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3.2 CdTe, CIS and Related Ternary and Quaternary Thin Film Solar Cells

Regression analysis of capacitance transients: a method to obtain information on the electric structure of thin-film solar cells

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Abstract

The production of thin-film solar cells implies several deposition and processing steps. Therefore for such a multiple-layered structure each processing step may influence the layers already present.

Assessment of the quality of such devices and understanding the impact of defects on their properties and performance is nowadays often based on the electrical characterization with capacitance-voltage profiling, admittance spectroscopy (AS), and deep level transient spectroscopy (DLTS). Although the development of components depends on the understanding of each layer on the device's electric properties, in complete devices the assignment of observed effects to particular layers, and even the interpretation of certain signals, is often quite difficult. On the other hand the relevance for the complete devices is not guaranteed if one studies isolated layers or simplified devices. Moreover, even single or double-layer structures require making of electric contacts, which may influence the observed results. Hence, characterization of finished products provides the most relevant information and is preferred by the manufacturers and many researchers.

DLTS & AS spectra recorded on thin-film devices have usually been interpreted in terms of defects in particular layers or at certain interfaces. Recently, in the context of interpretation of the capacitance spectroscopy signals observed for $CuIn_xGa_{x-1}Se_2$ (CIGS) solar cells, we have studied the DLTS characteristics of a non-Ohmic contact in layered structures.

It was shown that the famous N1 signal obeys the typical properties of such a non-ohmic contact.

In this work a fitting algorithm is presented for capacitance transients measured after voltage pulses for a thin-film semiconductor component comprising, in addition to the main junction, an additional p-n or schottky contact with opposite polarization. Both junctions are modeled with regular diode I-V and C-V characteristics and a thermally activated saturation current. The fitting tool in principle allows to extract the parameters describing the two junctions, although the uncertainty is markedly lower for the additional barrier.

It is tested on a model component built from commercially available diodes, whose characteristics can be assessed through static I-V C-V measurements on individual diodes. The fitting results are in excellent agreement with these static properties. Recently, we demonstrated that certain DLTS components measured for thin-film solar cells, e.g. the N1 signal for CIGS cells can be interpreted as originating from a non-ideal (schottky/p-n) contact in the thin-film structure. We estimate the activation barriers of the non-ideal contacts for a selection of CIGS and CdTe solar cells.

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Short introductive summary

An electric characterization method for additional barriers in the multiple-layered structure of thin-film solar cells is presented. This method is based on regression analysis of recorded capacitance transients after different voltage pulses. The model used in this analysis is a device with in addition to the main junction and additional p-n or schottky contact with opposite polarization. This fitting tool not only confirms that this additional barrier is a valid model for the N1 signal observed in capacitance spectroscopy on CIGS solar cell, but also allows to extract parameters that can describe these additional barriers. It is demonstrated that even barriers that have no distinguishable effect on the static IV curves of the whole device can easily be detected with capacitance transient spectroscopy and characterized with this numerical method.

1. Purpose of the work

The intended detection of carrier trap levels in thin film solar cells by means of DLTS or AS might be hampered by the very intense signals generated by the non-ideal contacts. But these signals originating from non-ideal contact may also provide very valuable information on the thin-film device. The purpose of this work is to extract the (electric diode) characteristics of the non-idel contact (its barrier height and saturation current). This information can provide useful parameters to assess its detrimental or beneficiary effect on the device property through simulation. Moreover this may also help to identify the corresponding layer and contribute to direct optimization of the device.

2. Approach

From non-linear regression of the DLTS spectra with regular and inverted pulses of various heights, information on the back contact can be extracted. The model circuit we use in this fitting algorithm is a normal diode perturbed with another diode as barrier. The electric properties of both components are modeled including their current and capacitance characteristics. Besides these two components, a series resistance is included to avoid discontinuities in the circuit response.
These parameters describing the model are optimized via fitting the numerically modeled transient to the experimental data. Although the whole transient provides information for unraveling the properties of the back contact, taking into account all points would make the calculations very time-consuming. Therefore, the optimization algorithm uses only the first four Fourier components of the capacitance transient b1, a1, b2, and a2 as the transients are non-exponential, these provide independent information. Figure 1 shows parity diagrams for these output parameters for a Cr-Si schottky model circuit, a CdTe solar cell, a Mo-CIGS-Al structure and three N1 signals for CIGS cells with different buffer layer comparing the experimental and simulated data after optimization.

