WORKING QUANTUM EFFICIENCY OF CDTE SOLAR CELL

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ABSTRACT

For p-CdTe/n-CdS solar cell, it is reported that the quantum efficiency and the collection efficiency are not only wave length dependent but also most importantly voltage dependent, since the CdTe solar cell is believed to be the diode which has non-shallow acceptors and deep levels where the roles of these levels are not clear. In this study, the quantum efficiency of CdTe solar cell with various optical biases, which is titled as “Working Quantum Efficiency (WQE)”, is measured. The result is compared with industrialized amorphous silicon solar cell. Simulation models are given to explain those measurements. The result shows the measurements of WQE is one of important evaluations for CdTe solar cell as well as it can contribute to its characterization and improvement.

BACKGROUND

The Standard ways of quantum efficiency (QE) and efficiency measurements are all under open circuit condition which is optimized for solar cells, shining 1 sun luminance. However, in real application, the incident light will either be weaker or has different color temperature. For example, the sunrise and sunset have lower color temperature or different spectrum. Measurements called apparent quantum efficiency (AQE) were shown by J.R. Sites [1] etc.

It is known that the current-voltage model of a solar cell is usually written as Shockley equation

$$I_F = -I_{sc} + \sum I_{0i}\left[\exp\left[\frac{q(V-I_F R_s)}{A_i kT}\right]-1\right] + \frac{V-I_F R_s}{R_{sh}} \qquad (1)$$

where I_{sc} is short circuit current or light current, the second summation term is the sum of current of a forward diode diffusion and several generation-recombination effect, and the last term is leakage current. A_i, R_s and R_{sh} is ideality factor, series resistance and shunt resistance. From the expression the effect with larger ideality factor will dominant at low voltage bias. The dark-leakage current term can be expressed as

$$I_{Dark} = I_F + I_{sc} = I_0\left[\exp\left[\frac{q(V-I_F R_s)}{A^* kT}\right]-1\right] + \frac{V-I_F R_s}{R_{sh}} \qquad (2)$$

where A^* is effective ideality factor, which varies, of course, in different voltage region.

Recently, some researchers show the result that the dark current term is a function of incident light intensity, which is not included in Shockley equation, such as the works by J.R. Sites [1], O. Vigil-Galán [2] and D.L. Lianm [3], etc. As shown in figure 1, which is measured Logarithmic dark current term vs voltage under various luminance for a CdTe/CdS solar cell. It is observed that there are changes on ideally factor and maybe saturation current near positive low bias, with the different luminescence condition. But different explanations were given: voltage dependent collection efficiency [1] and carrier tunneling [3]. However, the tunneling current satisfies the equation (68) in S.M. Sze’s [4] page 97. Considering the depletion region is wider than silicon because it is non-shallow doping, and the tunneling usually happens at larger voltage bias, the explanation from reference [1] is more reliable. Thus this kind of effect should also appear in α-Si thin film solar cells because there are more defects and surface effects.

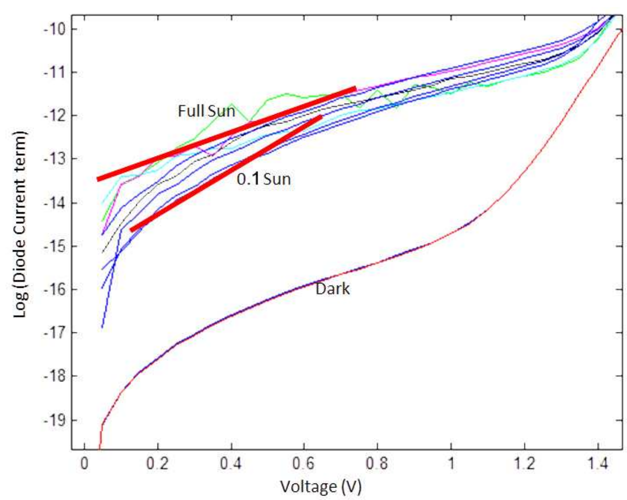

Figure 1. The diode dark current of amorphous silicon solar cell vs voltage under various luminance (from 0.1 sun to 1 sun, and dark).

