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PREVIEW

ELECTRONIC CHARACTERIZATION OF THIN FILM
CdS/CdTe PHOTOVOLTAIC CELLS

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ELECTRONIC CHARACTERIZATION OF THIN FILM
CdS/CdTe PHOTOVOLTAIC CELLS

by

LANCE D. LYONS, B.S.

THESIS

Presented to the Faculty of the Graduate School of
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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 approximately $1 \times 10^{18} \text{ cm}^{-3}$, $1 \times 10^{14} \text{ cm}^{-3}$ and $5 \times 10^{15} \text{ cm}^{-3}$ respectively. The IV measurements supported a multistep tunneling current over a range of temperatures and intensities. Typical α and I_0 's for dark and AM1 conditions were 15.0 v^{-1} and $.1 \times 10^{-6} \text{ amps}$, and 8.54 and $50 \times 10^{-6} \text{ amps}$ respectively. Non-translation in the cells investigated are explained by a illumination 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.

TABLE OF CONTENTS

	Page
LIST OF TABLES	vii
LIST OF FIGURES	ix
1. INTRODUCTION	1
1.1 Statement of purpose	1
1.2 A brief history of solar cells	1
1.3 Current trends with solar cells	2
1.4 The Photon Energy solar cell	4
2. BASIC SOLAR CELL THEORY	7
2.1 P-N Homojunction theory	7
2.2 Light current generation	12
2.3 Heterojunction theory	22
2.4 Current mechanisms	29
2.4.1 Injection currents	31
2.4.2 Recombination currents	35
2.4.3 Tunneling currents	37
3. EXPERIMENTAL TECHNIQUES AND PROCEDURES	41
3.1 I-V measurements	42
3.2 Capacitance measurements	47
3.3 Electron beam induced current(EBIC) measurements	49
3.4 Spectral Response measurements	50
4. RESULTS OF EXPERIMENTS	54
4.1 I-V Measurements	54
4.1.1 Room temperature I-V	55

4.1.2	Temperature dependent I-V	62
4.1.3	Intensity dependent I-V	90
4.2	Capacitance measurements	100
4.2.1	Room temperature C-V	103
4.2.2	Temperature dependent C-V	106
4.2.3	Intensity dependent C-V	113
4.2.4	Frequency dependent C-V	119
4.3	EBIC and Spectral response measurements	133
5.	DISCUSSION	142
6.	CONCLUSION	156
	REFERENCES	159
	<u>CURRICULUM VITAE</u>	161

LIST OF TABLES

Table	Page
4-1. Values of cell parameters at room temperature for 3525C	58
4-2. Values of cell parameters at room temperature for 3782A	58
4-3. Values of I_0 and α at room temperature	63
4-4. Cell parameters at different temperatures for 3525C	72
4-5. Cell parameters at different temperatures for 3782B	72
4-6. Values for I_0 and α at different temperatures and intensities	80
4-7. Values for I_0 , α , and A at different temperatures in light and dark	81
4-8. Values for I_{00} at different intensities for 3515C	85
4-9. Values for I_{00} in light and dark for 3782B	85
4-10. Values for $\log I_0$.vs. $1000/T$, slopes, and intercepts for 3525C	87
4-11. Values for $\log I_0$.vs. $1000/T$, slopes, and intercepts for 3782B	87
4-12. Values for α , I_0 , and A at different temperatures for 3525C	91
4-13. Values for α , I_0 , and A at different temperatures for 3782B	91
4-14. Values for α and I_0 at different temperatures and intensities	99
4-15. Values for α , I_0 , and A in the dark at various temperatures	102

4-16.	Values for N_a and V_d at different temperatures	112
4-17.	Values for N_a and V_d at various temperatures in small and large slope areas	118
4-18.	Saturation depletion widths for 3525 at various frequencies	124
4-19.	Saturation depletion widths for 3782 at various frequencies	124
4-20.	Values of Δc for various reverse biases	125
4-21.	Values for N_a and V_d at different frequencies for 3525	130
4-22.	Values for N_a and V_d at different frequencies for 3782	130
4-23.	Values for depletion widths and voltages for different frequencies	135
5-1.	Cause and effect table	152

