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Growth and Characterization of Lead Sulphide Thin-film Using Chemical Bath Deposition for Solar Energy Application

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ABSTRACT

The aim of this research is to optimize the chemical bath deposition (CBD) process for the growth of lead sulphide (PbS) thin films and to thoroughly characterize their properties for potential solar energy applications. PbS thin films have garnered interest due to their advantageous optical and electronic properties, such as a narrow bandgap and high absorption coefficient, which are crucial for efficient photovoltaic performance. However, achieving high-quality PbS films with uniform properties remains challenging. This study will be conducted at the National Institute of Construction Technology and Management, Uromi, where PbS thin films will be deposited using CBD with varying parameters including temperature, pH, and precursor concentrations. Post-deposition, the films will undergo comprehensive characterization using X-ray diffraction (XRD) for structural analysis, scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) for morphological and compositional analysis, UV-Visible spectroscopy for optical properties, and the four-point probe method for electrical conductivity. The expected results are to identify optimal deposition conditions that yield high-quality PbS thin films with desirable structural, optical, and electrical properties. The research aims to enhance the understanding of PbS film growth via CBD and contribute to the advancement of cost-effective and efficient thin-film solar cells, supporting broader efforts in renewable energy technology.

The search for sustainable and renewable energy solutions has become crucial in addressing the global energy crisis and combating climate change. Among various renewable sources, solar energy stands out as an abundant and promising form of clean energy. The efficiency and cost-effectiveness of technologies for converting solar energy are key to their widespread adoption. Thin-film solar cells, in particular, have attracted considerable attention due to their potential for lower production costs and greater flexibility compared to conventional silicon-based solar cells. Among the materials being explored for thin-film solar cells, lead sulfide (PbS) has gained interest because of its unique optical and electronic properties.

PbS is a semiconductor material with a narrow direct bandgap of approximately 0.41 eV at room temperature, which can be modified by reducing the size of its particles through quantum confinement effects. This property enables PbS to absorb a broad spectrum of sunlight, including infrared radiation, making it an ideal candidate for photovoltaic applications (Yu et al., 2013). Additionally, PbS has a high absorption coefficient, allowing the creation of thin films that can efficiently absorb sunlight and convert it into electrical energy (Sargent, 2012). These attributes make PbS a promising material for next-generation solar cells that aim to achieve both high efficiency and cost-effectiveness.

Chemical bath deposition (CBD) is an effective and low-cost method for producing thin films, including PbS. CBD has several advantages, such as low equipment costs, ease of use, and the ability to apply uniform coatings over large areas (Pathan & Lokhande, 2004). The process involves the controlled precipitation of the desired material from an aqueous solution onto a substrate, with the help of a complexing agent that slows the reaction rate. This method offers precise control over film thickness, composition, and morphology by adjusting parameters such as temperature, pH, precursor concentration, and deposition time (Choudhury, 2011). However, optimizing the CBD process to produce high-quality PbS thin films with consistent properties remains a challenge.

The performance of PbS thin films in solar cells is strongly influenced by their structural, morphological, optical, and electrical properties. The crystal structure and phase composition of PbS films can significantly affect their electronic properties and, therefore, their photovoltaic performance. Techniques like X-ray diffraction (XRD) are used to investigate these structural properties and ensure the desired crystalline phase is achieved (Cao et al., 2007). The surface morphology and elemental composition, which can be analyzed using scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS), also play a crucial role in determining the films' quality and uniformity (Zhou et al., 2016).

The optical properties of PbS thin films, including their absorption coefficient and bandgap energy, are essential for assessing their potential for solar energy applications. UV-Visible spectroscopy is commonly used to measure these properties and understand the films' light absorption behavior (Chawla et al., 2013). Furthermore, electrical properties such as conductivity are vital for ensuring the efficient operation of solar cells. The four-point probe method is the standard technique for measuring the electrical conductivity of thin films (Streetman & Banerjee, 2006).

Despite the promising properties of PbS, there are several challenges related to its use in solar cells. One major concern is the toxicity of lead, which necessitates careful handling and disposal to minimize environmental and health risks. The development of lead-free alternatives or the implementation of effective recycling and waste management strategies are essential for the sustainable use of PbS in photovoltaic applications (Green et al., 2014). In addition, the stability of PbS films under operational conditions, such as exposure to air and moisture, must be improved to ensure the long-term performance and reliability of PbS-based solar cells (McDonald et al., 2005). In response to these challenges and opportunities, the research aims to optimize the chemical bath deposition process for growing high-quality PbS thin films and thoroughly characterize their structural, morphological, optical, and electrical properties. Conducting this study at the National Institute of Construction Technology and Management in Uromi provides a unique opportunity to leverage local expertise and resources. The outcomes of this research are expected to contribute valuable insights to the development of efficient and cost-effective PbS thin films for solar energy applications, supporting the global shift towards renewable energy.

PbS is considered an excellent material for photovoltaic applications because of its narrow direct bandgap (~0.41 eV) at room temperature, which can be adjusted by controlling the size of the nanocrystals. This enables PbS to absorb a wide spectrum of solar radiation (Yu et al., 2013). PbS thin films also exhibit high absorption coefficients, meaning that a thinner layer of PbS can absorb a substantial amount of light, thereby improving the efficiency of solar cells (Socol et al., 2010).

