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A Brief Review of the Growth of Pulsed Laser Deposited Thin Films

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

In recent years, much attention has been emphasized on research to produce thin films using pulsed laser deposition. Therefore, the main objectives in this review were to address some important points such as the influence of different growth conditions on the properties of films using this method. The advantage of this method was discussed which including it could control the dimensions and display good crystallinity. The obtained experimental results from published articles were discussed and analyzed. So that, readers can know that this method could be used to prepare binary, ternary and quaternary films. Lastly, the power conversion efficiency of fabricated solar cells was reported in order to study these films could be applied in solar cell applications.

Keywords: Thin films; solar cells; pulsed laser deposition; band gap.

1. INTRODUCTION

Pulsed laser deposition method has attracted wide spread interest to grow many materials such as thin films, nanopowders, quantum dots, nanotubes and ceramic oxide. Smith and Turner [1] have prepared semiconductor and dielectric thin films using this method for the first time in

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1965. They have successfully reported some behaviors of this technique, including high deposition rates of about 0.1 nm per pulse and the occurrence of droplets on the surface of substrate. There are many advantages to apply this deposition method including able to control the dimensions and the crystalline phase by varying the laser parameters and the growth conditions as reported by Zhang et al. [2]. In addition, this technique offers stoichiometric preservation during materials transfer from target to substrate and display good crystallinity as described by Sun et al. [3].

Generally, pulsed laser deposition method consisted of some important parts. Each of them will greatly affect the quality of thin films. According to many researchers, these steps including laser radiation interaction with the target, dynamic of the ablation materials, deposition of the ablation materials with the substrate and growth of the thin films on the substrate. In other words, this deposition method depends on a photon interaction to produce an ejected plume of material from target. Then, the vapor was collected on a substrate which located a short distance from the target.

As we know, thin films have attracted much attention in recent years due to their unique properties. In this work, the focus is on the preparation of thin films using pulsed lased deposition method. This method could be used to produce binary, ternary and quaternary thin films as reported by many researchers. Following that, their optical, morphology, and structure properties were investigated.

2. LITERATURE SURVEY

As indicated in literature reviews, there are some scientists had produced zinc sulfide thin films onto various types of substrates using pulsed laser deposition method. Zhang et al. [2] have reported the preparation of ZnS films on Au-coated sapphire substrates. The XRD studies confirmed wurtzite structure and the most intensive peak is in the (111) direction. In optical properties analysis, the band gap of 3.82 eV for direct interband transitions could be observed. Photoluminescence spectra of the zinc sulfide thin films displayed two emission bands centered as 405 and 520 nm, respectively, indicating the obtained films could be used in the novel luminescent devices. On the other hand, they proved that the uniform films with a thickness of 3 µm as indicated in scanning electron microscopy analysis. Also, the energy dispersive X-ray analysis showed the obtain films displayed approximately atomic ratio of 1:1.

ZnS films have been prepared on sapphire and silicon substrates using this method by Xin et al. [4]. They claimed that successfully to produce ZnS films under various temperatures ranging from 200 to 680°C for the first time. The crystallography of the films is characterized by principal peak corresponding to wurtzite structure as indicated in XRD patterns. Furthermore, the XRD data show full width at half maximum 2θ values of 0.09° and 0.08° for the films prepared on sapphire and silicon substrates, respectively.

Quartz was used as substrates to deposit zinc sulfide thin films at room temperature by Yano et al. [5]. The experimental findings show the absorption is mainly influenced by excitonic formation. On the other hand, the influence of argon pressure such as 0, 5, 10, 15 and 20 Pa was studied by Chalana et al. [6]. The XRD patterns show that an increase in the argon pressure from 0 to 15 Pa is accompanied by an increase in the crystallinity of the ZnS films. However, the crystallinity decreases as the argon pressure beyond 15 Pa. Therefore, they claim that 15 Pa is the best argon pressure. In addition, these films show the highest photoluminescence intensity for excitation wavelength 325 nm and the best crystallinity.

ZnS films were deposited on to fluorine tin oxide substrate at different temperatures such as 150 and 200°C by Ming et al. [7]. The experimental results show the intensity of (111) peak increases and the surface were more homogenous with the increasing of the substrate temperature. The main phases obtained were both cubic zinc blende structure as confirmed in XRD data. The band gap was 3.48 and 3.54 eV for the films deposited at 150 and 200°C, respectively.

Lastly, another literature review reported that ZnS films have been investigated by McLaughlin et al. [8]. They found the good stoichiometric quality and typical luminescent crystal structures have been detected with a predominant hexagonal phase and little evidence of the cubic phase.

Cadmium sulphide thin films have been deposited on quartz substrate at various substrate temperatures in the range 100-600°C by Tong et al. [9]. It is worth mentioning that the crystalline, optical properties and surface quality of the films could be improved with increasing the temperature up to 450°C. However, degradation of the quality of the films could be observed as the temperature was increased to 600°C. On the other hand, Hendi [10] had prepared CdS films under high vacuum. The obtained CdS films are crystalline and have predominant orientation on the plane (110) of hexagonal system. Spectrophotometric measurements showing that band gap to be 2.44 eV with direct allowed transitions. The influences of thickness on properties of CdS films were studied by Alias et al. [11]. The crystallite grain size was observed increasing from 12.1 to 51.9 nm as the film thickness was increased from 130 nm to 780 nm. In the XRD studies, the grown CdS films were polycrystalline and the peaks appear sharper when the film thickness increases.