LIST OF FIGURES

Figure	Page
1-1. Photon Energy cell structure	6
1-2. Typical test device	6
2-1. P-N junction in equilibrium and with incident illumination	9
2-2. P-N junction with contacts and load	11
2-3. Equivalent circuit of a solar cell	13
2-4. P-N junction coordinate system for light current derivation	15
2-5. Heterojunction energy band model	23
2-6. Ideal efficiency .vs. band gap	24
2-7. Heterojunction band diagram	32
2-8. Lattice dislocation	36
3-1. I-V measurement station	43
3-2. EBIC response set up	51
3-3. Spectral response set up	53
4-1. Room temperature I-V curves for 3525C	56
4-2. Room temperature I-V curves for 3782B	57
4-3. Shifted room temperature I-V curves	60
4-4. $\text{Log}(I+I_{sc})$.vs. V at different intensities	61
4-5. I-V curves at different temperatures for 3525C	64
4-6. I-V curves at different temperatures for 3525D	68
4-7. I-V curves at different temperatures for 3782B	71
4-8. Shifted I-V curves at various temperatures for 3525C	74

4-9.	Shifted I-V curves at various temperatures for 3525D	74
4-10.	Shifted I-V curves at various temperatures for 3782B	75
4-11.	$\text{Log}(I+I_{sc})$.vs. V at different temperatures for 3525C	77
4-12.	$\text{Log}(I+I_{sc})$.vs. V at different temperatures for 3525D	77
4-13.	$\text{Log}(I+I_{sc})$.vs. V at different temperatures for 3782B	78
4-14.	$\text{Log } I_o$.vs. $1000/t$ for 3525D	83
4-15.	$\text{Log } I_o$.vs. $1000/t$ for 3782B	83
4-16.	α .vs. $1000/T$ for 3525C	86
4-17.	α .vs. $1000/T$ for 3782B	86
4-18.	Dark $\text{Log } I$.vs. V at different temperatures for 3525C	88
4-19.	Dark $\text{Log } I$.vs. V at different temperatures for 3782B	89
4-20.	Shifted I-V curves at different intensities and temperatures for 3525C	93
4-21.	Shifted I-V curves at different intensities for 3782A	95
4-22.	$\text{Log}(I+I_{sc})$.vs. V at different temperatures and intensities for 3525C	96
4-23.	$\text{Log}(I+I_{sc})$.vs. V at different intensities for 3525C	98
4-24.	$\text{Log } I$.vs. V_{oc} at different temperatures for 3525C	101
4-25.	Light $\left[\frac{1}{C^2}\right]$ -V curves at room temperature for 3525C	104

4-26.	Dark $\left(\frac{1}{C^2}\right)$ -V curves at room temperature for 3525C	105
4-27.	Dark $\left(\frac{1}{C^2}\right)$ -V curves at different temperatures for 3525C	107
4-28.	$\left(\frac{1}{C^2}\right)$ -V .vs. V at different intensities for 3782F	114
4-29.	Depletion width .vs. V at different intensities for 3782F	116
4-30.	C-V curves at different frequencies for 3782	121
4-31.	C .vs. V curves at different frequencies for 3525	123
4-32.	$\left(\frac{1}{C^2}\right)$.vs. V curves at different frequencies for 3782	127
4-33.	$\left(\frac{1}{C^2}\right)$.vs. V curves at different frequencies for 3525	129
4-34.	N_{is} .vs. V for 3525	131
4-35.	N_{is} .vs. V for 3782	132
4.36.	Effective concentrstion .vs. V at different frequencies for 3782	134
4-37.	Typical EBIC measurements	136
4-38.	SEM picture with EBIC response overlay	137
4-39.	Spectral response with no white light bias for 3525C	139
4-40.	Spectral response with white light bias for 3525C	140
5-1.	Proposed band structure of CdS/CdTe cell in the dark.	151

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 without 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 polycrystalline nature of thin film eliminates expensive crystal growth techniques and allows for cheaper production options such as: closed space sublimation, hotwall vacuum evaporation, 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 $.302 \text{ cm}^2$ with 4 cells per test device as shown in figure 1-2.

