CHAPETER 1

INTRODUCTION

1.1 THIN FILM TECHNOLOGY

Thin film devices play an important role in the development of modern science. The thin film is a two dimensional form of solid material, whose one dimension, called the thickness, is much smaller than the other two dimensions (Chopra 1969). The thin film is formed by atom to atom or molecule to molecule condensation process. In technical terms, the thickness of the films must be limited to the order of mean free path of the carriers participating in the particular electronic transport process for which the film has been fabricated. The limit of thickness may vary from a nanometer to a few micrometers depending upon the field of application.

At the initial stages, investigations on the thin films were made out of scientific curiosity, particularly for their significantly different properties from those of the same material in bulk form. However, the acquired capability of controlling properties of the thin films in subsequent years, helps immensely the use of thin films in electronic, opto-electronic and other devices and as a result, the electronic industry has become the greatest beneficiary of thin film technology. On the other hand, the thin film technology contributes to the development of microelectronics, by reducing the sizes of semiconductor devices to two dimensions.
The use of thin films in making active and passive electronic components made it possible to produce VLSI and microcomputer. Due to use of thin film technology, now the three dimensional bulk display units become flat. Because of compactness, better performance and reliability and low production cost thin film devices and components are preferred over their bulk counterparts. The development of thin film technology has led to its application in diverse fields from microelectronics to optics, space science to aircrafts and superconductivity to photovoltaics. One of the most important applications of thin films is in the photovoltaic devices and other solar cells (Maissel et al 1970 and Chopra et al 1985). In the photovoltaic devices, the use of thin films, or rather thick films (2-3 μm thickness) enables not only material costs saving but also the fabrication of large area devices at a comparatively low cost. The investigations on thin films have led to the development of new kind of active devices and passive components, different types of sensors (Joachim et al 2002), storage of solar energy and conversion to other forms, magnetic memories (Cavaco et al 2007), superconducting films (Li ta et al 2005), optical image storing devices (Shinya Maenosono et al 2000 and Junichi Kimura 2003), electromechanical device like strain gauge(Stephen et al 2004), gas detecting transducer (Johnson et al 1988), interference filter (Pierre 2002), reflecting and anti-reflecting coating (Koc et al 2005) and many others (Maissel et al 1970, Chopra et al 1985 and Aicha et al 1998). Hence in addition to major contribution to variety of new and future scientifically based technology, the thin films studies have directly or indirectly caused the advancement of many new areas of research in solid state physics and chemistry and will continue to play increasingly important roles in the study of a variety of problems of basic and technological importance.
1.2 THE “SULFURCELL”

1.2.1 Fundamentals

Although big efforts are devoted to the development of thin film photovoltaic technologies, the results achieved up to now are still limited. Further investigations are needed in order to solve many fundamental and technological aspects, and to reduce the production costs for making photovoltaics competitive in front more classical energy production systems. Chalcopyrite materials have already demonstrated to be potential candidates for large-scale productions. However, current technologies based on CIS present some problems. The adjustment of the stoichiometry, the necessity to introduce other alloy elements (Ga, Na, S) in order to achieve high efficiencies are important difficulties, which at the same time increase the production costs. Besides, from the environmental point of view, common CISe-based technology involves some steps which one wish to eliminate. Se in the absorber is incorporated through the selenization of the metallic precursors in H₂Se atmosphere. This gas is highly toxic and it must be manipulated very cautiously. Even if this step were removed or substituted for another one less problematic, the presence of Se in the cells would still be a disadvantage, due to the potential toxicity of this element.