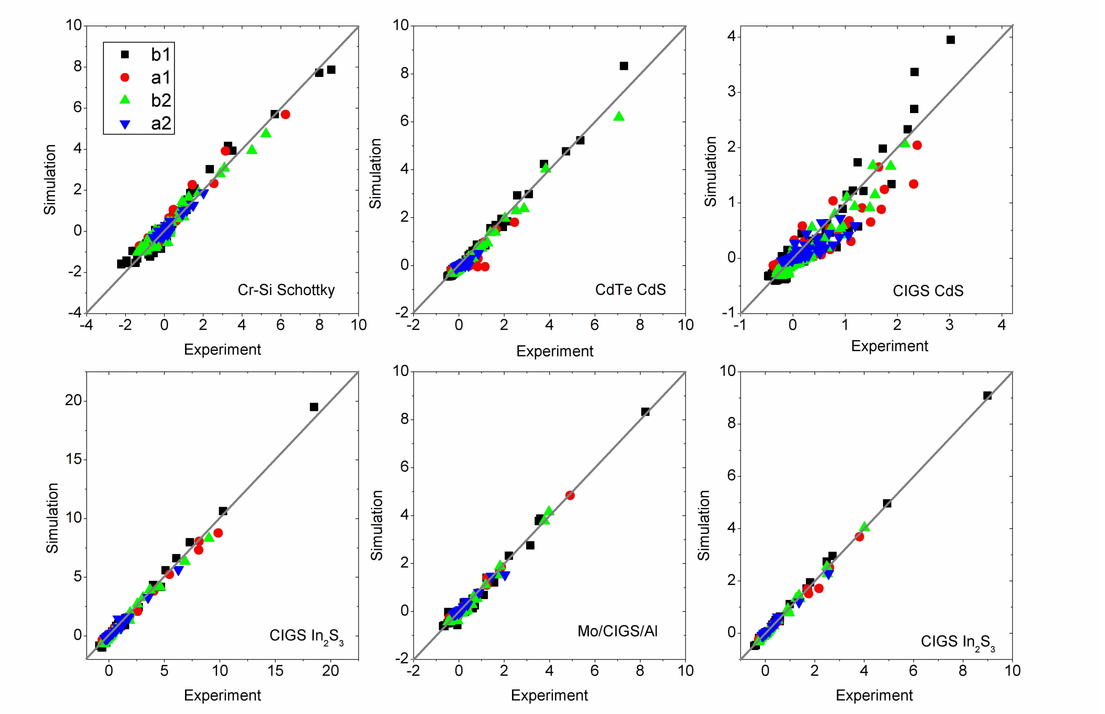

Figure 1: Parity diagrams for the output parameters b1, a1, b2, and a2 for the model circuit and the solar cells. Grey lines indicate "experiment=simulation" guide for the eye.

From these parity diagrams it can be seen that the proposed model is valid to explain the anomalous behavior of the observed DLTS back contact signals. Moreover, the presence of the same signal in a simplified Mo/CIGS/Al multiple-layered structure convinced us that the signal originate from the back contact, while the model itself does yields no information on the location of the extra barrier.

3. Scientific innovation and relevance

Thin film solar cells that make use of a direct band gap semiconductor are offering the prospect of efficient and cost-effective photovoltaic energy conversion. To further improve these devices a good electric characterization of this multiple-layer structure is necessary. The combination of recording capacitance transients with device modeling allow to obtain information on the additional barriers present in the structure. This information cannot easily be obtained in another way. Although roll-over effects might be present in the IV curve of solar cells as an effect of the presence of a barrier, the static IV measurements are not so sensitive to detect the presence of a barrier comparing with the registration of the capacitance transients. The demonstrate this, IV curves have been simulated corresponding with the parameters obtained for a CIGS In_2S_3 buffer solar cell with and without the additional barrier. Figure 2 a shows that no difference can be detected in the measured current due to the presence of the additional barrier. This is certainly not the case in the reverse bias situation where the resistance of the barrier pulsed forward is clearly negligible with respect to the main junction. While in the DLTS spectrum as shown in figure 2b a clear N1 signal is observed, from which regression analysis can determine the electric parameters

