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Morphology and electrical properties of photosensitive films based on PbS

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ABSTRACT

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Introduction

The development of civilization is accompanied by the steady increase in energy consumption. Issues related to the provision of electricity to the provincial areas are highly relevant to Egypt. One solution is to convert solar energy into electricity. Indeed, on the surface of the Earth in one hour falls approximately 4.3×10^{20} joules of solar energy, which is about the total consumption of energy on the planet in one year. Most of this energy is emitted in the form of electromagnetic radiation in the range of 0.2-3.0 microns. In addition, about 30% of the radiation falls on the infrared (IR) region of 1-3 microns.

However, the part of the electricity obtained by conversion of solar radiation is less than 1% of the total energy consumed in the world. The main reasons behind this are the high cost of solar energy conversion and their relatively low efficiency.

Currently, the most promising technology are the so-called multijunction photovoltaic cells (tandem or triplet), consisting of sequentially deposited two or three subcells with different band gap semiconductors. The efficiency of such elements is significantly higher than that of conventional solar cells.

While, wide-gap semiconductors for tandem solar cells are under intensive investigation, less work related to IR region has been reported. In this context, we proposed to use photosensitive films, which provide better absorption and so conversion of infrared spectrum. One of the best-proposed materials to be used is the narrow-gap semiconductor PbS. This material was used in photoresistors since 30th of the 20th century, as well as in gas sensors, and other different applications. Despite the long time using this material, as detectors and the massive work that has been done on this topic, many issues related to physical work of photosensitive films are still unclear. In this respect, our work aims to explain that particular point and more information will be presented.

Aim of the work

The aim of the work was to study the morphology, electrical properties and composition of photosensitive films based on PbS produced by different technological methods with the help of state-of-the-art equipment to explain the change in parameters and characteristics of photosensitive films. Moreover, we aimed to assess the possibility of using these films in tandem solar cells and other fields. In order to achieve this plan, the following tasks have been successfully done

1. Studying morphology, electrical properties and composition of photosensitive films based on PbS,
2. Finding the correlation between physical parameters and characteristics of photosensitive films and their morphology,
3. From this study, we can optimize the technology process, suitable for the formation of tandem solar cells based on photosensitive PbS films and multi-element matrices (Infrared System "beholder" type).

Research techniques

The object of research was studying the photosensitive PbS films as an important type of lead chalcogenides (semiconductors of the group A^4B^6). The studied PbS films were synthesized by two different experimental techniques, namely chemical vapor deposition (CVD) and physical vapor deposition (PVD). The morphology and the crystallography of the PbS polycrystalline thin films were studied by atomic force microscopy, scanning the surface and energy dispersive microanalysis (EDXS) and high-resolution transmission electron microscopy (HRTEM). Electrical characterization, noise power spectral density **(**NPDS**)** and DLTS analysis of those films were studied by using computerized system based on K54.410 and ASEC-03, in addition to constructing the corresponding models. Finally, we assess the reliability of the results and compare it with literature studies.

Scientific novelty of the work

1. Appearance of the second phase in the PbS films synthesized by CVD is due to bonding between lead and carbon, as expected (G.A. Kitaeva). It is shown that the formation of this phase will decrease the sensitivity in short-wave region of the spectrum.
2. The change in the spectrum peaks of charge deep level transient spectroscopy (Q- DLTS) is due to the sensitivity of PbS films to interacted ethanol. The trapping centers created by physical adsorption of non-bonded oxygen may cause this sensitivity.
3. The partial appearance of generation-recombination noise with $1/F^{\alpha}$ noise in noise power spectral density for CVD synthesized films may be due to the presence of non-bonded oxygen .
4. Investigation of the surface morphology of PbS films using AFM reveal that, the decrease in reflection coefficient up to 20% (instead of 37%, arising from the fundamental properties of this material), due to the presence of surface roughness up to 1.5 microns.
5. Increasing the concentration of chemically bonded oxygen in the CVD-synthesized films, on one hand leads to increase in the resistance of photosensitive films, and on the other hand shift the long-wavelength sensitivity to shorter wavelengths due to the Moss Burstein effect, which has been known in the structures based on InSb.

Conclusion

1. Films of lead sulfide can be used in various fields of application, but for each individual case it must have strongly defined structure of the films and its corresponding physical properties:
   1.1. For gas sensors should be used with thin layers of fine (unannealed) structure;
   1.2. For photodetectors when sensitivity is important (high excess hole concentration) must be added to the films bonded and non-bonded oxygen to form acceptor states at the boundaries of the crystallites, as well as other methods of forming electron traps;

1.3. For tandem solar cells where the sensitivity in the visible and infrared regions of the spectrum is important, the lower layer can be used as polycrystalline films of PbS semiconductor having a block structure with a reduced influence of the surface and minimum distortion of the crystal lattice. On the other hand, quantum dots of PbS can be used to construct the upper layer, with particular consideration must be given to changes in the structure of PbS during the transition to nano-scale structure and quantum dots structure.

2. When developing structures based on lead sulfide for using in various fields for example optoelectronics (photoresistor fluorescent quantum dot structures and others) must be clearly understood the role and influence of oxygen on the characteristics of the photosensitive films.
   2.1. Increasing impurities of oxygen concentration inside photosensitive films, will increases the resistance, therefore the spectral characteristics "maximum spectral characteristic" will be shifted to short-wavelengths, increasing the sensitivity of the device.
   2.2. For photosensitive films with low impurity of oxygen concentration, the charge carrier lifetime will be decreased, thus leads to improvement of frequency characteristics of devices.