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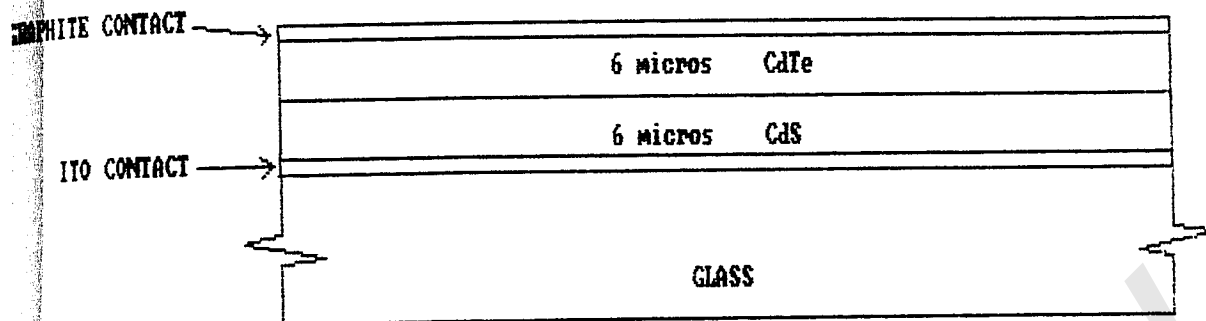


Figure 1-1 Typical structure of a Photon Energy cell

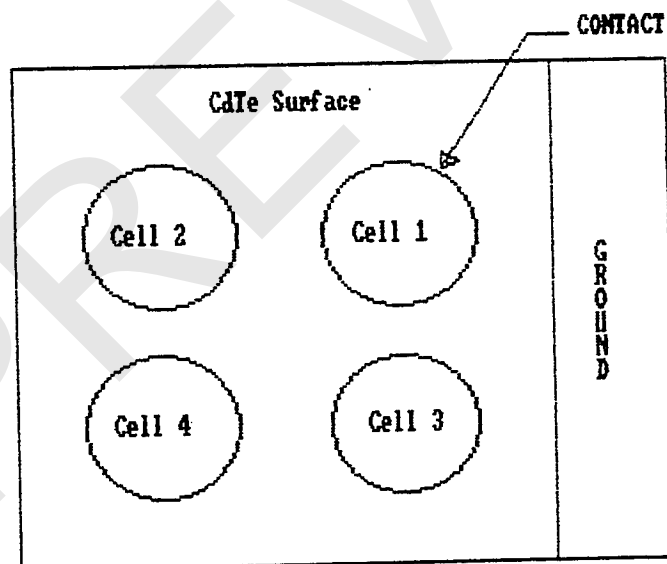


Figure 1-2 Typical test device

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 *figure2-1*, 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 diffusion 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

