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Dark Current Transients in Thin-Film CdTe Solar Cells

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DARK CURRENT TRANSIENTS IN THIN-FILM CdTe SOLAR CELLS

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ABSTRACT

Dark current transients measured by changing the voltage bias in a stepwise fashion on CdTe cells results in minutes-long transients after each step. Transients measured at room temperature are controlled by carrier trapping that corresponds to the well known voltage transient phenomena [1]. Transients measured on the same CdTe cell at elevated temperature (60°C and 90°C) show a much slower decay process. We associate this physical process with "shunt" current paths induced with reverse bias and removed with forward bias. A different back contact process may produce an opposite voltage dependence. The lack of these transients may be required for the fabrication of "stable" thin-film CdTe solar cells

BACKGROUND

In the past, current transients taken at room temperature lasting hundreds of seconds resulting from stepwise changes in voltage bias were used to study metastable shunt paths in a-Si:H single- and triple-junction solar cells [2]. In single-junction cells, the authors saw stepwise current changes that increased in size and number with reverse bias and that could be removed with forward bias. The stepwise, on-and-off switching is due to a discrete shunt path conduction mechanism. The kinetics of these metastable shunt paths show that both the "on-state" and the "off-state" possess memory. The longer they are on and conducting, the longer the turn-off time. After repeated switching they remain on, and the cell becomes shunted.

In a-Si:H cells, the abrupt steps and the ability to switch between a conducting "on-state" and a nonconducting "off-state" by changing the sign of the bias is very similar to the switching mechanism discovered by LeComber et al. [3]. In their switching devices, very small metal shunt paths are formed that act as switchable current paths. Recently, bias-dependent switching on a-Si p+/metal devices "formed" with various metal contacts was attributed to charged metal inclusions [4]. Those authors suggest that V, W, Ni, or Co contacts form different geometrical chains yielding "quantum" or "analog" switching.

In this paper, we discuss the result of applying this type of current transient measurement technique to CdTe cells at three temperatures (T = 25, 60, and 90°C). At 25°C, we see the current transient that is the root of the notorious "voltage transient" that has been the plague of CdTe efficiency measurements and blamed on trapping [1]. At 60°C, we see the time constant for the trapping process shrink with the appearance of a new, much slower process, which we attribute to shunting, as we did in the case of the a-Si:H cell. At 90°C, the trapping times become less than a few s and the metastable shunting transient becomes the main feature lasting hundreds of seconds. After repeated voltage stress, full reversibility diminishes, and shunt currents are permanently increased. They are the focus of this paper.

EXPERIMENT

Slow sweep rates of 50 s/cm are used on a Hewlett Packard 7047A X-Y recorder to monitor current transients resulting from stepwise changes in voltage applied to CdTe solar cells of about 1 cm^2. A cell is kept in the dark except for occasionally shining a flashlight beam on the cell to determine polarity and/or to look for trapping effects. Positive (forward) bias voltages of generally less than 0.5 volts and negative (reverse) bias voltages of less than 1.0 volt were applied in a step function manner. Measurements made above T = 25°C were done in an oven.

Before and after each series of transient measurements at each of T = 25, 60, and 90°C, an I-V trace was run at each T. The sinusoidal sweep cycle time was 3 min, allowing a quick look at the hysterises loops caused by these transients and any change in shunt currents occurring because of repeated voltage stress at these T. The close space sublimation (CSS) CdTe cells, for which the data in this paper are shown, are a couple of the many studied having different back contact recipes. Data were selected to best exhibit effects of trapping and shunting.

RESULTS

Current-voltage I-V curves

The effect of these transients is to cause hysteresis loops in the current-voltage (I-V) curves shown in Fig. 1. The forward bias loop at 25°C is due to trapping effects, which can be seen in the current transients that follow. Note that there is no visible loop at negative voltages, because the traps being emptied of charge have no measurable effect on reverse currents of this size. At T = 60 and 90°C, hysteresis loops are seen in both directions. The transient results below show these are due to a second and much slower phenomenon. Also of note is that these curves were measured at the end of all the transient characterizations. The currents at the maximum reverse bias voltage of - 0.45V for T = 25, 60, and 90°C are I = -1.6μA, -7.2μA, and -19.5μA, respectively. At the beginning of the study, these currents were somewhat lower at I = -1.5μA, -1.9μA, and -3.9μA, respectively, showing that some irreversible shunting has occurred during these measurements.

