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Improved Performance in CuInSe2 and Surface-Modified CuGaSe2 Solar Cells

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Improved Performance in $CuInSe_2$ and Surface -Modified $CuGaSe_2$ Solar Cells

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ABSTRACT

In this paper, we present an update and review on the progress made in the development of low-bandgap $CuInSe_2$ (CIS) and wide-bandgap $CuGaSe_2$ (CGS) solar cells. Our research project is primarily concerned with the optimization of the bottom and top cells of the tandem solar cell. This past year, we achieved new world record total-area efficiencies of 15.0% and 10.2% for CIS and surface-modified CGS solar cells, respectively. These achievements were possible by modifying the growth process for CIS and CGS absorbers. We attempt to modify the surface region of the CGS absorber to be CIGS-like in composition. In the mean time, we are designing a mechanical-stacked tandem solar cell where the CIS cell serves as the bottom cell.

1. Objectives

The main objective of our project is to optimize photovoltaic performance of CIS and CGS solar cells and then apply the knowledge gained in improving the cells to the tandem solar cell.

2. Technical Approach

Our technical approach is based on:

Growth: We investigated the dependence of the device performance of CIS and CGS solar cells on the growth conditions of the respective absorber layers. We deposited CIS and CGS absorbers on Mo-coated soda-lime glass substrates using the three-stage process. We deposited the new CIS absorber (S2279) at temperatures higher than those used during the growth of the previous one (S2044) [1]. We deposited the new CGS film (S2194) under more Cu-rich conditions and with the addition of very small amount of In at the end of the growth. Therefore, S2194 will be referred to as surface-modified CGS. Then we made solar cells by depositing CdS, ZnO, Ni/Al front contacts and MgF_2 anti-reflecting coating layers. In this paper, we present a comparison in device performance between the previous and new record CIS and CGS cells.

Characterization: We analyzed our devices using a number of device characterization techniques. We used deep level transient spectroscopy (DLTS) and admittance spectroscopy (AS) techniques to study the defects in our solar cells. We also used a number of materials characterization techniques to examine our absorbers. Due to lack of space here, we will not include all data.

3. Results and Accomplishments

We achieved a new record efficiency of 10.2% for surface-modified CGS solar cells. The NREL-confirmed device operating parameters for this cell are given in Table 1. For comparison, the device parameters for the previous record CGS cell (S2087) [2] are also given. Figure 1 shows the I-V data for the new record cell. CGS is a candidate top cell absorber material for thin film tandem devices. Its bandgap is ideal at 1.67 eV. This particular device had a bandgap of 1.64 eV. Improving CGS device efficiency has proven to be a challenge over the past several years. The recent understanding of the differences in structural and electronic properties between CIGS and CGS thin films and devices has led to varying the growth process in a way that is likely to make the CGS surface region similar to that of CI(G)S and to minimize defects in the material. This change led to a gain in the current density of about 3.7 mA/cm^2 versus the previous record cell.

Recently, we also achieved a new record total-area efficiency of 15.0% for CIS solar cells. The NREL-confirmed device parameters for this cell (S2279) are given in Table 1. Figure 2 shows the I-V for this cell. For comparison, the device parameters for the previous CIS cell (S2044) [1] are also given.

Figure 3 shows the absolute external quantum efficiency (QE) curves for the previous (S2087) and new (S2194) CGS record cells. It also shows the absolute external QE for the new record CIS cell. The better QE gain and the higher currents for sample S2194 resulted from a modified deposition scheme and a modified-surface of the CGS absorber. This figure reveals higher overall collection for the 10.2% cell compared to the 9.53% one. About 30% of the increase in current comes from a slight decrease in the energy bandgap, whereas the remaining current (~70%) comes from better overall collection. In sample S2194, the Voc and the fill factor decreased compared to sample S2087, which indicate that the recombination mechanisms are different in the two devices.

Table 1. Device parameters for previous (S2044 and S2087) and new (S2279 and S2194) CIS and CGS record cells, respectively.

Sample Number	V_{oc} (V)	J_{sc} (mA/cm^2)	Fill factor (%)	Total-area efficiency (%)
S2194-B23	0.823	18.61	66.77	10.2
S2087-B33 [2]	0.905	14.88	70.79	9.53
S2279-B31	0.491	40.58	75.15	15.0
S2044-A35 [1]	0.491	41.1	71.9	14.5

For the new record CIS cell (S2279), the absolute external QE is almost similar to that of the previous one (S2044) [1]. The major improvement in device performance comes from the fill factor. The increase in fill factor is 4.4% (70.79% for S2044 compared to 75.15% for S2279). The series and shunt resistance for sample S2044-A35 are ~ 1.2 and ~ 1893 Ω-cm, and those for sample S2279-B31 are ~1.1 and ~ 3000 Ω-cm, respectively. This higher shunt resistance for sample S2279-B31 may be responsible for the higher fill factor. The V_{oc} and J_{sc} for samples S2044-A35 and S2279-B31, respectively, are almost the same.

