Thrust Area 4: Solar (Low Cost PV Manufacturing)

Development of Low Cost CIGS Thin Film Hot Carrier Solar Cells

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Description: PV has entered into a period of record growth. Most of the current production is based on crystalline Si technology. However, there are fundamental limits to the ultimate Si costs that may inhibit it from achieving the desired level of contribution to worldwide energy production. In contrast, thin-film PV technology can reach the desired outcome due to fast deposition rates and lower cost. Our study is focused on hot carrier solar cells for cell conversion efficiency improvement in a low cost, high throughput CIGS system. The rapid thermalizaton loss of hot photoexcited carriers interacting with the lattice can potentially be reduced through phonon engineering in the absorber layer; the subsequent extraction of the hot carriers may be realized through device engineering of energy selective contacts.

Budget: $ 126,112.00
Universities: UF

Progress Summary

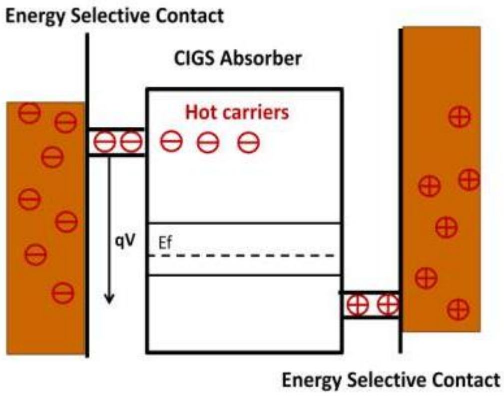

Figure 1: Schematic Presentation of A Hot Carrier Solar Cell

Hot carrier solar cells allow hot carriers to be collected before energy is lost to the lattice. This is accomplished by slowing carrier cooling in the absorber and collecting the carriers using energy selective contacts. This ultimately leads to both a higher open circuit voltage since the average energy of the collected electron is greater than the band gap energy. It also leads to a higher short circuit current, leading to an overall greatly improved efficiency. Phonon engineering in the absorber helps to increase the hot carrier lifetime. Photocurrent measurements as a function of applied bias were carried out on fabricated CIGS solar cell structures to characterize the hot carrier effect. The incident photon energy defines the initial hot carrier energy. The bias dependent electric field in the space charge region affects high-energy carriers differently than low energy carriers. For a given field strength, low energy, thermally generated carriers will be directed to their traditional collecting contacts, but the hot carriers with randomly directed initial velocities may overcome the field effect and scatter into opposing contacts reducing the photocurrent in this way. Hence via a simple device physical model, a relationship between initial hot carrier energy, electric field in the space charge absorber region, and photocurrent has been established from which the relative density of hot electrons potentially can be determined from measured current voltage data. The current-voltage characteristics of a 20% efficiency CIGS solar cell under 455nm blue light and 633nm red light illumination were measured, respectively. Currently modeling efforts are underway to separate hot carrier effects from other device phenomena.

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The focus of this period is studying the hot carrier effect in the photocurrent-voltage characteristic of CIGS based solar cells. A simple model of the relationship of the hot carrier initial energy, electric field in the space charge region and the photo-current was developed. Simulation based on the model is presented for comparison with experimental data.

As shown in the figure 2, high energy photon excited electrons generated within the region of W-x1 to W have a 50% chance of going to the p region reducing the overall current; while those generated within the region of 0 to x1 will bounce from the conduction band Ec and subsequently be collected in the n region contributing to the photon current which can be written as

$$J_{opt} = q \times g_{op} \times x_1 + \frac{1}{2} \times q \times g_{op} \times (W - x_1)$$

$$= \frac{1}{2} \times q \times g_{op} \times (W - x_1)$$

where the photon generation rate g_{op} is assumed constant in the depletion region.

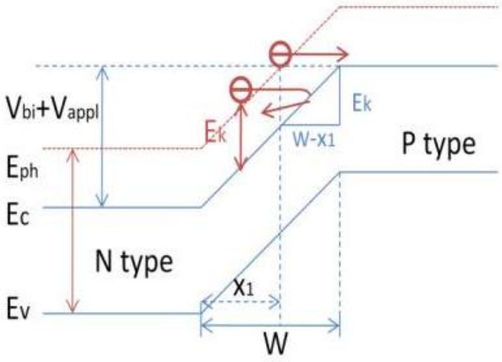

Figure 2: Band Diagram ff Hot Carrier Effect

The simulated reverse bias JV characteristic of a n-type ZnO and a p-type CIGS cell with 2.7eV incident photons based on this model is shown in figure 3. In low bias, hot carriers can overcome the barrier scattering to both contacts. Only half of them are collected on electron contact. Therefore the current density considering the hot carrier effect is half of the one without a hot carrier effect. As bias increases, more of the hot carriers bounce back from the E_C potential energy barrier and are collected via the n-side contact. Therefore the current density increases rapidly, as shown in figure 3 for reverse bias voltages larger than 0.5 V.

