DEPOSITION AND CHARACTERIZATION OF CdTe/CdTe (111) GROWTH BY CLOSE – SPACED SUBLIMATION (CSS)

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PREVIEW

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To my beloved

PARENTS, PHANI PRASAD AMMU *and* ***SUSEELA AMMU***

and ***AMMU family***.

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by

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ABSTRACT

Polycrystalline CdTe was grown on CdTe (111) using the Close-Spaced Sublimation (CSS) technique. A series of experiments were designed to determine the experimental parameters which would result in a low growth rate of approximately 1µm/hr, and the deposition of a high quality epilayer of CdTe onto single crystal CdTe (111) substrates using a close spaced sublimation reactor (CSS). The study was classified into five stages. The substrate surface cleaning/surface preparation was done using an etchant consisting of HNO_3, H_3PO_4 and DI water (1:70:29) in order to remove the native oxide and surface impurities. A smooth epitaxial layer was obtained at maximum ΔT values of 5°C between the source and substrate, and substrate temperatures of 550°C. A growth rate less than 1µm/hr was achieved. The samples were characterized using optical microscope, scanning electron microscope (SEM) and an Alpha Step Profiler. Granular and planar films were obtained with pyramid/triangular features inherent in the growth process for both types of films.

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Chapter 1

INTRODUCTION

Thin film fabrication technology plays an important role in present day solar cells and opto-electronic devices. These devices are used in many fields of application today, both civilian and defence oriented. Much of the recent studies are centered around environmental applications, such as pollution detection and medical applications like blood analysis. CdTe, CdZnTe (CZT) and HgCdTe (MCT) belong to the group IIB-VIA semiconductor. CdTe has been regarded as a prime candidate for solar cell fabrication [1]. CZT has been the traditional substrate for epitaxial MCT growth [2]. MCT is an important material for the fabrication of optoelectronic detectors and detector arrays for infrared detection and thermo-imaging applications [3].

1.1 Previous Work

Close–spaced sublimation (CSS) is a simple low-cost technique to deposit high quality thin films of CdTe [7]. Studies at the National Renewable Energy Lab (NREL) by Chang et. al. have deposited CdTe over single crystal CdTe (111) substrate and CdS (0001) substrates [10]. The substrate temperature used was 550^{o}C and the source temperature was 640^{o}C. The resulting growth rate was approximately 1 μm/min. The thickness of the deposition was 8 μm. The authors reported epitaxial growth based on X-ray diffraction (XRD) and that the structure of the CdTe films using this technique was relatively independent of the structure of the substrate. In addition, the authors did not mention whether or not the deposition was granular or planar.

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Larramendi et. al. reported atomic layer epitaxy (ALE) growth of ZnTe films using an isothermal close–spaced sublimation system (ICSS) [11]. This reactor includes good control of elemental evaporation source times and temperatures.

1.2 Current Work

In the current study, the deposition of CdTe on CdTe (111) is investigated using a CSS reactor with limited control of deposition temperature and time. The growth rate and surface morphology is reported and the aim of this research is to deposit epitaxial layers using the existing reactor. Due to lack of XRD data the epitaxial growth is not confirmed but it appears to be epitaxial growth. In order to achieve the goal several studies were made to find the proper substrate preparation method and by systematically altering the growth conditions.

A brief overview of this thesis is described in this chapter along with the importance of thin film fabrication technology. Chapter 2 provides the background associated with thin film fabrication methods and applications. Chapter 3 includes the experimental procedures carried out in this study. The procedure includes the critical cleaning step, CdTe source preparation, cleaning the CSS reactor, and the deposition of CdTe. Chapter 4 discusses the results obtained including characterization all samples. Chapter 5 provides the conclusions and future work of this study.