Copper Indium disulphide (CIS) is one of the most promising chalcopyrite absorbers in terms of competitiveness, with other thin film polycrystalline materials. CIS has a bandgap of 1.5eV, which is well suited for terrestrial and space applications. The substitution of Se by S avoids one of the most critical steps of the CISe technology, decreasing the production costs. Moreover, the replacement of the Se by S increases the gap of the material from 1.1 eV to 1.5 eV, thus increasing the open circuit voltage of the cell. In terms of module design, it is possible to reduce the number of interconnects or to reduce the thickness of the ZnO window layer. Moreover,
the final module becomes less sensitive to infrared transmission losses induced by the cover glass. Finally, the higher bandgap favours the device response at higher temperatures and improves the blue response of the cell. Important progresses in the understanding on the properties of CuInS$_2$ and other chalcopyrite materials have been made during the last decade’s (Jaffe and Zunger 1983, and Jaffe et al 1984) though a lot of questions are still opened. The device performance has also been improved in the recent years. Cells with total area efficiency of 11.4% have been reported (Kai Siemer et al 2001) and currently efficiencies up to 12.1% have been achieved. Although this value is still far away from the values obtained for other materials, especially CISe, other considerations must be taken into account. First, one should keep in mind that the difference in the efficiency between different materials is much less important when dealing with modules. For instance, although CIS submodule technology has started very recently, efficiencies up to 9.2% have already been reported (Klaer Jo et al 2001) (the best sub-module fabricated up to now achieve an efficiency of 10.2%). This may be compared with the submodule efficiency of other materials as Cu(In,Ga), (Se,S)$_2$ (14.7%), CdTe (10.6%) or unstabilised Si (12%). Moreover, CIS devices show excellent stability and can be produced with low energy consumption. From the technological point of view, the absorbers can be produced in a much more reproducible way than CISe ones. This is so because the performance of the CIS devices seems to be not affected by the out diffusion of Na from the glass (Luck et al 2001). This avoids the requirement for the utilisation of Na diffusion barriers or the fair control of the incorporation of Na, as in the case of CISe films. Moreover, by selecting Cu-excess growth conditions high quality and stable CIS films are obtained and therefore cell performance is insensitive to local stoichiometry variations during growth. This constitutes an important difference with respect to CISe technology in which the stoichiometry of the film must be carefully controlled. It is expected to be possible to produce modules using Rapid Thermal Process
(RTP) which ensures a very fast formation of the absorbers. This would decrease the cycle time of the process, in comparison with other technologies. CIS cells are designed following similar procedures that those used for other chalcopyrite materials. The heterojunction is constituted by the p-type CIS absorber, the ZnO:Al window layer and a CdS buffer layer, which is placed in between the CIS and the ZnO layers. From the electrical point of view, the configuration window/absorber forms a heterojunction presenting the advantage that a great part of the photocurrent is generated at the surface of the absorber, where the electric field is maximum.

1.2.2 Anti-reflection Coatings for Solar Cells

Since transparent oxide layer reduces the surface recombination velocity, the short circuit current increase in a solar cell. Also, their refractive index values are in the range of 1.8 - 2.0, which makes them useful as anti-reflection coatings on silicon solar cells.

1.2.3 Opto-electronic Devices

Conducting oxides have been extensively used as transparent electrodes in various display devices, which includes electrochromic displays, light emitting diodes and liquid crystal displays. Also, TCO films have been used as transparent gates on charge-injection devices (CIDs) and charge-coupled devices (CCDs).

1.2.4 Gas Sensors

Oxide thin films have shown promising results in the detection of gases such as CO, CO₂, H₂, H₂S, alcohols and hydrocarbons. Usually, a change in electrical conductivity is observed when a change in the ambient occurs and this property forms the basis of gas sensing. The change in
conduction can be either due to direct transfer of electrons from the absorbed gas to the oxide semiconductor or due to a reaction of the absorbed gas with previously chemisorbed surface oxygen.

1.2.5 Heat Mirrors

Transparent conducting oxide films with plasma edge at about 1.5 Ωm are well suited for keeping heat radiation confined in a closed space.

1.2.6 Reflector-Absorber Tandem for Photo Thermal Conversion

A coating of a transparent conductor on any semiconductor absorber surface will yield a selective absorber tandem. These materials can also be used as anti-reflection coatings in photo thermal conversions.

1.2.7 Thin Film Resistors

TCO materials exhibit low temperature co-efficient of resistivity (TCR) and high degree of stability. As a consequence of these attractive properties, highly stable to resistors are being manufactured commercially.

1.2.8 Wear Resistance Applications

In order to reduce damaging of glass containers during manufacturing or filling, it is desirable to apply a low friction wear resistant coating to the glass surface. Transparent oxide coatings are engaged for this purpose.