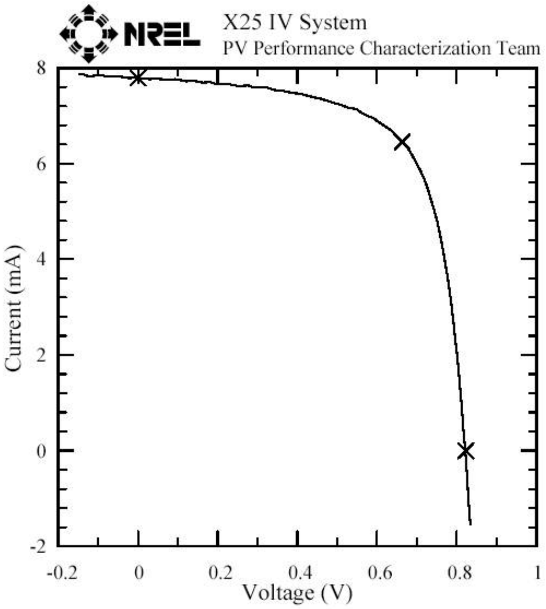

Figure 1. Total-area current-voltage characteristics of the 10.2% surface-modified $CuGaSe_2$ solar cell. Cell measured under standard reporting conditions (1000W/m^2, AM1.5 Global spectrum at 25 ºC. Total area of the cell is 0.419 cm^2.

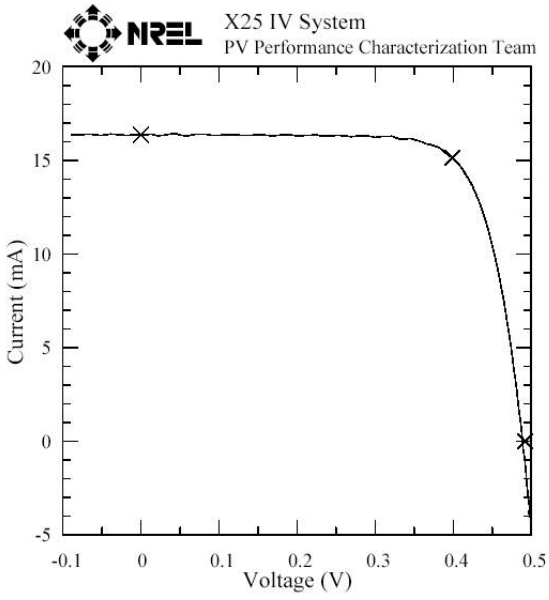

Figure 2. Total-area current-voltage characteristics of the 15.0% $ZnO/CdS/CuInSe_2$ solar cell. Cell measured under standard reporting conditions (1000W/m^2, AM1.5 Global spectrum at 25 ºC. Total area of the cell is 0.403 cm^2.

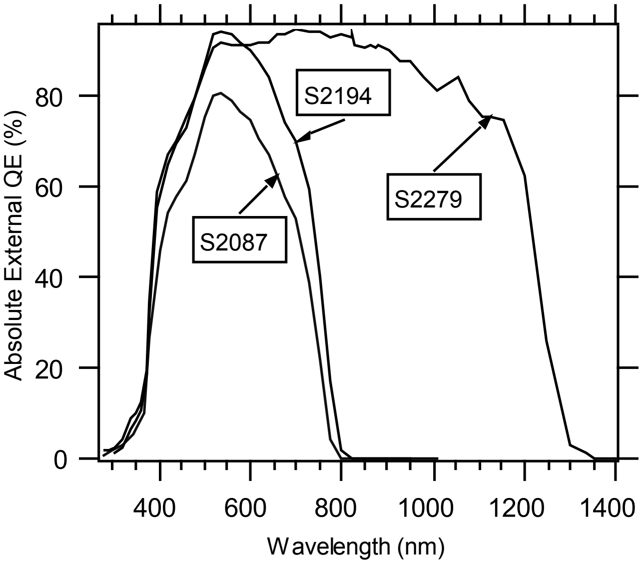

Figure 3. Absolute external quantum efficiency (QE) for record surface-modified CGS cell, S2194-B2#3. For comparison, absolute external QEs for record CIS cell [1] and previous record [2] CGS cell are also included.

4. Conclusions

We modified the growth process for CIS and CGS thin films. This modification resulted in new world record total-area efficiencies for these cells. The improved device performance in the new record CGS cell resulted, in part, from varying the growth process in a way that is likely to make the CGS surface region similar to that of CI(G)S and to minimize defects in the material.

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14. ABSTRACT *(Maximum 200 Words)*

In this paper, we present an update and review on the progress made in the development of low-bandgap $CuInSe_2$ (CIS) and wide-bandgap $CuGaSe_2$ (CGS) solar cells. Our research project is primarily concerned with the optimization of the bottom and top cells of the tandem solar cell. This past year, we achieved new world record total-area efficiencies of 15.0% and 10.2% for CIS and surface-modified CGS solar cells, respectively. These achievements were possible by modifying the growth process for CIS and CGS absorbers. We attempt to modify the surface region of the CGS absorber to be CIGS-like in composition. In the mean time, we are designing a mechanical-stacked tandem solar cell where the CIS cell serves as the bottom cell

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