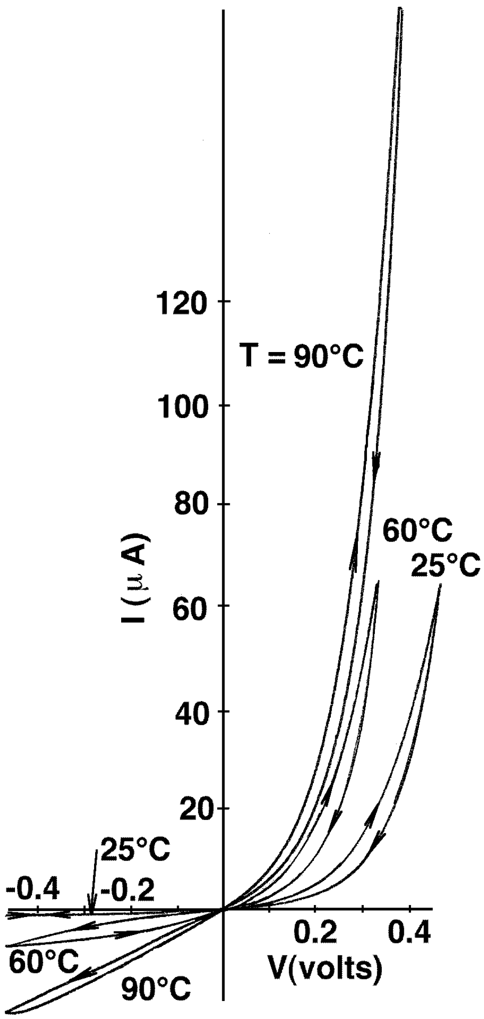

Fig. 1. I-V traces for CdTe cell taken at each T = 25, 60, and 90°C for a 3-min sweep time after voltage/thermal stress of transient measurements.

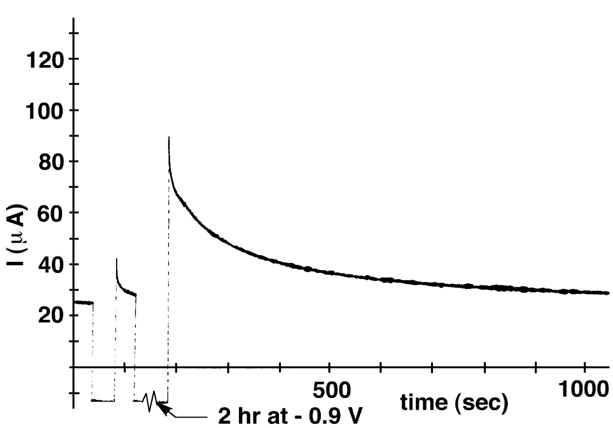

Fig. 2. Current transients at 25°C from switching between -0.9V and +0.5V.

Transient results at 25°C

When the cell bias is changed between -0.9 and +0.5 V in a stepwise fashion, as shown in Fig. 2, we see long slow current transients in the forward bias that are controlled by carrier trapping effects. Comparing the first transient, which has a precursor dwell time of 45 s at -0.9 V, to the second, much larger and longer transient, which has a precursor dwell time of 2 h at -0.9V, we see it matters how long the cell was in reverse bias. Either there is a relaxation process stabilizing the trapped charge, or there are many energy levels available for the charge to thermalize in. The trapped charge causes the change in the forward bias current either by modifying the barrier or changing the recombination current. Note that no transient is seen after switching to -0.9V at these time scales up to a period of 2 h, consistent with the absence of the reverse loop in Fig. 1.