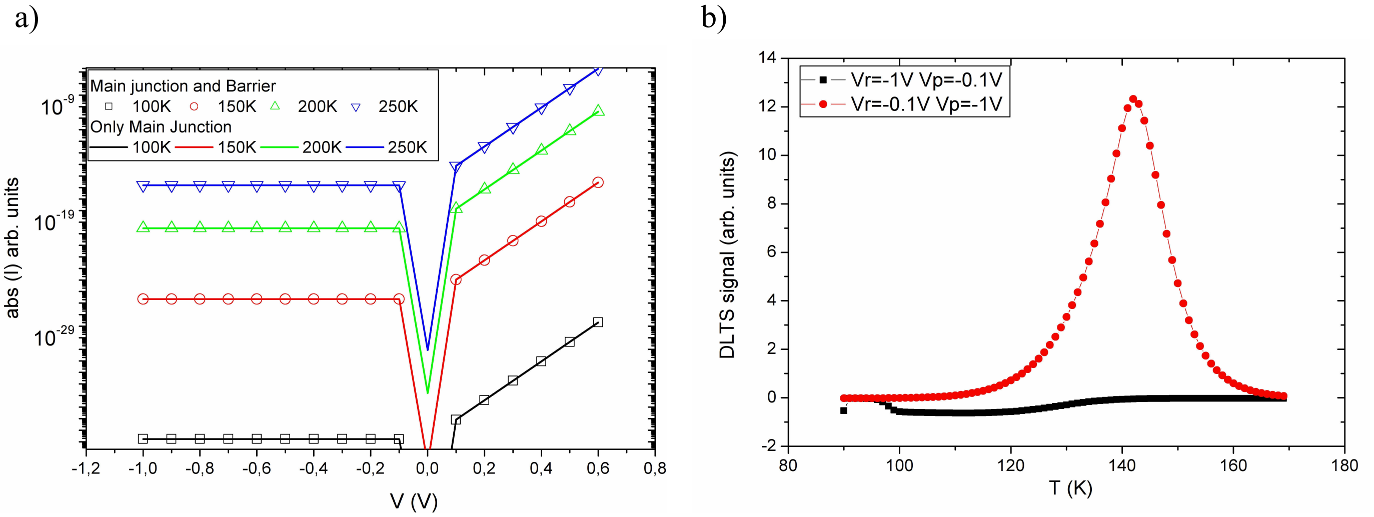

Figure 2: a) Simulated IV curves for corresponding with the parameters obtained of the CIGS In2S3 b Cell showing that no difference is expected to be detected in the static IV curves from the present barrier. b) The modeled N1 signal showing with the same parameters showing that even for a small barrier not detectable in the static IV curves a DLTS signal can be detected.

4. Results and conclusions

We conclude that fitting a model for the circuit to the DLTS spectra with different biases allows to determine parameters for the additional contact responsible for the N1 peak. An overview of the barrier heights and saturation currents is shown in table I. From this, the barrier height can be accurately determined, without removal of layers and without influencing the total structure. This method makes it possible to characterize barriers within finished products. The possibility to study complete devices can not only contribute to the discussion of the origin of the N1 signal in CIGS and related thin-film solar cells but can also support the engineering of other complicated electronic thin film structures.

	ΔE (meV)	$\ln\left[A \quad (\mathrm{AK}^{-2})\right]$
Schottky Cr-Si	638 ± 2	0.58 ± 0.01
CdTe CdS	380 ± 28	-9.78 ± 1.64
CIGS CdS	19 ± 4	-20.9 ± 0.7
CIGS $\mathrm{In_2S_3}$ a	177 ± 3	-11.1 ± 0.54
CIGS $\mathrm{In_2S_3}$ b	188 ± 5	-10.3 ± 0.38
Mo/CIGS/Al	153 ± 9	-13.1 ± 0.54

TABLE I. Parameters for the additional non-ohmic barrier in the structure (95% confidence intervals are included).