# CHAPTER 6

# CONCLUSIONS AND SUGGESTIONS

In this research the current-voltage characteristics of $ZnO/CdS/Cu(In,Ga)Se_2$ heterojunction thin film solar cells have been investigated: (1) the J-V characteristics measurement at room temperature, (2) the effect of incorporated impurities in the CBD-CdS layer on the J-V characteristics, (3) the illumination intensity effect on J-V characteristics, and (4) the J-V characteristics measured as a function of temperature. Conclusions based on the finding of the research were as follows:

(1). Analysis of the J-V characteristics of $ZnO/CdS/Cu(In,Ga)Se_2$ at room temperature show that the diode behavior can be described by a standard diode model. The junction current mechanism is controlled by SRH recombination in the space charge region, which yields the diode ideality factor $A$ is between 1 and 2.

(2). Prior to this research work, there existed a large number of publications where the structural, electrical, optical and electro-optical properties of CBD-CdS thin film have been investigated as a function of various deposition parameters. In this work, the role of the CBD-CdS layer on the $Cu(In,Ga)Se_2$-base thin film solar cells has been investigated. The approach in the present work to study the effect of impurities in the CBD-CdS was to change the concentration of thiourea in the CBD bath. Although it was not possible to completely illustrate the role of the chemically deposited CdS buffer layer in the $Cu(In,Ga)Se_2$-based thin film solar cells, the results from this research indicate that the different in bulk properties of the CdS layer play a minor role on the junction formation and cell performances. However CBD-CdS thin films prepared from CBD bath containing thiourea concentration 0.06M exhibited the high average cell performance compared to the films prepared with thiourea concentration 0.03M and 0.1M.

(3). The dependence of the $Cu(In,Ga)Se_2$-based thin film solar cell on illumination intensity and temperature were mainly studied for the recombination mechanism at the interface or the space charge region. The results of this work indicated that the mechanism controlling the junction behavior is SRH recombination in space charge region and no improvement on the recombination mechanism with increase the illumination intensity. However, the heat treatment or light soaking effect on the low efficiency solar cell was observed. The result showed that the light soaking enhances the free electron density in the CdS layer and lead to positive charge trapping in this layer. This trapping enhances the photocarriers separating barrier in the absorber and improves the solar cell performance.

(4). The results of from the temperature dependence current-voltage measurement show that the superposition principle fails to hold at low temperature ($T<290K$). It has been suggested that a conduction offset and/or non-ohmic contact may be cause, resulting in two distinctively different non-exponential J-V curves. The diode ideality factor $A$ strongly depends on temperature and the values of $A$ are between 1 and 2 in a temperature range between 370 and 290 K. This indicates a thermally activated recombination via a distribution of trap states in the space charge region of the $Cu(In,Ga)Se_2$ absorber layer. For $T<290K$, $A$ may increase above two due to an increased contribution of tunneling.

(5). Although it was not possible to accurately proposed the complete band diagram due to the $Cu(In,Ga)Se_2$-based thin film solar cell is the complexity system, the proposed band diagram in the present work, which is based on the analysis of the experimental data corresponds and can explain the J-V characteristics of Cu(In,Ga)$Se_2$-based thin film solar cells in this research.

As a result of the finding of this research, the following suggestions for further study included:

(1). The further study should characterize the CdS film with different impurity concentration with other techniques to understand the interaction of the CBD grown CdS with the underlying Cu(In,Ga)$Se_2$ surface because the surface chemistry taking place during heterojunction formation is decisive for the final device performance.

(2). To more fully understand the junction formation and the energy band alignment of ZnO/CdS/Cu(In,Ga)$Se_2$ heterojunction, the devices should be characterized by using the capacitance-voltage (C-V) measurements and C-V measurements as a function of temperature to obtain the doping profiles and carrier concentration.

(3). To extend the rang of data collection, the development of J(V,T) system with capability to cool down lower 150 K and to vary illumination intensity at the same time without the effect on the temperature of sample should be considered.

(4). The spectral response of Cu(In,Ga)$Se_2$-based thin film solar cells with different impurity concentration in CdS layer should be investigated by quantum efficiency (QE) measurements.

(5). Although the high efficiency of the Cu(In,Ga)$Se_2$-based thin film solar cells took place when using CBD-CdS as a buffer layer, Cd is known to be highly toxic substance. The CdS layer should be substituted by the alternate buffer layer such as ZnS, ZnSe, ZnO and still with the high efficiency.