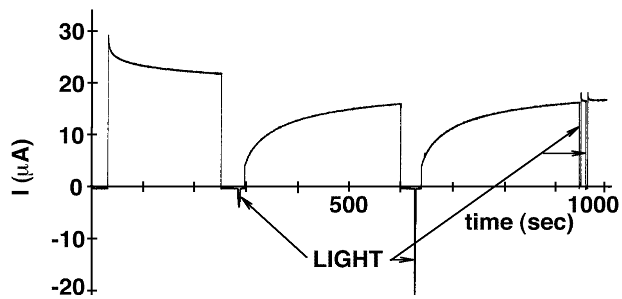

Fig 3. Effect of light on current transients at 25°C. Cell bias switched between -0.4 and +0.4 V. Four light exposures indicated by the negative spikes occurring during - or + biasing.

Figure 3 shows that similar transient times can be obtained by shining a flashlight on the cell. The first transient shows the usual decaying transient behavior following a -0.4V bias period in the dark. If light is shone during the bias periods at -0.4V preceding the switch to forward bias, the effect on trapping to the forward bias current transient is large and the same no matter the amount of light, as measured by the negative current spikes. However, if light is shone during the +0.4V bias period, the light has little effect on the current, except, of course, while it is on. Light, as well as forward bias, will split the quasi-Fermi levels, so shining light while in forward bias would have little effect. On the other hand, shining light at the reverse biased cell will cause splitting where there was none, changing the cells state in a huge way before switching to the forward bias.

Transient results at 60°C

Transients at 60°C in Fig. 4 show a shortening of the forward bias trapping process with the emergence of a reverse bias transient. A hysteresis loop now appears in the reverse bias I-V shown in Fig. 1.

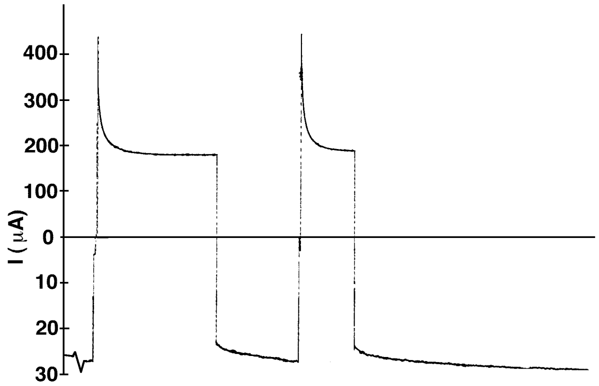

Fig. 4. Current transients at 60°C from steps at -0.9 V stepped up to 0.5 V. (Note scale difference from + to - current scales.)

Transient results at 90°C

Fig. 5 shows a complete cycle of biasing at 90°C, consisting of two traces: the first starts at 30 µA for 200 sec at -0.25V before switching to -0.5V. The negative current continues to the 1200 s mark before retracing back to t = 0, where it is maintained for another t = 150 s. Then the bias is switched to v = +0.25V. We now see the a sharp peak caused by forward bias trapping that goes well over 60 µA. Its effect settles out within a few seconds, leaving a new, much slower current transient. Unlike the trap controlled transients at T=25°C, this new process produces a reverse bias current transient as well.

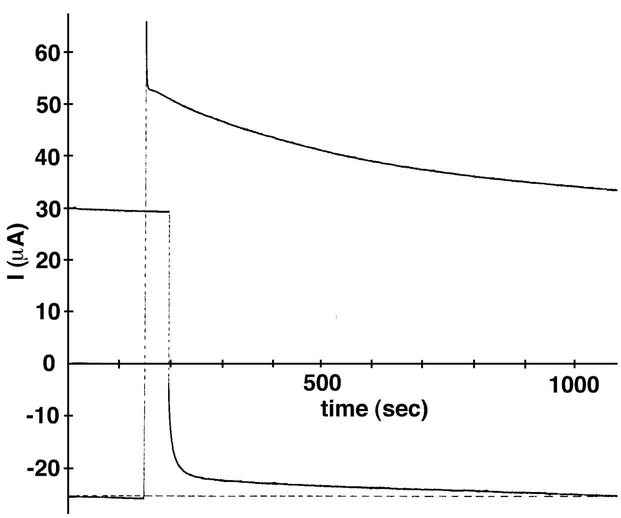

Fig 5. Current transients at 90°C from steps at -0.5 V stepped up to 0.25 V.