1.3 ADVANTAGES OF THIN FILM

Thin film studies have indirectly advanced many areas of research based a phenomenon uniquely characteristic of the thickness, geometry and structure of the films. Thin films today in most of the photovoltaic cells
(Sekhar et al 2001), gas sensors (Yatendra et al 2004), heat reflecting filters (Cristina Nasar et al 1997), production of heat layers which protect vehicle wind screens from freezing and misting over (Nasser et al 1998), antistatic surface layers on temperature control coatings in orbiting satellites (Ki Hyun Yoon et al 2000), antireflection coatings (Rakshani 1986), high sensitivity photo detectors (Balamurugan et al 2001), and protective coatings to glass containers (Morales et al 2005). Due to these facts increasing demands have stimulated in recent years, the production of transparent conductors in thin film form.

It is well known that the structure of the films are determined by the process of film formation ie. nucleation and growth phenomenon of thin films. The unique growth stages of the vapor deposited films play a dominant role in the microstructure of film. Formation and annihilation of structure defects the deposition rate, vacuum content of the system etc., influence the kinetics of film growth stages and thereby, films of appreciable structure variations are obtained.

1.4 CuInS$_2$ THIN FILMS

1.4.1 Introduction

Due to the world’s issues on environment and energy, interests on the development of renewable energy resources such as the solar energy by fabricating environment-friendly, stable and promising photovoltaic (PV) materials are increasing. Solar photovoltaic energy conversion is a one-step conversion process which generates electrical energy from sunlight. Since time a memorial, the sun is the almost non-exhaustive source of power and energy which is free and safe. Being the pioneer material in the PV technology, crystalline silicon (Si) dominates the PV market nowadays. However, Si has low optical absorption ($\sim 10^3$ cm$^{-1}$) due to an indirect
transition. (Madelung 2004) Hence, Si-based PV technology requires large amount of Si raw material and complex manufacturing leading to high installation cost. In this light, Si-based PV power generators are not competitive in areas where conventional power generators are available. Thus, alternative, if not a replacement of Si, active absorber materials such as the direct gap I-III-VI$_2$ ternaries for example CuInX$_2$ (X=S or Se) are now explored.

CuInS$_2$ is one of the promising absorbers for thin film solar cells due to its direct fundamental energy bandgap of ~1.5 eV that matches well to the solar spectral region and its absorption coefficient ($10^5$ cm$^{-1}$) is 100 times higher than that of Si. To date the reported efficiency of CuInS$_2$-based solar cells is about 12% in laboratory scale (Klaer et al. 1998), while in mini-module scale it is about 9.2% which are still low compared to its selenide counterpart CuInSe$_2$ that has an energy bandgap different from that of the optimum value. (Klaer et al. 1998 and 2001) Many approaches have been tried to produce highly efficient CuInS$_2$-based thin film solar cells but it seems difficult to obtain it at present. Hence, it is necessary to investigate the fundamentals of such devices by studying the crystal quality of the absorber layer which is one of the important aspects to be considered in the fabrication of solar cell devices. CuInS$_2$ in bulk generally crystallizes to chalcopyrite structure. But in thin films, it seems hard to produce chalcopyrite single phase alone. Coexistence of Cu-Au and chalcopyrite structures was confirmed in the CuInS$_2$ films grown on Si (001) by molecular beam epitaxy (MBE) and it was found that the difference between their formation energies is small as predicted by Su and Wei from first principles calculations (Su 1999). On the other hand, Metzner et al. (2000) reported the growth of Cu-Au structure with sphalerite structure for the films grown on Si (001) prepared by MBE. One approach to improve the crystallinity of the epitaxial films is selecting the suitable substrate. In the two substrates the monocrystalline Si and GaP
oriented at (001) are used as templates in growing epitaxial CuInS$_2$ thin films. Although, there were already reports on the growth of CuInS$_2$ thin films on Si (001), it is deemed wise to note that the film growth varies with growth conditions and methods of preparation.

1.4.2 Material Properties

A first fundamental work about the growth and the structural characterization of chalcopyrite compounds was published by Hahn et al (1953). Later work on chalcopyrites was mostly motivated by their potential for non-linear optical applications, visible-light emitters, and photodetectors (Wagner 1973 and 1975, Smith 1975 and Bridenbaugh et al 1975). In the beginning of the seventies a first comprehensive review of chalcopyrite compounds was given in the book by Shay et al 1975. Later, Pamplin 1975 published several reviews about phase formation rules, thermodynamic phase relations and experimental results of ternary adamantine compounds, among them the Cu-chalcopyrites (Pamplin 1975 and 1979). Whereas earlier work was almost entirely about single crystal specimen, more recent experimental investigations have been focused on thin films, due to the high potential of these materials for large area photovoltaic modules.