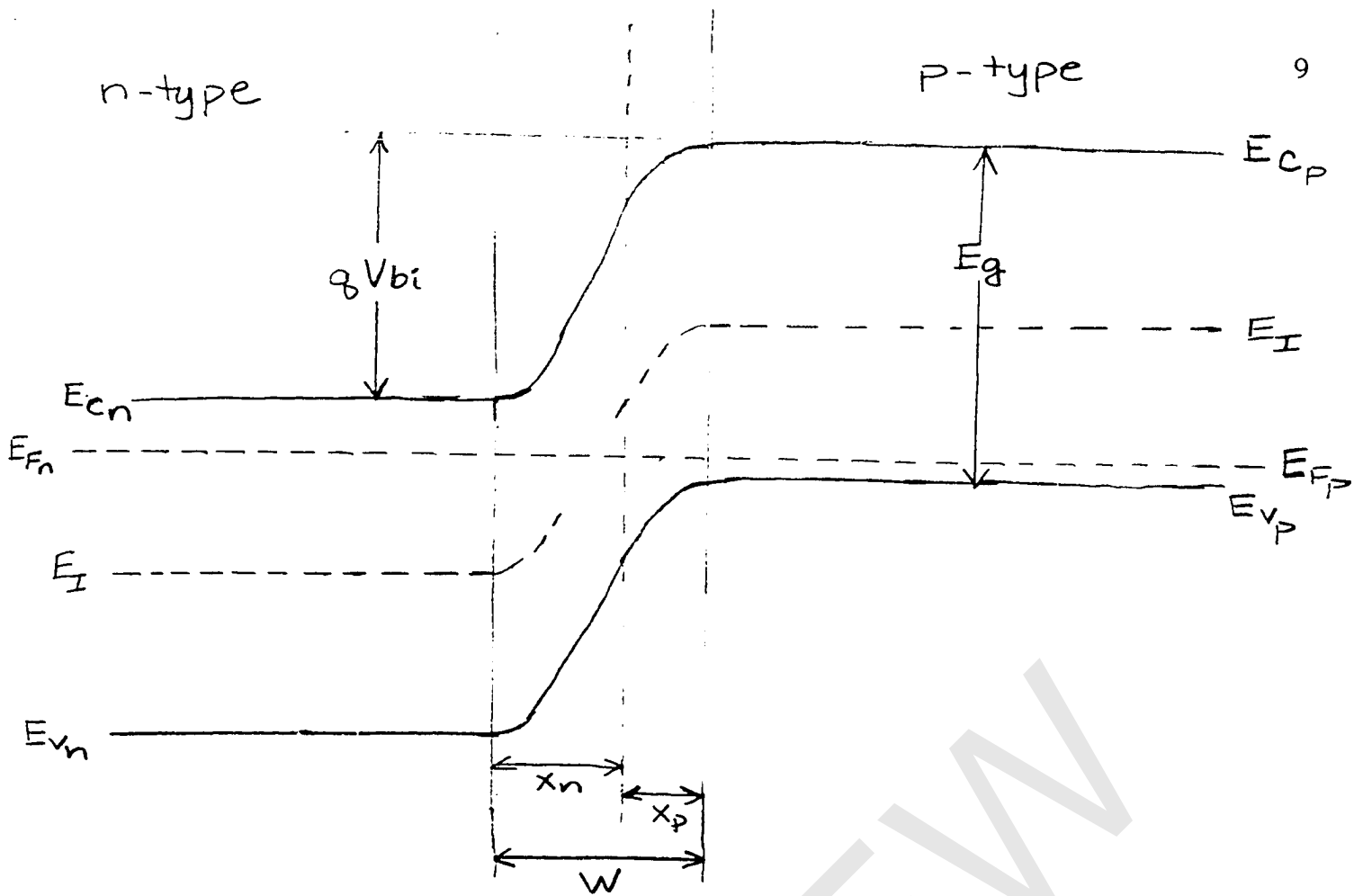


Figure 2-1a P-N JUNCTION IN EQUILIBRIUM

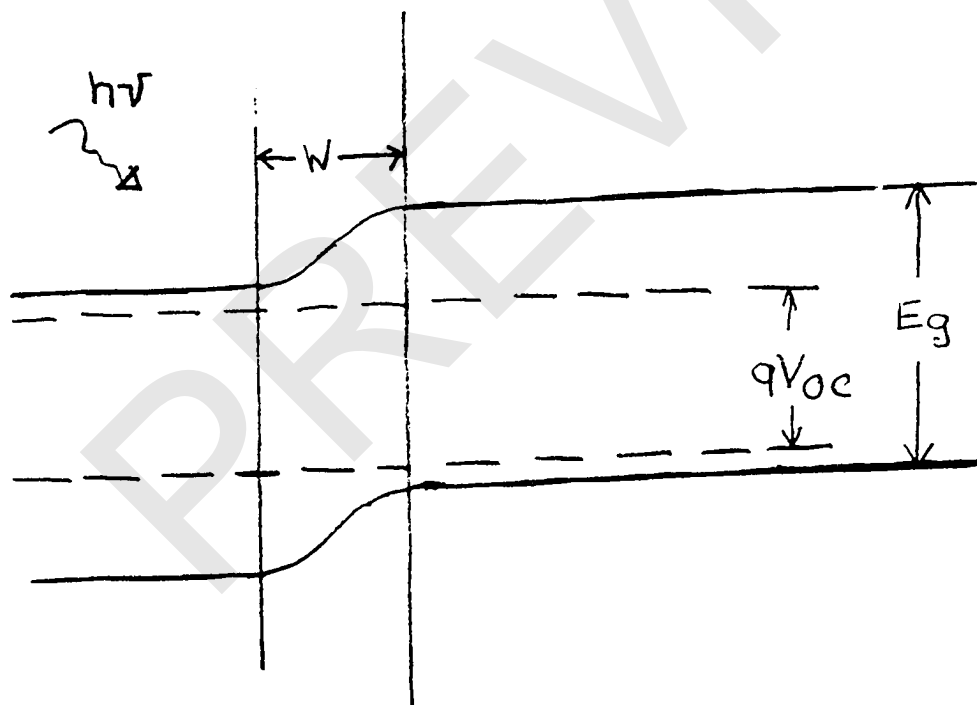


Figure 2-1b P-N JUNCTION WITH INCIDENT ILLUMINATION