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ELECTRONIC CHARACTERIZATION OF THIN FILM

CdS/CdTe PHOTOVOLTAIC CELLS

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ELECTRONIC CHARACTERIZATION OF THIN FILM
CdS/CdTe PHOTOVOLTAIC CELLS

by

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THESIS

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ABSTRACT

The current voltage characteristics along with capacitance, spectral response and EBIC measurements were performed in an attempt to understand the properties of CdS/CdTe photovoltaics provided by Photon Energy Inc., of El Paso, Texas. The results of these studies indicate a device that is heavily dependent on the illumination intensity. Capacitance and EBIC measurements indicated a CdTe compensated region that exists between a CdS and a higher concentration CdTe layer. Concentrations in the three different regions were approxmately 1 X 10^{18} cm^{-3}, 1 X 10^{14} cm^{-3} and 5 X $10^{15}$$cm^{-3}$ respectively. The IV measurements supported a multistep tunneling current over a range of temperatures and intensities. Typical α and I_o's for dark and AM1 conditions were $15.0v^{-1}$ and $.1x10^{-6}$amps, and 8.54 and $50x10^{-6}$ amps respectively. Non-translation in the cells investigated are explained by a illuimination dependent loss current model which primarily supports decreasing barrier heights with increasing intensity and thus higher dark current components. The band structure was proposed to be different from a modeling stand point when in dark and illuminated conditions. The dark band structure showing the effects of a compensated p-CdTe region while the light band structure shown essentially as a true heterojunction.

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power without any of the air polluting effects of fossil fuels. However, because of the large costs involved in producing these cells, the idea of using solar cells for producing power eventually died off.

Not until man's movement into space exploration in the late 50's and early 60's did scientists realize the benefits of solar cells. Solar cells could produce power for orbiting satellites continuously with out any air pollutants and without any need for constant maintenance. Even today, space use remains the primary use of solar cells.

1.3 Current trends with solar cells

With this accelerated interest in solar cells came more and more research into the underlying mechanisms involved in solar cells. Additionally, finding other materials, besides silicon, that could produce photovoltaic power with relatively high efficiencies and lower cell cost became important. In the late 60's scientists turned to thin film materials because of the reduced cost in producing these type cells. In the early 70's came increasing fossil fuel costs, along with many government sponsored programs set up to investigate alternate energy sources.

Since then, solar cell research has produced an abundance of knowledge that has led to a reduction in cell cost from around $100.00 per peak watt of cell output to the

present cost of $4-5.00 per peak watt. Most of this research has primarily been centered around silicon based cells. Even today, the cost of pure grade silicon cells for use in residential power systems remains much higher than conventional fossil fuels. Therefore, the need for inexpensive photovoltaic cells are necessary in order for them to be attractive for consumer use.

The need to produce a low cost solar cell to compete in large scale power production has forced the industry to compromise high efficiency devices for those costing much less. Cells with efficiencies of 10-16% at reduced cost will be competitive with present large scale power plants.

Today most of the current research is centered around reducing these costs even further. The primary reason for the high cost in silicon cells is directly attributed to the complexity of making pure grade silicon crystals. With thin film devices, cells can be made much more cheaply because the complexity involved in making silicon cells isn't present in making thin film cells, thus the need for understanding thin film photo voltaic properties. However, compared to silicon based cells, thin film cells have several problems that must be overcome if they are to be effective as an alternate energy source. These problems include; low efficiency in producing electricity from sun light and small useful lifetimes due to instabilities

associated with various atmospheric constituents. The key to achieving better efficiencies and stability is in understanding the basic physical processes involved in thin film cells. The experimental techniques discussed in this report give some indications of the underlying mechanisms and are therefore useful in developing a reasonable understanding of the photo voltaic cell, and in developing a working model.