1.4.3 Crystal Structure

CuInS$_2$ belongs to the group of ternary chalcopyrite compounds which derives from the group IV class of tetrahedrally bonded semiconductors according to the Grimm-Summerfield rule, i.e. there must be an average of 4 valence atoms per atomic site. In these structures each atom has four neighbors arranged at the corners of a regular tetrahedron bonded by sp$^3$ bonds. The tetrahedral structure of the chalcopyrites can be considered as a superlattice structure of the sphalerite or zincblende structure which has a diamond like structure (such as Si) consisting of two inter-penetrating face
centered cubic lattices, separated by a translation vector of \((1/4, 1/4, 1/4)\). One sublattice is occupied by cations and the other by anions (II-VI and III-V compounds). In a ternary chalcopyrite the cations are furthermore replaced by a one cation of higher valency and one cation of lower valency which occupy the cation sublattice in an ordered manner as shown in Figure 1.1. In that sense CuInS\(_2\) can be envisioned as the ternary analogue of the binary ZnS. The reduced symmetry, due to the two kinds of cations, leads to a primitive cell of eight atoms in the chalcopyrite structure compared to a primitive cell of two atoms in the zincblende structure. The Bravais lattice of the chalcopyrite is body centered tetragonal. Compared to the face centered cubic Bravais-cell of the zincblende the unit cell is doubled along the crystal \(c\) axis. If the different cations are distributed at random, the ternary compound has a sphalerite structure. Each S atom in the lattice is at the center of a tetrahedron with four cations at each corner. Since in a chalcopyrite structure, in contrast to the zincblende, the sulfur atom is bonded to two types of cations the respective bond lengths are not necessarily identical. As a result the tetrahedron is no longer regular but is distorted along the crystal \(c\)-axis such that the \(c/a\) ratio deviates from the ideal value of 2.0. In addition, the difference in bonding length leads to an internal displacement of the anion away from the ideal position 0.25 so that the anion sublattice is slightly distorted. In the case of CuInS\(_2\) the Cu-S bond length is 2.335 Å, whereas the In-S bond length is 2.464 Å (Abrahams and Bernstein 1973). As a result the sulfur atom moves away from the In-atoms and towards the Cu-atoms resulting in a stretched unit cell with a \(c/a\) ratio of 2.014 (Jaffe et al 1983). In the case of the CuGaS\(_2\) lattice the Ga-S bond is shorter than the Cu-S bond, hence the unit cell is compressed with a \(c/a\) ratio = 1.97 (Jaffe et al 1983). Precise X-ray diffraction measurements of CuInS\(_2\) and CuGaS\(_2\) crystals were performed by Abrahams and Bernstein (1973) at samples grown from the melt and by Spiess et al (1974) at samples synthesized by halogen vapor
transport reaction. The determined lattice parameters are listed, together with the values of the early work of (Hahn et al 1953).

1.4.4 Characteristics of CuInS$_2$

CuInS$_2$, a chalcogenide material, belongs to a group of ternary semiconductors with ABX$_2$ molecular formula. The ABX$_2$ group is composed of two major groups: the chalcopyrite’s (A$^{III}$B$^{II}$C$_2$ $^{VI}$) and the pnictides (A$^{II}$B$^{IV}$C$_2$ $^{VI}$). CuInS$_2$ is in the chalcopyrite group with A, B and C atoms corresponding to cu, in, and s, respectively. Chalcopyrite materials are the ternary isoelectronic analogues of II-VI binary compounds. The analogue binary compound for a given chalcopyrite material is obtained by taking the cation located in the Periodic Table between the A and B atoms. For CuInS$_2$, the corresponding binary analogue is Zn$_{0.5}$Cd$_{0.5}$S. Despite the similarities between the ternary compounds and their analogues, difference in their structural and electronic properties exists. Take for instance, the ternary materials exhibit bandgap anomaly wherein their energy bandgaps are much lower than their analogues. (Jaffe and Zunger 1983). In chalcopyrites, the atomic distributions are given as follows. (Shay and Wernick 1975)

- Equivalent position, 000; 1/2 1/2 1/2,
- 4A positions, 000; 0 1/2 1/4,
- 4B positions 00 1/2; 0 1/2 1/4, and
- 8C positions x 1/4 1/8; -x 3/4 1/8; 3/4 x 7/8; 1/3 -x 7/8.

