Electroluminescent and Photoluminescent studies of stressed and unstressed CdTe/CdS cells

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ABSTRACT

Emission studies of unstressed and stressed cells were conducted to examine changes in the junction region. Electroluminescence (EL) was observed for unstressed cells at various forward biases under conditions of high minority carrier injection. Detailed structure near the CdTe band gap energy at low temperatures show similarity to photoluminescence (PL) from the same devices. EL at nominally room temperature also showed a broad feature near the CdTe band gap. EL images reveal inhomogeneities as well as emission from the entire cell. High injection levels corresponding to many Suns caused irreversible decreases in EL and a 50% decrease in efficiency. Similarly cells degraded by stressing with forward and reverse bias stress conditions at 373K show a loss in EL. This suggests EL changes can be explored as a nondestructive signature of cell degradation

1. Introduction

Luminescence provides insight into the electrical and material properties of II-VI materials. Photoluminescence (PL) studies [1,2] have been used to explore alloying effects, diffusion and cell degradation for CdTe-based solar cells. Not as common are electroluminescence (EL) studies, which relies on injected minority carriers under forward bias as the excitation source. Although EL of II-VI compounds are reported for phosphors, few studies have been performed on devices made of polycrystalline thin film CdTe [3].

EL has advantages relative to PL for photovoltaic studies. EL tests are performed under forward bias, similar to the actual operating conditions of the cell. The EL radiative emission also arises from the interface region where carriers are injected, whereas PL can be produced from throughout the device (and even in a 'dead' device). Finally the excitation source is simple and lends itself to simple diagnostic tools, including imaging and in situ monitoring.

2. Experimental details

The cells studied were fabricated with CdS and CdTe deposited using vapor transport by First Solar, LLC on SnO_2:F-coated 3 mm thick glass substrates. The back contact was an annealed Cu/ZnTe layer with a final gold contact pad. Contact was made for both standard I-V characterization and EL measurements through the gold pad and an indium strip contacting the SnO_2:F after etching away CdTe/CdS layers from part of the substrate.

PL and EL spectral measurements were made with a Spex 1301 spectrometer and a cooled GaAs photocathode photomultiplier tube. The sample temperature was varied during measurements with a closed-cycle He cryostat. Samples were mounted with the cells directly contacting the copper cold finger covered with a thin teflon electrically insulating layer. Electrical bias was applied via a spring-loaded contact lightly touching one gold pad and a clip attached to the indium strip. Excitation for PL was provided by either a He-Ne laser (632.8 nm) or 457.9 nm Ar laser emission.

EL images were made at room temperature with a commercial CCD grayscale computer camera. The CCD (TC255P) had 10 µm square pixels in a 324×243 array. The device was imaged directly onto the CCD with a 5× microscope objective. Images could be obtained with integration times up to 300 seconds. Since dark frame subtraction, thresholds and gain were software-controlled, the images provide qualitative data only.

3. Results and discussion

Figure 1 compares PL and EL spectra at nominally the same temperature (~15 K).

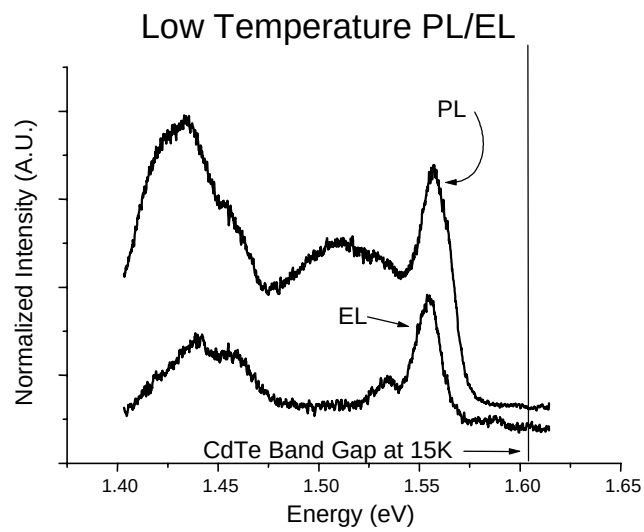

Fig. 1 EL and PL from CdTe/CdS cell at ~15K. PL excitation He-Ne at 3 mW/cm^2; EL excitation J = 86 mA/cm^2 at 4.6 V.

Both the EL and PL spectra show a dominant feature near 1.555 eV that has been attributed to a transition in the CdS_xTe_{1-x} alloy region near the interface [1,2]. There is a ~5 meV shift between the PL and EL data, but this may be due to local heating (~30 K) since the power dissipated by the device during EL is significantly greater than during PL. Both also show a broad feature with structure at ~1.45 eV. The most striking difference between the two spectra is the presence of a broad feature at ~1.52 eV in the PL spectra,

but not EL. This has been observed in CdTe solar cells previously and attributed to a donor-acceptor pair, possibly involving V_{Cd} [2].