Fig. 6 shows the state of the cell after it was left at 90°C and v = 0V for 16 h. The forward current transient is nearly unchanged, but the reverse transient has developed a new feature; first its size increases and then it begins to decrease toward an equilibrium value. These produce the loops seen in Fig. 1, and since they look like shunt currents, why not call the transients "shunt current transients" as for the case of the a-Si cell work [2].

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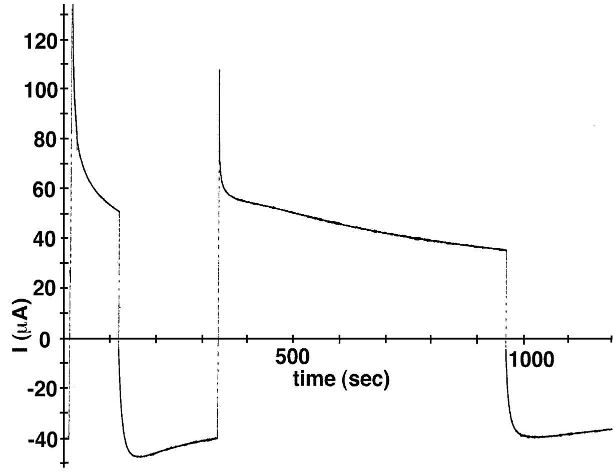

Fig 6. Current transients at 90°C from steps at -0.5 V stepped up to 0.25 V after 16 h at v = 0V and 90 °C. (Note new feature in reverse transient)

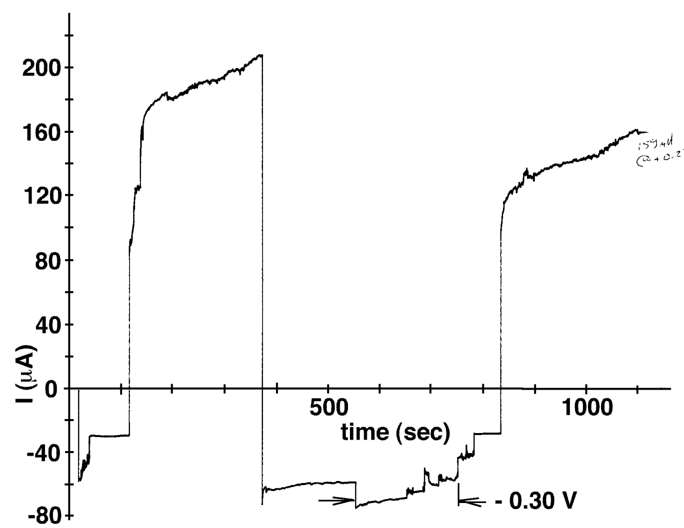

Fig. 7. Current transients at 90°C from steps at -0.23 V stepped up to 0.23 V

Fig. 7 shows that the opposite sign behavior exists. This is a CSS CdTe cell having a different back contact recipe that includes a 15 s nitric/phosphoric acid etch. It is highly shunted and exhibits a very erratic current transient, almost as though current paths are switching between "on-" and "off-states."

CONCLUSIONS

Current transients resulting from stepwise, forward-to-reverse, and back to forward bias changes were shown for thin-film CdTe cells. At T = 25°C, the current transient is controlled by trapping that changes the barrier or recombination-controlled currents in forward bias. At T = 90°C, the forward and reverse bias current transients are probably controlled by shunt paths, which are turned on and off by metal ion migration, maybe Cu. This type of characterization may prove valuable for monitoring change in cell performance caused by heat and voltage bias. The lack of these transients may be required for the fabrication of "stable" thin-film CdTe solar cells

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