With the same logic, we could also expect the Apparent Quantum Efficiency (AQE), which had been proved to be voltage and spectrum dependent, is incident luminance dependent as well. So we title the measurement for AQE under different luminance as Working Quantum Efficiency (WQE). Two experiments are carried out: I-V measurements with various incident light intensities and working quantum efficiency (WQE) which describes the spectrum response under different bias voltage and also with the incident light intensity.

MEASUREMENTS AND SETUPS

A piece of industrialized α-Si thin film tandem cell from the production line of EPV Inc with 5.1% efficiency And a piece of bad CdS/CdTe thin film sample with 1.5% efficiency are measured. The setup of WQE measurement is shown in figure 2. With this setup, we can plot WQE as a function of voltage, intensity and wavelength of incident light.

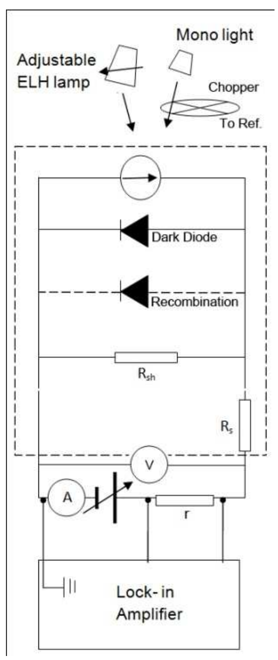

Figure 2. The WQE setup. The equilibrium circuit of a solar cell is in the dashed box.

The pure photon absorption of material CdTe should not be voltage dependent but wavelength dependent. The absorbed photon will mostly generate electron hole pair, with a little portion of heat loss. The intensity actually influence the excess minority carrier density n_c. The lost part is the change of dark current part. The WQE is defined as

$$WQE\ (V, n_{e-h}, \lambda) = \Delta N_q(V, n_c, \lambda) / \Delta N_{hv}(\lambda)$$

$$= [\Delta N_{eh\ pair}(\lambda) - \Delta N_{lost}(V, n_c, \lambda)] / \Delta N_{hv}(\lambda)$$

$$= \text{Constant} - \Delta N_{lost}(V, n_c, \lambda)/\Delta N_{hv}(\lambda) \qquad (3)$$

The intensity of white light is from 60mW/cm^2 to 120mW/cm^2, calibrated with central wavelength 550nm. The output intensity of monochrometer is set around 13uW/cm^2 with ±3uW vary for different wavelength but it is small enough to be perturbations. The resistor r is 500Ω for ΔV signal from the lock-in amplifier in order to get ΔI.

RESULTS

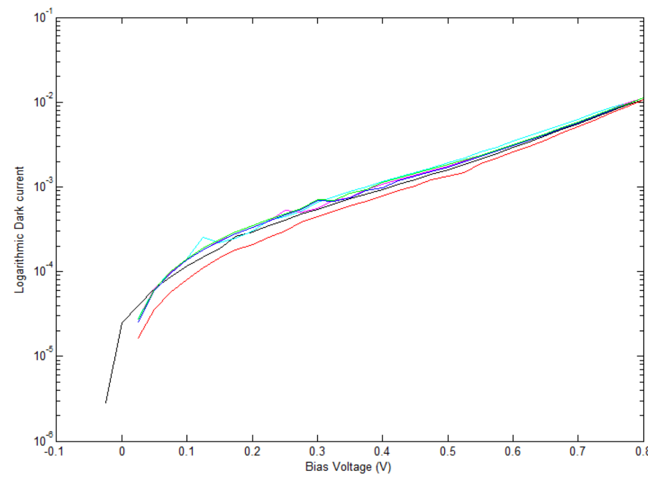

Figure 3. The Logarithmic dark current of the bad CdTe solar cell under different luminance.

From figure 3, one cannot tell the current change due to various incident light intensities, not like in figure 1, the amorphous silicon solar cell. However, it is because the large leakage current has covered the diode currents.