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Chapter 2

BACK GROUND

In the past, electricity was completely produced from non-renewable resources (fossil fuels such as coal, crude oil) which led to emission of harmful gases into the atmosphere. This pollution contributed to ozone depletion and global warming. There is a focus now on renewable resources (sources of energy which cannot be exhausted) like the sun and wind. Energy generated from sun is solar energy. Solar cells are made up of semiconductor p-n junctions and the technology associated with producing electricity is based on the photovoltaic effect.

2.1 Photovoltaic Effect

The photovoltaic effect is a physical process where photovoltaic cells convert sunlight into electrical energy. Sunlight reaches the earth as packets of energy called photons, and these photons have specific energies corresponding to the wavelengths of the solar spectrum. When the packets of energy (photons) with a given energy ($h\nu$) strike the solar cell, they may be reflected, absorbed or transmitted. Semiconductors can absorb light energy with $h\nu > E_g$, whereas low energy photons with $h\nu < E_g$ will pass through the semiconductor. There is a potential barrier that is set up by the opposite electric charges facing one another on either side of the p-n junction. This potential barrier selectively separates the light generated electrons and holes, sending more electrons to one side of the cell and more holes to the other side. This charge separation sets up a voltage difference between either sides of the cell, which can be used to drive an electric current in an electric circuit.

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The demand for solar energy has been increasing during the last 20 years and research on optimum semiconductor materials is taking place in order to develop a material, design and fabrication process that will produce an efficient solar cell that can be mass produced. Cadmium telluride (CdTe) is one of the most promising materials as a thin film photovoltaic semiconductor [1].

The II-VI semiconductor, CdTe, is suitable for solar cells because of its optimum energy gap (Eg =1.5eV) and high absorption co-efficient ($>10^4$ cm^{-1}) for visible solar radiation [4]. CdTe has a band gap which is very close to the theoretically-calculated optimum value for solar cells under un-concentrated AM1.5 sunlight.

2.2 Conversion Efficiency

Converting the maximum amount of available solar energy into electrical energy is a key issue in the design of solar cells.

The Air Mass (AM) value describes the spectrum (but not necessarily the intensity) of sunlight at specified latitude. It is defined as the distance through the atmosphere that the light from the sun travels in order to reach the solar cell. This is expressed relative to conditions at the equator, where the sun is almost directly overhead, and where the light is therefore described as AM1. Thus, in space with no atmosphere, the spectrum is referred to as AM0. AM0 (Air mass zero) curve is the measured radiant energy just outside the earth's atmosphere and is of interest in orbiting satellite applications.

For most terrestrial applications, the generally accepted solar cell testing standard is that of AM1.5 conditions (Average terrestrial U.S). The AM1.5 curve, normalized to yield a total spectral power density of $100mW/cm^2$, is representative of average terrestrial

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conditions in the United States. When using solar concentrators, for example, the intensity might be increased by a factor of 1000, but the shape of the spectrum would remain AM1.5.