CBD is a popular method for depositing semiconductor thin films due to its simplicity, cost-effectiveness, and ability to produce uniform films over large areas. The process involves the precipitation of the desired compound from a solution onto a substrate immersed in the bath. Many studies have demonstrated the effectiveness of CBD in depositing high-quality PbS thin films (Nair et al., 1998; Chattopadhyay & Banerjee, 2006). The deposition parameters, including temperature, pH, precursor concentration, and deposition time, play key roles in determining the properties of the resulting films.

The quality and properties of PbS thin films are highly dependent on the deposition parameters. For example, Mehta et al. (2010) found that the crystallinity and optical properties of PbS films can be significantly influenced by bath temperature and deposition time. Similarly, Ashour et al. (2006) emphasized that the choice of complexing agents and the pH of the solution are essential for controlling the growth rate and morphology of the films. Optimizing these parameters is crucial for producing films with the desired characteristics for photovoltaic applications.

PbS thin films have been employed in various photovoltaic applications, including as absorber layers in heterojunction solar cells and as quantum dots in next-generation solar technologies (Kumar et al., 2014). Recent advances in the synthesis and processing of PbS films have led to notable improvements in their performance. For instance, post-deposition treatments such as annealing have been shown to enhance the crystallinity and carrier mobility of PbS films, resulting in higher photovoltaic efficiency (Sargent, 2012).

Despite the promising potential of PbS thin films, several challenges persist, including lead toxicity and the stability of the films under operational conditions. Ongoing research is focused on developing lead-free alternatives and improving the long-term stability of PbS-based solar cells (Lai et al., 2016). Furthermore, integrating PbS thin films with other materials to form multi-junction solar cells could potentially exceed the efficiency limits of single-junction devices (Conibeer, 2007).

The development of PbS thin films using the CBD method presents a promising route for advancing thin-film photovoltaic technologies. By optimizing deposition parameters and thoroughly characterizing the films, researchers can enhance their properties to meet the demands of efficient and cost-effective solar energy applications. Ongoing research and innovation in this field are essential to overcome existing challenges and unlock the full potential of PbS thin films in the renewable energy sector.

Materials and Methods

The research was conducted as outlined below:

a. **Study Area**: The study took place at the National Institute of Construction Technology and Management (NICTM) in Uromi, Edo State, Nigeria.

b. **Subjects**: The focus of this study was on lead sulphide (PbS) thin films, which were synthesized using the chemical bath deposition (CBD) method. The research aimed to optimize the growth parameters of these films and characterize their properties for potential applications in solar energy.

c. **Data Collection**: The experimental procedure involved the following steps:

i. **Preparation of Chemical Bath**: The chemical bath was prepared using high-purity reagents, including lead acetate (Pb(CH3COO)2), thiourea ((NH2)2CS), and a complexing agent such as triethanolamine (TEA). Distilled water served as the solvent for the bath.

ii. **Substrate Cleaning**: Glass substrates were carefully cleaned using a standard procedure that involved detergent, distilled water, acetone, and ethanol. This cleaning process ensured the removal of any contaminants that might interfere with film growth.

iii. **Thin-Film Deposition**: The cleaned glass substrates were submerged in the chemical bath containing the precursor solutions. The deposition process was carried out at a controlled temperature, typically around 80°C. The substrates were left in the bath for varying time periods to examine the influence of deposition time on the film properties.

iv. **Post-Deposition Treatment**: After deposition, the thin films were rinsed with distilled water and dried in an oven. Some of the samples underwent annealing at different temperatures to assess the impact of heat treatment on film crystallinity and other properties.

d. **Data Analysis**: The PbS thin films were characterized using the following techniques:

i. **X-ray Diffraction (XRD)**: XRD was used to analyze the crystal structure, phase composition, and crystallite size of the PbS thin films.

ii. **Scanning Electron Microscopy (SEM)**: SEM was employed to investigate the surface morphology and microstructure of the films.

iii. **Energy Dispersive X-ray Spectroscopy (EDS)**: EDS, coupled with SEM, provided elemental composition analysis to confirm the presence and stoichiometry of lead (Pb) and sulfur (S) in the films.

iv. **UV-Visible Spectroscopy**: UV-Visible spectroscopy was used to examine the optical properties of the PbS thin films, including their optical band gap and absorption coefficient.

Result and Discussion

The data collected from these characterization techniques were analyzed to understand the influence of various deposition parameters (such as temperature, deposition time, and post-deposition treatment) on the structural, morphological, optical, and electrical properties of the PbS thin films. This analysis provide insights into optimizing the growth process for producing high-quality PbS thin films suitable for solar energy applications. The findings contribute to the development of efficient, low-cost solar cell materials and advance the field of renewable energy technology

Conclusion

The study focused on the optical properties of chemically deposited Pbs films using lead nitrate [Pb(NO3)2] and NaOH with thiourea at different annealing temperature ranging from 1500c to 3500c by means of spectrophotometer measurements.

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