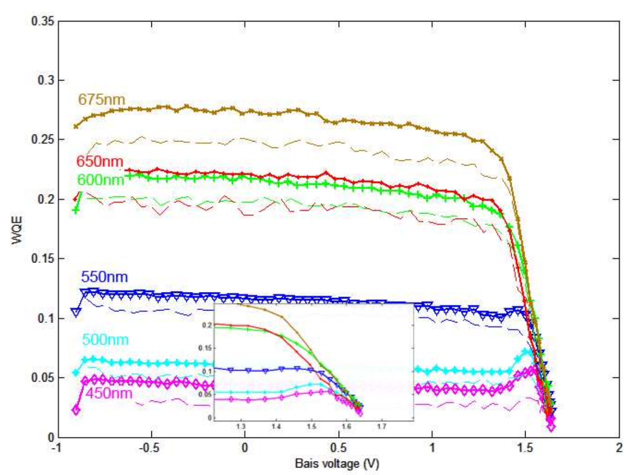

Figure 4. The WQE measurements for the tandem amorphous silicon solar cell. The marked lines indicate that it is measured under 60mW/cm^2 white light bias while dashed lines indicate 120mW/cm^2.

In figure 4, the WQE is kept nearly constant for bias under V_{oc}. For different luminance, the shape of WQE does not shift.

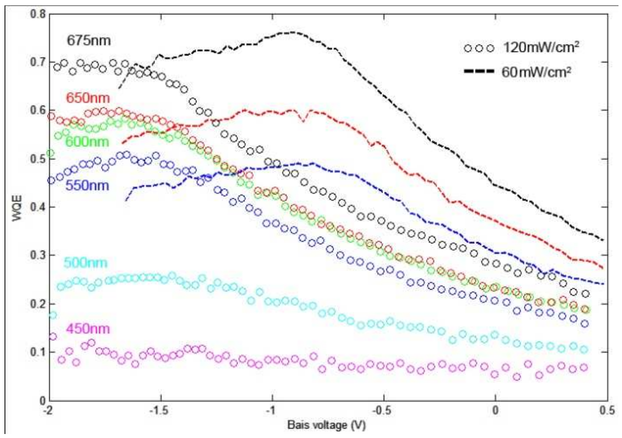

Figure 5. The WQE measurements for the bad CdTe solar cell. The dashed lines indicate it is measured under 60 mW/cm^2 white light bias while the circles indicate 120 mW/cm^2.

The large WQE loss from -0.7V to forward bias can be found in figure 5. The peak of WQE shifts towards reverse bias, lowering down the efficiency in forward bias.

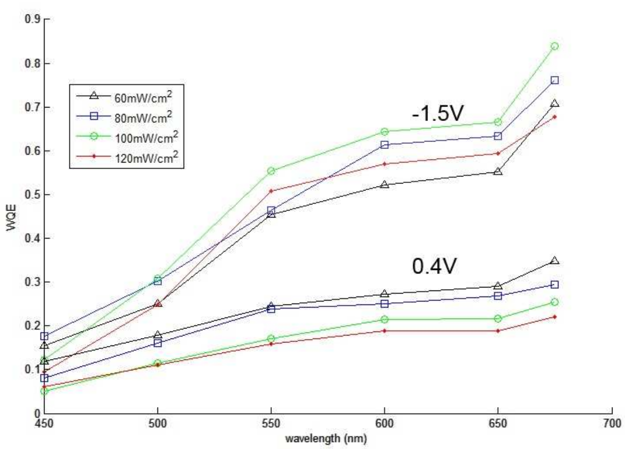

Figure 6. The WQE vs wavelength under two different bias, which verifies the shift in figure 5.

The WQE is lowered in forward bias if the incident light intensity is increased, which indicates higher loss of electrons.

Conclusions

1. The Working Quantum efficiency indicates the collection efficiency and the efficiency loss especially when the curve shifts were observed while changing incident luminance. The shift shows the electron loss changes.
2. The higher incident intensity, less AQE, and the increase of efficiency will be smaller.
3. The dark I-V of the bad CdTe cell does not change significantly with various luminance because it has large leakage current. But the loss is shown in the WQE measurement: the WQE peak shifts towards to reverse bias, especially lowering down the WQE significantly in forward working area. This does not appear in good a-Si cell.

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