Photoelectric Material $CuInSe_2$*

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Abstract: This paper gives a review of $CuInSe_2$ solar cells techniques and recent developments in $CuInSe_2$ materials, it is reported that solar cells based on $CuInSe_2$ have demonstrated efficiency of 18%. It also introduces the characteristics of $CuInSe_2$: the extraordinarily high absorption coefficient($> 10^5$ cm^{-1}), the use of thin layers(1 ~ 2 μm), long-term stability. The understanding of $CuInSe_2$ will be helpful to the research of thin-film solar cells with high conversion efficiency both at home and abroad.

Key words: photoelectric material; $CuInSe_2$; solar cell
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1 Introduction

Exploit new energy and regenerable energy is one of the most decisive fields of technology in world ' s development, it is also an important way to solve problems of energy and environment. In 1954, the first modern solar cell was developed in Bel Lab, laid a foundation for using solar cells in large scale. For decades, especially after the 1970 ' oil crisis, environmental pollution and the advantages of solar cells, such as: large in quantity, safety, no moving parts, no air and water pollution, require little maintenance etc., make solar cells develop rapidly.

The mechanism that makes solar cells work is photoelectric effect. In 1876, scientists found the first solid material which possesses photoelectric effect-Se, showed that semiconductors are the most suitable materials for energy conversion between photo and electricity[1].

Silicon is indirect energy gap semiconductor, it has low absorption coefficient, in turn its films are thick and large. Though commercial silicon solar cells are comparatively simple, the needed purity of raw material is low, but efficiency and stability are the problems which needed solve. Additionally, silicon used in solar cells mostly come from substandard product of semi-conductive silicon. So it can not satisfy with the need of photovoltaics.

Binary compounds, such as: GaAs, CdS, CdTe, InP etc., have high absorption coefficient, so are suited to prepare films of several microns, and can reach high conversion efficiency. But GaAs is very expensive and As is poisonous. To prepare binary compounds thin-films need sophisticated equipment, large funds and long period of time. So they do not suit to large scales produce.

Ternary compounds provide vast vistas for choosing photoelectric materials. Chalcopyrite compounds are becoming important solar cell materials, for their excellent performances, cheaply technology. $CuInSe_2$ is one of the most promising materials, its band gap is about 1.04 eV which is within the maximum solar absorption region. This is very important as far as the optimum conversion efficiency is concerned. The direct energy gap of $CuInSe_2$ results in a large optical absorption coefficient ($> 10^5$ cm^{-1}), which in turn, permits the use of thin layers(1 ~ 2 μm) of active material. $CuInSe_2$-based solar cells have shown efficiency of 18%[2], $CuIn_{1-x}Ga_xSe_2$-based solar cells have reached 18.8% of efficiency[3]. $CuInSe_2$ solar cells are also known for their long-term stability.

The problems we faced are to find an advanced technology to reduce production costs, raise efficiency and prepare $CuInSe_2$ in large scale. This paper reviews the research of $CuInSe_2$ solar cells history, current situation, character, existing problems and trend of development.

2 Present situation of $CuInSe_2$ solar cells

Since Bel Lab developed single-crystal $CuInSe_2$ in 1974, conversion efficiency of $CuInSe_2$ has been raised rapidly, as showed in Fig.1, and the cost of $CuInSe_2$ is increasingly reduced.

In 1976, Maine University first developed $CuInSe_2$ solar cells, which reached 6.6% of efficiency.

In 1982, Boeing Company developed $CuInSe_2$ solar

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cell by evaporating Se, Cu, In, its efficiency was over 10%.

In 1983, Arco Solar Company put forward a new technology-selenization. The technology is simple, low cost, and is one of the most important techniques for preparing $CuInSe_2$ solar cells.

In 1988, Arco Solar Company developed $CuInSe_2$ solar cell which showed conversion efficiency of 11.1%, exceeded 10% of efficiency for the first time and showed long-term stability.

In 1994, Sweden Royal Institute of Technology reported 17.6% of efficiency in area of 0.4 cm^2, set a word record of $CuInSe_2$ solar cells, marked $CuInSe_2$ solar cells good prospects for industrialization development.

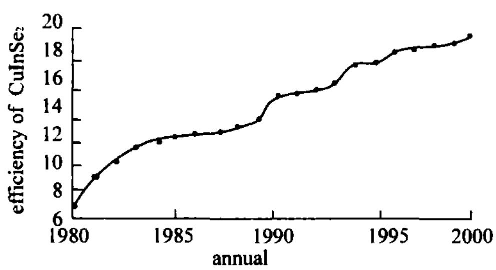

Fig.1 The effeciency of thin film solar cells CIS varies annually

Contreras and Shock developed $CuIn_{1-x}Ga_xSe_2$ solar cells reached 18.8% of efficiency in the year of 1999 and 2000 respectively, by using multi-vacuum technology.