The crystal structure of the ternary chalcopyrite belongs to the space group I 42d, with eight atoms per primitive unit cell. Chalcopyrite structure may be thought of as a superlattice of the zincblende structure.
1.4.5 Existence of Other Phases

Experimental results demonstrate that the only ternary compounds which are stable at room temperature are the chalcopyrite ordered structure of \( \text{CuInS}_2 \) and the cubic spinel \( \text{CuIn}_5\text{S}_8 \) (Brussler et al 1988). In addition to these reported equilibrium phases of \( \text{CuInS}_2 \), it also shows an order-disorder transition, that is from chalcopyrite to sphalerite transition, at temperature 1253K (Rincon 1992). It is worth noting that this order-disorder transition temperature is below the melting point (1320 or 1364K) of \( \text{CuInS}_2 \). A list of the order-disordered transition structures is provided by Wei et al in their results in first principles calculations (Wei et al 1992). The coexistence of the metastable crystal domains such as Cu-Au ordered domains was reported for Cu-In-S system since the difference of the formation energy of the ordered chalcopyrite and the Cu-Au crystal domains is very small (Su et al 1998). Table 1.1 Material parameters of some semiconductors. Unless stated otherwise these parameters have been measured at 300K. The parameters of IV, III-V and II-VI are taken from reference (Schroder 1998), while the ternary I-III-VI\(_2\) chalcopyrite’s are from reference (Madelung 2004) and if from other references it is otherwise stated in the superscript. D – Direct and I – Indirect energy band gap.
The semiconductor compounds of I-III-VI\textsubscript{2} and II-IV-V\textsubscript{2} are known to be the ternary analogs of II-VI and III-V binary semiconductor compounds, respectively. By ordered substitution of other atomic groups by maintaining an electron-to-atom ratio of 4, the ternary compounds can be derived. Copper indium disulphide (CIS) is considered as one of the most promising chalcopyrite absorbers for photovoltaic application compared to other polycrystalline thin film materials such as copper indium diselenide (CIS). In CIS, S replaces Se in CuInX\textsubscript{2} (X=Se or S) and as a result the band gap increases from 1.1 to 1.5eV. Thus, the open circuit voltage of the CIS-based solar cell increases also. Furthermore, this higher band gap allows CuInS\textsubscript{2}-based solar cell devices to withstand higher temperatures and it also improves the blue spectrum response of the cell.