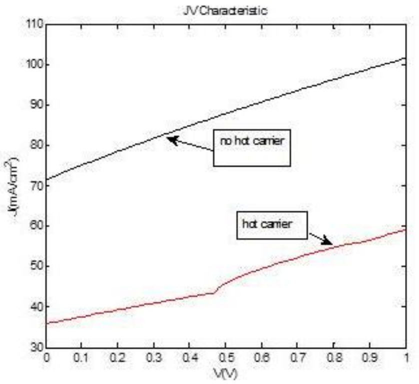

Figure 3: JV Characteristic of Hot Carrier Effect

A 19% efficient "champion" CIGS solar cell was illuminated with 455nm blue light and 633nm red light, respectively. In a parallel theoretical study, a n-ZnO/p-CIGS diode is simulated under the same condition. Figure 4 shows the photon current density versus voltage relationship of the experimental and simulation results. The photon energy of 455nm blue light is 2.7 eV, which is about 1.4 eV higher than the CIGS optical band gap and is able to generate high energy, hot electron-hole pairs. The photon energy of 633nm red light is only 1.9eV. The generated electron-hole pairs are closed to the conduction band edge and are more likely to relax as cold carriers. As shown, the experiment with blue light illumination reveals a rapidly increasing current density at high bias while the experiment with red light illumination does not show this effect. The trend of the experimental data matches with the simulated prediction. However, the optical current extraction needs to be better understood with respect to the reverse bias dark current since they are comparable parts in the total current. A study of the reverse bias dark JV characteristic will be carried out based on a space charge limited charge transport model. This will help improve the accuracy of the quantitative assessment in the future.

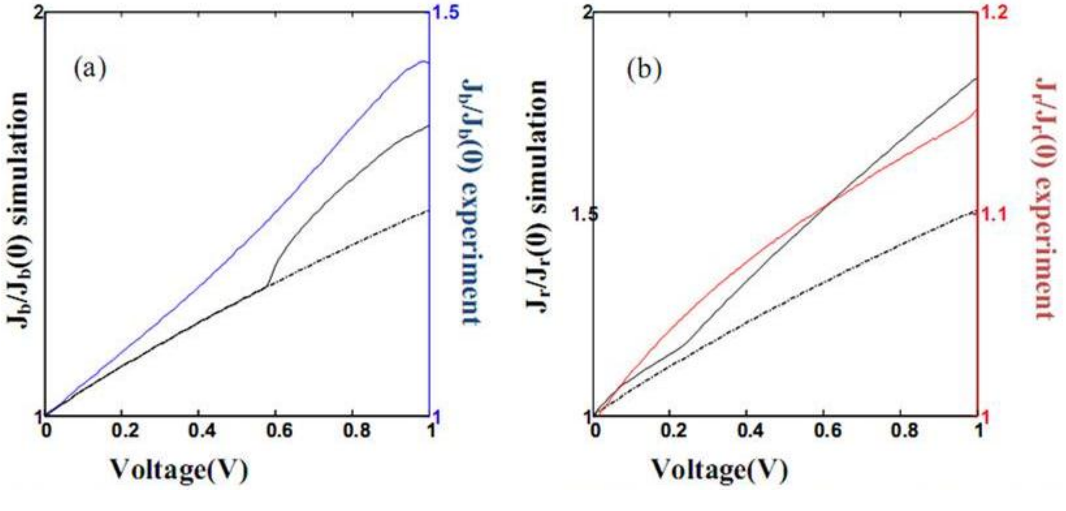

Figure 4: Reversed bias JV characteristics under (a) blue light illumination and (b) red light illumination. The current density on the y-axis is normalized to the current density value at V = 0. The blue line on (a) and the red line on (b) are the experimental data. They refer to the blue axis and the red axis respectively. The black solid line and black dash line are simulation results assuming photon generated carriers staying hot 100% and 0% respectively. Both refer to the black axis on the left.