Thin film cells such as CdS/CdTe can be produced more economical than single crystal cells because relatively little material (e.g. a few micron thickness) is used. Furthermore the polycrystaline nature of thin film eliminates expensive crystal growth techniques and allows for cheaper production options such as: closed space sublimation, hotwall vacuum evaporization, sputtering and deposition. Even though steady progress has been made in improving cell efficiencies, they still remain well below their single crystal counterparts. Not only are efficiencies compromised but modeling of thin film devices through experimental techniques becomes more difficult.

1.4 The Photon Energy CdS/CdTe cell

The cells to be investigated, were furnished by Photon Energy Inc.(PEI) of El Paso, Texas. These cells are typical cells developed at PEI with a unique processing method(1).

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The cells were from lots 3525 and 3782, and both are of the backwall configuration type with a typical device structure shown in *figure* 1-1. Contact to the CdS was made with indium tin oxide (ITO) and contact to CdTe was made via a graphite paste with exact composition unavailable. Cell areas are .302 cm^2 with 4 cells per test device as shown in *figure* 1-2.

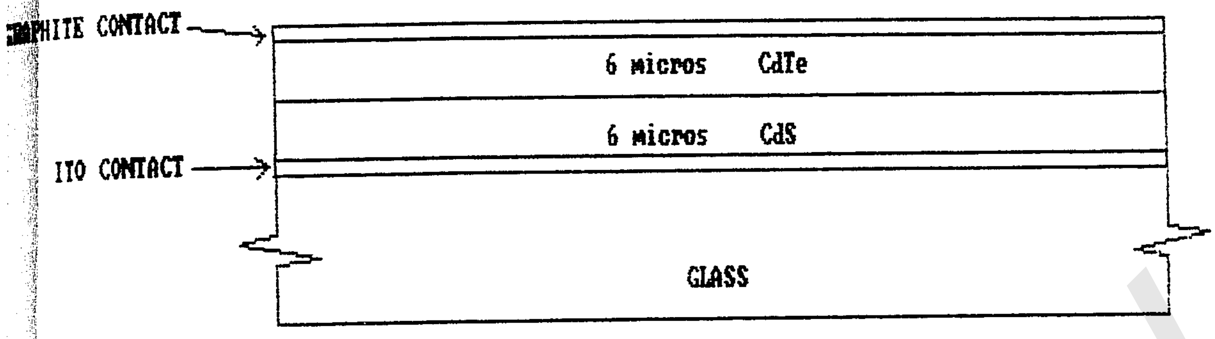

Figure 1-1 Typical structure of a Photon Energy cell

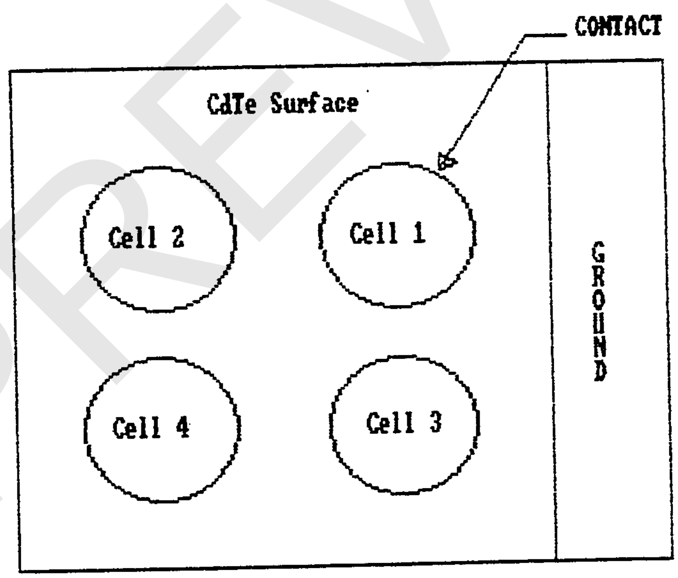

Figure 1-2 Typical test device

Chapter 2

BASIC SOLAR CELL THEORY

In order to understand the experimental techniques used in modeling photovoltaic devices, it is first necessary to understand basic photovoltaic theory. The basic single crystal p-n homojunction cell will serve as a general introduction since its' properties are more easily explained and many of its' properties will carry over to the more complicated heterojunction often associated with thin film polycrystalline devices.