Several research groups have prepared devices-quality $CuInSe_2$ or $CuIn_{1-x}Ga_xSe_2$ by using either one-step or multistep processes[4]. In the one-step process, the $CuInSe_2$ or $CuIn_{1-x}Ga_xSe_2$ thin-film is grown by codeposition of Cu, In(Ga) and Se simultaneously. The techniques used for one-step processes are physical evaporation, chemical deposition and electrodeposition. The multistep process involves, for example, the deposition of precursor films of In(Ga)-Se in the first step, Cu-Se in the second step, and again deposition of In(Ga)-Se in the final stage. To date, the techniques used for multistep processes are physical evaporation and sputtering.

3 Structure of $CuInSe_2$

$CuInSe_2$ belongs to Ⅰ - Ⅲ - $Ⅵ_2$ compounds, it is a derivation of Ⅱ - Ⅴ compounds.

The elements of Ⅱ are substituted by Cu and In, thus forms ternary compound semiconductor. $CuInSe_2$ has two allotropic substances: chalcopyrite and blende. When temperature is above 980 ℃, it is blende structure; when the temperature is below 810 ℃, it belongs to chalcopyrite structure, as shown in Fig.2. Chalcopyrite $CuInSe_2$ is excellent match with CdS, this make it superior to the other chalcopyrite alloys.

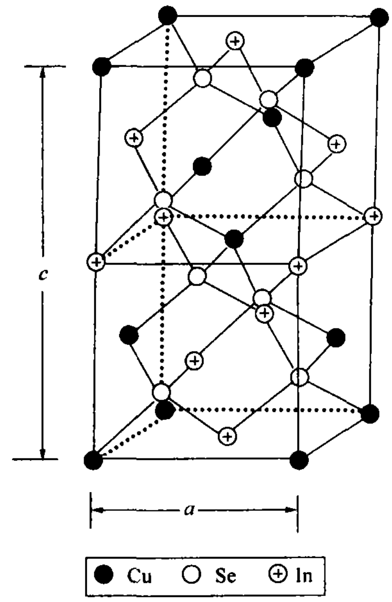

Fig.2 Chalcopyrits CIS

From the phasic graph of $CuInSe_2$, we can see when ratio of composition elements deviate from Cu∶In∶Se = 1∶1∶2 to a certain degree, the materials still have chalcopyrite structure and the same physical and chemical characters. Because Ⅰ - Ⅲ - $Ⅵ_2$ compounds have twelve kinds of intrinsic point defect, and these point defect can create new energy band in band-gap. Meanwhile, $CuInSe_2$ can be prepared either p-type or n-type semiconductors, by adjusting ratio of composition elements, not by inclusing other elements.

4 Character of $CuInSe_2$

$CuInSe_2$ band-gap is about 1.04 eV at room temperature, the most suitable band-gap to absorb sun shine is about 1.45 eV. So scientists incluse other elements in $CuInSe_2$ to raise the efficiency of $CuInSe_2$. Researchers mainly use Ga substitute In, S substitute Se. In fact control content of Ga and S will influence the ratio of Cu/In. Incluse Ga and S also influence crystal size and lattic defect, so the efficiency is not the highest when band-gap nears 1.45 eV. At large, incluse Ga can raise open-circuit voltage, lower the short-circuit current. Now $CuIn_{1-x}Ga_xSe_2$ solar cells have reached 18.8% of efficiency, it is the highest efficiency reported.

$CuInSe_2$ is direct-band semiconductor, its absorption coefficient is high (> 10^5 cm^{-1}), and the absorption spectrum of $CuInSe_2$ is large, showed in graph(3)[5].

5 Prospect of $CuInSe_2$

The importance of $CuInSe_2$-based solar cell for photovoltaic system has been recognized for thirty years. In the last decade, the cells' efficiency has rapidly progressed by understanding the $CuInSe_2$ film formation, the role of Na and solid solution of Ga and S etc. $CuInSe_2$ solar cells continue to advance with an efficiency of exceeding 18%.

Although $CuInSe_2$ is a promising material, it has many limitations. It is no doubt that $CuInSe_2$ is long-term stability, high efficiency, but the cost is a problem which needs to be solved, because of the cost of In and the process. In is the most expensive element in $CuInSe_2$, we can overcome it by preparing thinner film, retrieving In and using other elements to substitute In.

So, the understanding of $CuInSe_2$ will be helpful to the research of thin-film solar cells with high conversion efficiency.

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光电材料 $CuInSe_2$ 薄膜

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摘 要:概述了 $CuInSe_2$ 太阳能电池技术,$CuInSe_2$ 材料的最新发展;同时也介绍了 $CuInSe_2$ 薄膜的特性:非常高的光吸收系数($>10^5\ cm^{-1}$),可以将薄膜做的很薄($1\sim2\ \mu m$),长期的稳定性,抗辐射性等。对 $CuInSe_2$ 材料的认识、了解将有助于对高效、低成本的薄膜太阳能电池的研究。

关键词:光电材料;$CuInSe_2$;太阳能电池

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