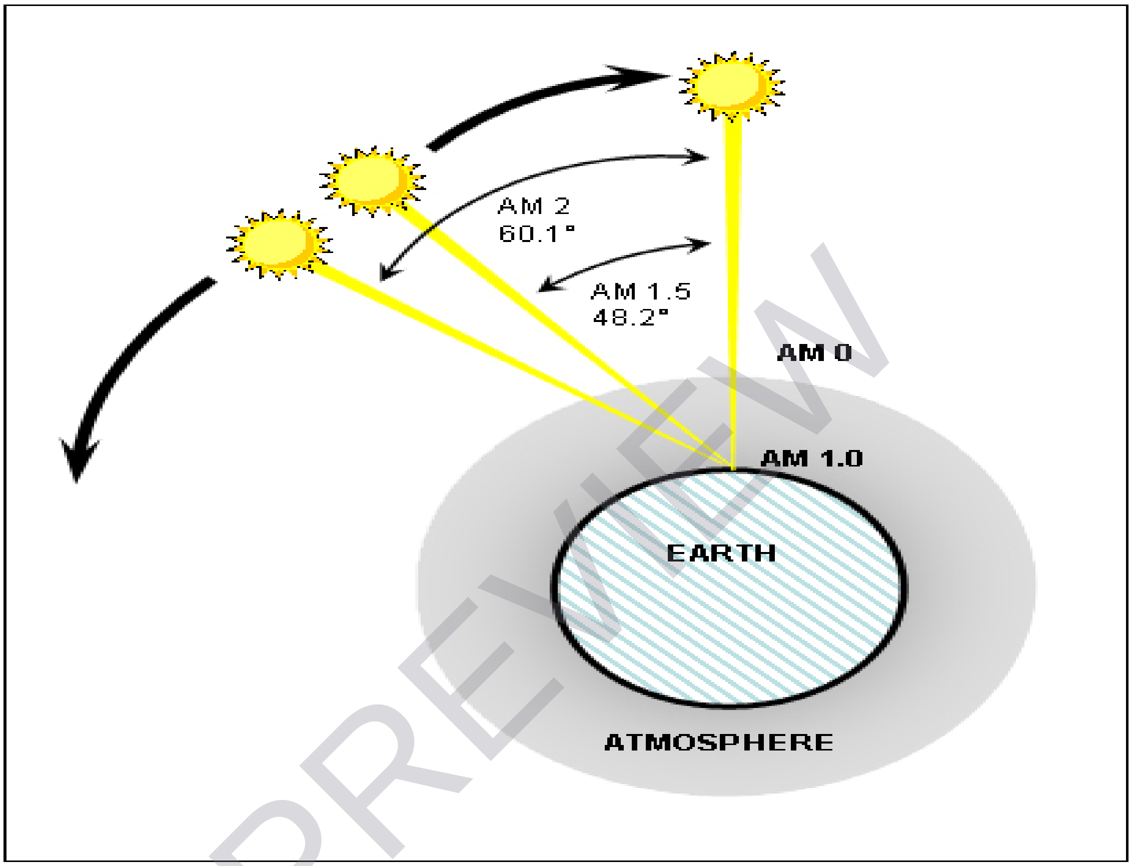

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Figure 2.1. Spectrum of sunlight at different latitudes

CdTe has a band gap which is very close to the theoretically-calculated optimum value for solar cells. CdTe also has a high absorption coefficient, so that approximately 99% of the incident light is absorbed by a thickness of only 1µm (compared with around 10µm required for Si), cutting down the quantity of semiconductor material required.

Most commercially available solar cells are made from wafers of very pure monocrystalline or polycrystalline silicon. Such solar cells can attain efficiencies of up to

18% in commercial manufactured solar cells and over 20% in solar cells fabricated under laboratory conditions. The silicon wafers traditionally used to make solar cells are relatively expensive, making up 20-40% of the final module cost. Although silicon is highly abundant (comprising one quarter of the earth's crust), making a very pure wafer suitable for solar cell manufacture requires much energy and expense. Moreover, a solar cell made using a 300-400 μm thick wafer generates 90% of its energy from the top 15-20 μm layer. The rest of the wafer is required simply to hold the cell together. The alternative to these "bulk silicon" technologies is to deposit a thin layer of semiconductor onto a supporting material such as glass. Various materials can be used such as cadmium telluride,(CdTe) copper-indium-diselenide ($CuInSe_2$) and silicon (Si). Thin film solar cells are made from CdTe or $CuInSe_2$ have yet to be fully commercialized, but offer some promise of achieving reasonably good efficiency at a much lower cost.

2.3 Thin Film Solar Cell Structure

Polycrystalline thin-film cells are made of many tiny crystalline grains of semiconductor materials. The materials used in these polycrystalline thin-film cells have properties that are different from those of silicon. An electric field is created at the interface between the two different semiconductor materials that drives the movement of carriers from one side to the other. This type of interface is called a heterojunction ("hetero" because it is formed from two different materials, in comparison to the "homojunction" formed by two doped layers of the same material, such as the one in silicon solar cells).

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