2.1 P-N Homojunction theory

As with all solar cells there is an energy band diagram showing electron and hole energies in the conduction and valence bands respectively for each material used in the cell. The energy difference between the conduction and valence bands is often termed the energy gap or band gap energy. In all semiconductor devices, as in solar cells, two materials with varying differences in properties are joined together to form a junction at their interface together. These materials may be the same yet with different distinctive property differences. In the case of a homojunction, the two materials are the same, but with slight differences in electrical properties. One of the

materials is made more electrically positive (p type) while the other is made more electrically negative (n type) . This is accomplished through a doping technique that determines, among other properties, the band diagram profile. This polarity difference between the two materials sets up a depletion region, as shown in *figure*2-1, that is essentially depleted of any charge. However, at the depletion region edges there is a build up of charge due to the excess electrons in the n-type material and excess holes in the p-type material that were present in each material before joining. These separated charges produce an electric field that plays an important role in current conduction. Without any external excitation such as; temperature, voltage, or light, these charge areas will come into equilibrium and no current conduction takes place.

If light of energy ($\mathcal{E} = h\nu$) is greater than the band gap energy is incident on the cell, then individual photons will impart energy to loosely bonded electron-hole pairs causing the electrons to move up to the conduction band and the holes to move down to the valence band. Once these charges are in the conduction and valence bands, they are swept across the junction provided they are within a minority diffussion length of the depletion region edge. Electron-hole pairs generated outside a diffusion length of the depletion edge can still be swept across the junction but the probability that these carriers make it across