PL spectra (not shown) obtained with a higher energy excitation (Ar 457.9 nm line) showed strong CdS emission. However EL spectra measured over the same region showed no emission at low temperature. This observation suggests that EL originated only in the CdTe, close to the interface. This should occur since the CdS layer is believed to be heavily doped, resulting in little hole injection, while CdTe is lightly doped, permitting greater electron injection [4].

Room temperature EL spectra (Figure 2) showed an asymmetric feature near the CdTe band gap (E_g ~1.52 eV). The high energy tail is typical of a Boltzmann broadening of emission to higher energies in band to band recombination although other forms of inhomogeneous broadening are likley present.

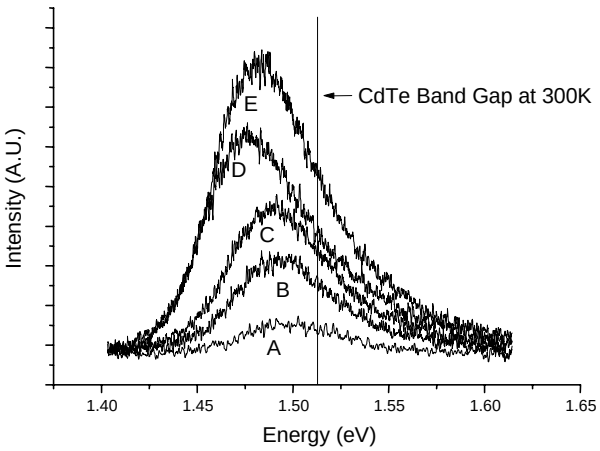

Fig. 2 EL at nominally room temperature at different excitation current densities. **A**: J= 229 mA/cm^2, **B**: J= 443 mA/cm^2, **C**: J= 590 mA/cm^2, **D**: J= 1608 mA/cm^2, **E**: J= 1177 mA/cm^2.

For EL spectra it was necessary to use a relatively high excitation level. Cell voltage drops were 2 - 3.6 V, and the current densities are many times greater than typical values for the short circuit current, J_{SC}, resulting in the equivalent average "illumination" ranging from 9 to 64 Suns.

The integrated EL intensity increased approximately linearly up to 1177 mA/cm^2 (45 Suns). The peak position also showed a shift of ~10 meV. The shift is likely dominated by heating effects. Although the sample block measured only a 7 K change, a simple calculation based on changes in the CdTe band gap suggest that the sample heated ~30 K. Further increasing the current resulted in a dramatic reduction in EL emission and a peak shift, indicative of another ~30 K increase.

The integrated signal can also be spatially observed with an IR sensitive detector. Figure 3 shows EL emission from a single Au contact observed from the glass side. The EL was in registry with the Au pad, which was visible in reflection though the CdTe and glass using sub-bandgap illumination. Several bright spots ~10-40 µm in diameter (this magnification limits our resolution to ~5 µm due to pixel size) are visible. These non-homogeneities, as well as the diffuse background emission increase with current. On some cells the emission is sufficiently strong that high contrast, high gain images can be acquired in real time.

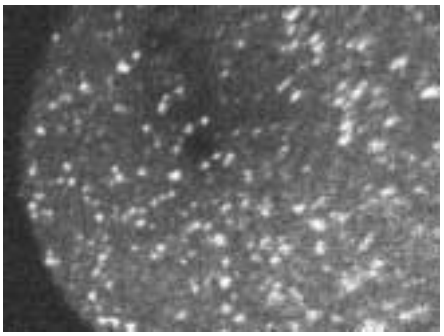

Fig. 3 EL image of CdTe/CdS cell at room temperature obtained by 480 s CCD integration. The excitation current density was 40 mA/cm^2 and the gold pad radius is 0.96 mm.

Excitation current densities exceeding 1 A/cm^2 showed a loss of EL in the images (not shown), starting from the point of contact of the spring clip (highest power) and spreading outward. Cells degraded by this excess current show irreversible changes in both image and current - voltage characteristics. I-V curves show a loss of efficiency due mostly to fill factor and rollover. Such changes are often attributed to back contact changes, but may also be due to changes at the main diode.

Cells were also degraded at 373 K under reverse and forward bias. EL measurements after long periods show no emission. The loss of this highly inhomogeneous EL was correlated with to low efficiency in all of our measured cells.

4. Conclusions

These preliminary results show the potential of EL for basic studies as well as a monitoring tool for degradation and cell efficiency. Low temperature measurements show comparable features to PL and are likely due to CdTe in the electrically-active junction region only. The room temperature EL shows high sensitivity in imaging and showed significant changes with degraded samples.

5. Acknowledgements

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REFERENCES

[1] M. H. Aslan, Ph.D. thesis Physics, Colorado School of Mines, Golden, CO 1999.

[2] D.Grecu, A.D. Compaan, D. Young, U. Jayamaha, D.H. Rose, J. Appl. Phys. **88**, 2490 (2000).

[3] M.D.G. Potter, M. Cousins, K. Durose, and D.P. Halliday, J. Materials Sci:Mats. Electronics **11**, 525 (2000).

[4] P.R. Thornton, Physics of Electroluminescent Devices, E.&F.N. Spon Ltd, 1967.