**Table 1.1 Material parameters of some semiconductors**

<table>
<thead>
<tr>
<th>Semiconductor</th>
<th>Band Gap (eV)</th>
<th>Electron Mobility (cm\textsuperscript{2}/Vs)</th>
<th>Hole Mobility (cm\textsuperscript{2}/Vs)</th>
<th>Lattice Constant (Å)</th>
<th>Density (g/cm\textsuperscript{3})</th>
<th>Melting Point (K)</th>
<th>Coefficient of Thermal Expansion (10\textsuperscript{4}K\textsuperscript{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>1.12(I)</td>
<td>1400</td>
<td>470</td>
<td>5.43095</td>
<td>2.328</td>
<td>1685</td>
<td>2.92</td>
</tr>
<tr>
<td>Ge</td>
<td>0.67(L,D)</td>
<td>3900</td>
<td>1900</td>
<td>5.64613</td>
<td>5.327</td>
<td>1231</td>
<td>5.90</td>
</tr>
<tr>
<td>GaAs</td>
<td>1.42(D)</td>
<td>8000</td>
<td>340</td>
<td>5.6533</td>
<td>5.32</td>
<td>1510</td>
<td>5.734</td>
</tr>
<tr>
<td>GaP</td>
<td>2.26(I)</td>
<td>350</td>
<td>100</td>
<td>5.4512</td>
<td>4.13</td>
<td>1750</td>
<td>4.65</td>
</tr>
<tr>
<td>ZnS</td>
<td>3.66(D)</td>
<td>165</td>
<td>5</td>
<td>5.410</td>
<td>4.079</td>
<td>2100</td>
<td>6.7</td>
</tr>
<tr>
<td>ZnO</td>
<td>3.35(D)</td>
<td>200</td>
<td>180</td>
<td>a = 3.252</td>
<td>5.66</td>
<td>2242</td>
<td>4.75</td>
</tr>
<tr>
<td>CuInS\textsubscript{2}</td>
<td>1.53(D)</td>
<td>165</td>
<td>499</td>
<td>a = 5.52</td>
<td>4.74</td>
<td>1320</td>
<td>11.7</td>
</tr>
<tr>
<td>CuInSe\textsubscript{2}</td>
<td>1.01(D)</td>
<td>6</td>
<td>3.1</td>
<td>a = 5.78</td>
<td>5.77</td>
<td>1260</td>
<td>10.6</td>
</tr>
<tr>
<td>CuInTe\textsubscript{2}</td>
<td>0.98(D)</td>
<td>189</td>
<td>50.6</td>
<td>a = 6.17</td>
<td>6.10</td>
<td>1050</td>
<td>10.9</td>
</tr>
<tr>
<td>CuGaS\textsubscript{2}</td>
<td>2.43(D)</td>
<td>---</td>
<td>15</td>
<td>a = 5.35</td>
<td>4.38</td>
<td>1550</td>
<td>11.2</td>
</tr>
<tr>
<td>CuGaSe\textsubscript{2}</td>
<td>1.68(D)</td>
<td>---</td>
<td>3.12</td>
<td>a = 5.61</td>
<td>5.57</td>
<td>1310</td>
<td>11.1</td>
</tr>
<tr>
<td>CuGaTe\textsubscript{2}</td>
<td>1.23(D)</td>
<td>---</td>
<td>50</td>
<td>a = 6.00</td>
<td>5.95</td>
<td>1140</td>
<td>10.1</td>
</tr>
</tbody>
</table>
The films of CuInS$_2$ are not homogenous, but consist of masses of crystallites, which may randomly orient or may show preferred orientation. Porosity is a characteristic of many materials in films form, the extent of voids depending on the film thickness. Films of this type may possess a gradient of refractive index in the direction of the normal to the surface. Some important physical properties are given below

a. The pressure in the evaporation chamber  
b. Rate of deposition  
c. Thickness of film  
d. Nature and temperature of substrate  
e. Crystal binding energy  
f. Substrate cleaning  
g. Mobilities of molecules of evaporation substrate and growing film  
h. Purity and Physical state of evaporate  
i. Evaporation temperature

CuCl$_2$ film coupled with InCl$_3$ is widely used in Solid-State Image intensifier (SSI). Its main application is to reduce the X-ray dosage and increase the image brightness in the Solid-State Image intensifier screen.

1.5 AIM OF THE PRESENT WORK

Objectives of present work

To prepare CuInS$_2$ thin films by spray pyrolysis method.

- To study the structural, optical, surface morphology, electrical, photoluminescence and compositions of Undoped, Sb, Zn, and Bi doped CuInS$_2$ thin films.
- To study the fundamental changes in the optical, electrical and photoluminescence properties associated with structural changes.

- To prepare nano crystalline CuInS$_2$ thin films using ethylene glycol and study their properties

**Outline of the present work, this thesis comprises of nine chapters**

- The first chapter deals with an introduction and objectives of the present work.

- The second chapter gives a detailed literature survey on CuInS$_2$, Sb, Zn, Bi doped and Ethylene glycol assisted CuInS$_2$ films.

- The third chapter reveals the experimental techniques used to form CuInS$_2$, Sb, Zn, Bi doped and Ethylene glycol assisted CuInS$_2$ films.

- Chapter four deals with the structural, optical and photoluminescence properties of CuInS$_2$ films prepared by spray pyrolysis.

- Structural, optical and photoluminescence properties of antimony (Sb) doped CuInS$_2$ thin films and Influence of antimony (Sb) concentration and temperature on the properties of Sprayed Sb-doped CuInS$_2$ thin films are studied in the chapter five.

- Chapter six reveals the effect of zinc doping and temperature on the structural, optical, electrical and photoluminescence properties of sprayed CuInS$_2$ thin films.
• Chapter seven deals with the effect of Bi incorporation and temperature on the structural, optical, electrical and photoluminescence properties of CuInS$_2$ thin films.

• Structural and optical properties of Ethylene glycol assisted CuInS$_2$ thin films and its characterization has been dealt in the chapter eight.

• Finally, the important summary and conclusions of the present work is given in the ninth chapter.