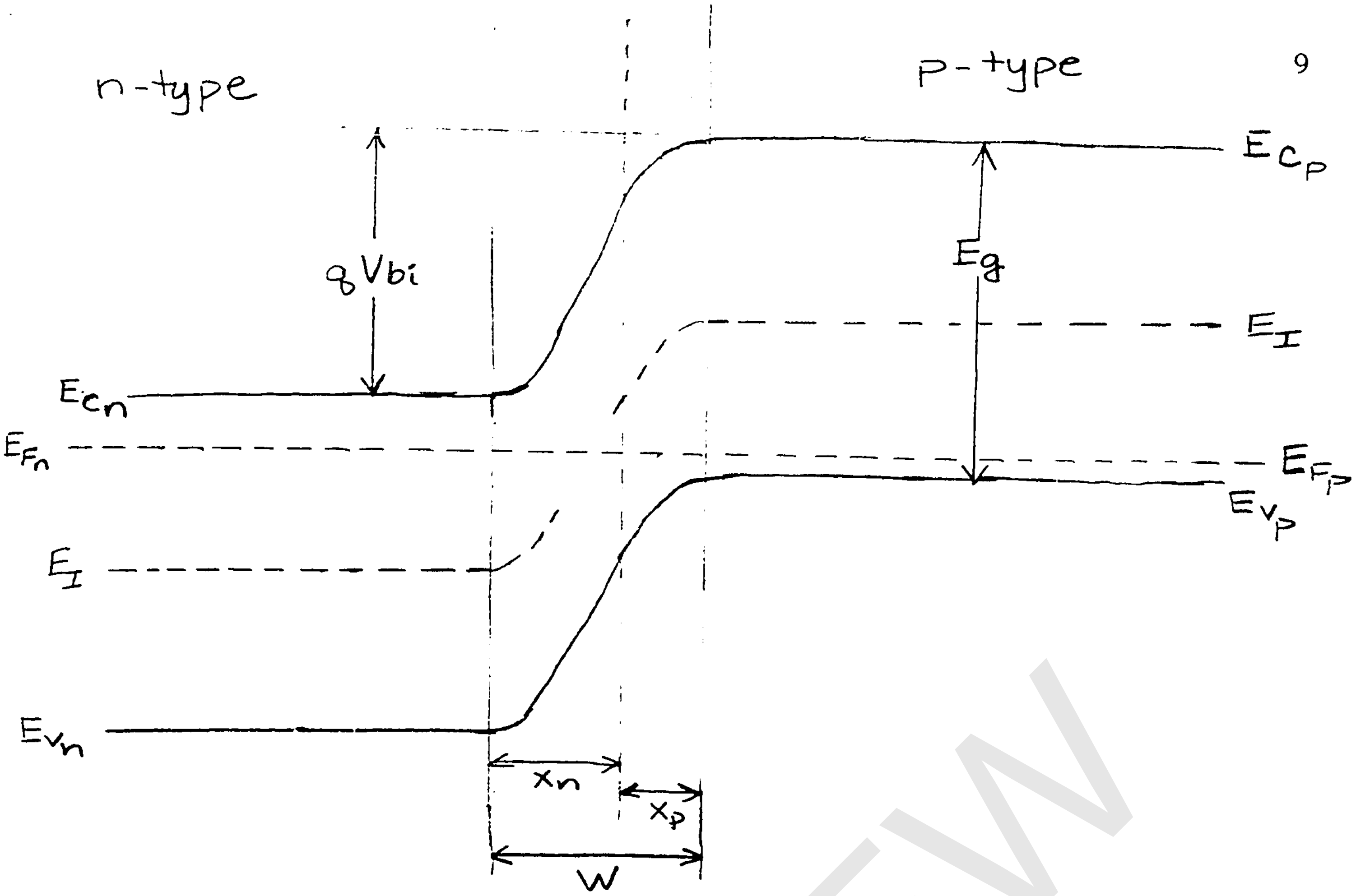

Figure 2-1a P-N JUNCTION IN EQUILIBRIUM

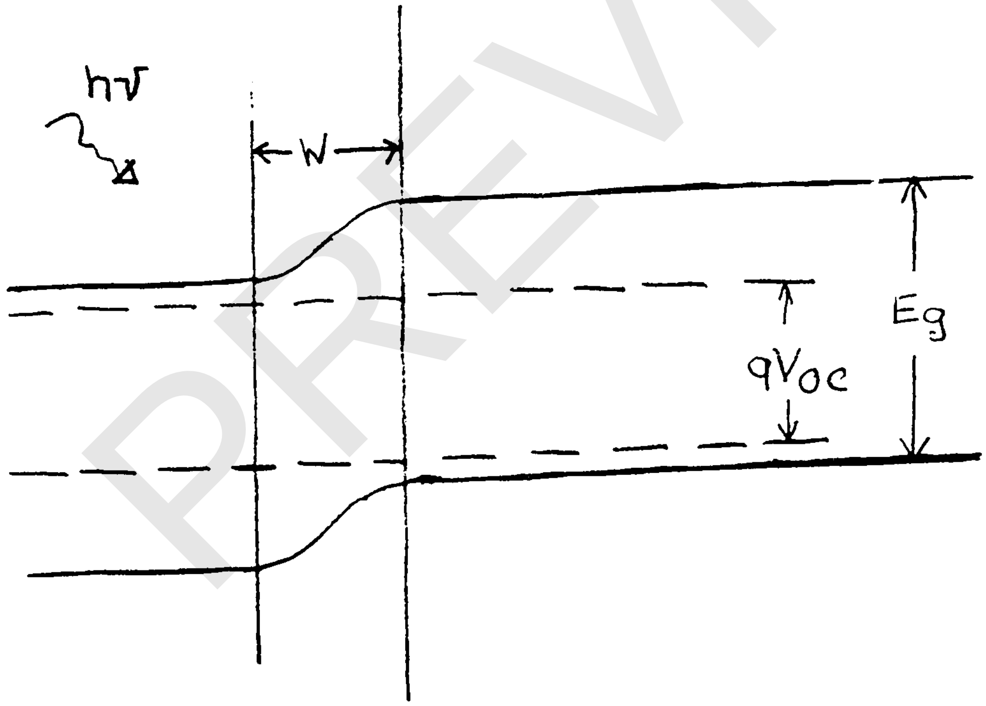

Figure 2-1b P-N JUNCTION WITH INCIDENT ILLUMINATION