Table 1. Chemical bath deposition of thin films

No	Thin films	Scientist(s)
1	zinc sulfide	Anuar et al. [21]
2	Bismuth sulphide	Ubale [22]
3	Zinc selenide	Anuar et al. [23]
4	Indium sulphide	Asenjo et al. [24]
5	Copper sulfide	Anuar et al. [25]
6	Cadmium sulphide	Caballero-Briones et al. [26]
7	Lead selenide	Anuar et al. [27]
8	Antimony sulphide	Ezema et al. [28]
9	Tin sulphide	Anuar et al. [29]
10	Lead sulphide	Raniero et al. [30]
11	Nickel sulphide	Anuar et al. [31]
12	Manganese sulphide	Anuar et al. [32]
13	Iron sulphide	Anuar et al. [33]
14	Zinc cadmium sulphide	Song et al. [34]
15	Copper tin sulphide	Anuar et al. [35]
16	Zinc indium selenide	Babu et al. [36]
17	Copper indium selenide	Bari et al. [37]
18	Copper antimony sulphide	Ekuma et al. [38]
19	Nickel lead sulphide	Ho [39]
20	Lead iron sulphide	Joshi et al. [40]

$CuInSe_2$ thin films have been prepared on Mo-coated soda lime glass by pulsed laser deposition method. The XRD data confirmed that the obtained films have good crystallinity preferentially oriented along the (112) direction as reported by Luo et al. [12]. Experiments showed that the band gap to be 0.95 eV and absorption coefficient near 10^5 cm^{-1}. The role of the annealing temperature on the properties of $CuInSe_2$ film was investigated by Kuranouchi & Yosbida [13]. They conclude that the composition of annealed films was copper rich and no significant loss of selenium was detected. Also, they pointed out that the structure of films was drastically changed after annealing process as indicated in XRD patterns. On the other hand, solar cells which consisted of $CuInSe_2$/CdS/ZnO heterojunctions were prepared by Dittrich et al. [14]. The power conversion efficiency about 8.5% was obtained in their experiment.

The technique of pulsed laser deposition of $CuIn_3Se_5$ was developed by Anatoly et al. [15]. They suggest that the best crystallinity of $CuIn_3Se_5$ films was attained at substrate temperatures ranging from 320 to 400°C. They also found that obtained films are photosensitive materials and have the positive photocurrent in positive range of applied potential values.

Kim et al. [16] have reported the use of Zn-S-Cu-Al films in green emitting materials. They point out that these films were very sensitive to stress and strain. The obtained results show that the best substrate temperature was 700°C, which was confirmed by desorption of copper acceptors and crystalline quality. The X-ray diffraction and optical properties analysis suggest that these films have the hexagonal wurtzite phase and ban dgap about 3.71 eV.

Cu_2ZnSnS_4 (CZTS) thin films have large absorption coefficient (Sun et al. [3]) and the ideal direct band gap to be 1.5 eV (Lin et al. [17]) were the promising absorber materials for the solar cells. The CZTS films were prepared by Yao et al. [18]. They developed that the films with the novel structure of FTO/CdS/CZTS/Mo provided fill factor of 0.485 corresponding to the conversion efficiency of 0.19% at the illumination. On the other case, annealed Cu_2ZnSnS_4 thin films have been prepared on Molybdenum coated glass substrate by Moholkar et al. [19]. The observed main peak position of the annealed sample was (112) orientation as shown in XRD patterns. Meanwhile, SEM analysis showed that these films are smooth, uniform and densely packed. Finally, they claimed that the solar cell fabricated with glass/Mo/CZTS/CdS/ZnO:Al/Al structure indicated the best conversion efficiency of 4.13% (Moholkar et al. [20]).

In spite of the mentioned benefits of pulsed laser deposition method, some shortcomings have been identified by many researchers. Some problems such as splashing, narrow angular distribution of the ablated species and limit the usefulness in producing large area uniform thin films could be observed. In contrast, chemical bath deposition (Table 1) and electrodeposition method (Table 2) are very simple, economical and able to produce large area thin films on substrate. As results, many scientists are focusing on these methods to produce various types of thin films in optoelectronic and solar cell applications.

Table 2. Electrodeposition of thin films

No	Thin films	Scientist(s)
1	SnS	Subramanian et al. [41]
2	SnSe	Mustafa & Ilkay [42]
3	CdSe	Rashwan et al. [43]
4	ZnSe	Mahalingam et al. [44]
5	ZnS	Anuar et al. [45]
6	$SnS_{0.5}Se_{0.5}$	Subramanian et al. [46]
7	Cu_4SnS_4	Anuar et al. [47]
8	(Cd,Bi)S	Mishra et al. [48]
9	$CuGaSe_2$	Lee et al. [49]
10	Cu_2ZnSnS_4	Lin et al. [50]

3. CONCLUSION

In the literature review, an increasing number of publications have reported the preparation of thin films using pulsed laser deposition. In other words, this method could be used to produce binary, ternary and quaternary films effectively by many researchers. Experimental results indicated that the growth parameters influenced the structure, morphology and optical properties of films.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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