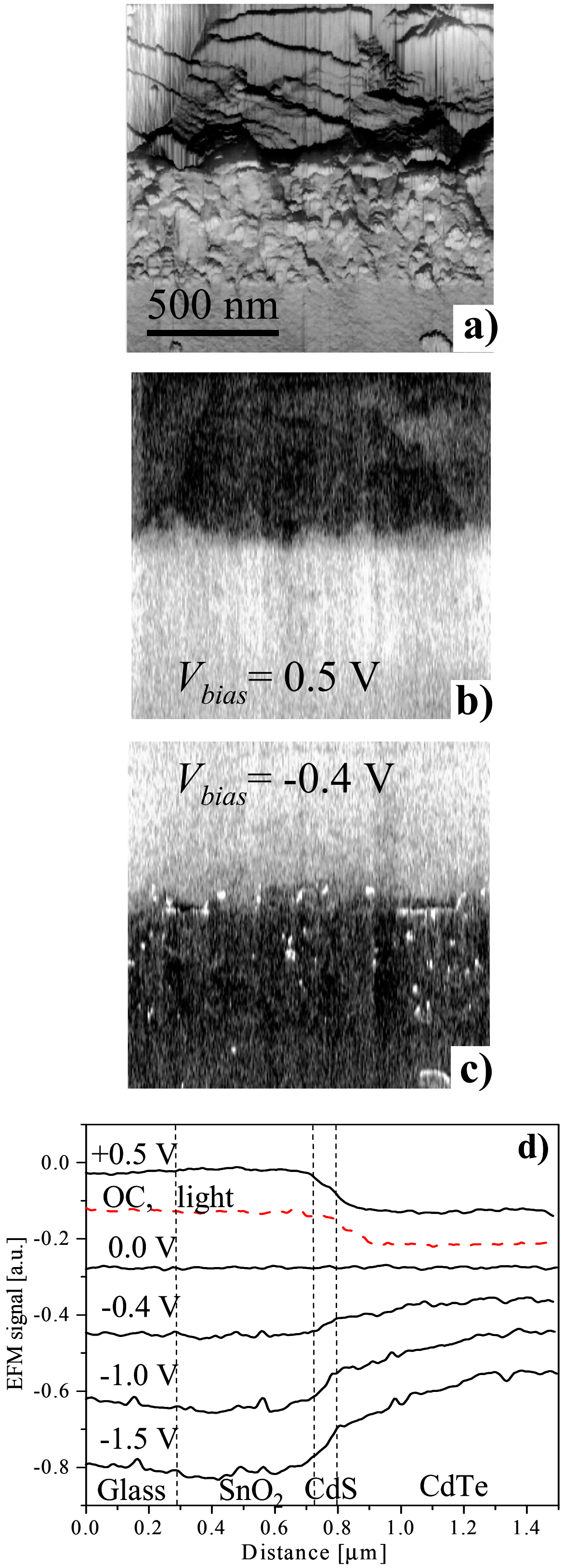

Figure 3 – AFM images of a CdTe/CdS solar cell cross section. (a) Topographic image. (b)(c) EFM images. (d) EFM line scans for different cell bias. OC denotes open-circuit configuration, i.e., device under illumination with no external voltage applied.