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Cite as: AIP Conference Proceedings **2432**, 050025 (2022); <https://doi.org/10.1063/5.0089906>
Published Online: 16 June 2022

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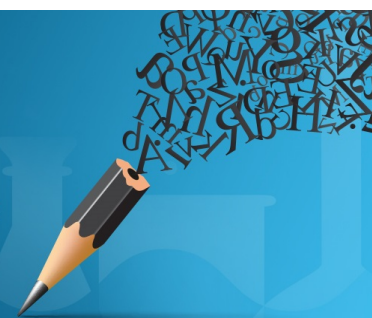


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Chemical Element Distribution of Cadmium Sulfide Obtained on Silicon Substrate

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Abstract. The injection photodiode based on $n^+CdS-nCdS-nSi$ and $n^+CdS-nCdS-pSi$ structures was created and the distribution of chemical elements of these structures was studied. It was shown that when a cadmium sulfide film is deposited on the silicon surface, an intermediate layer is formed between the silicon and cadmium sulfide, which helps smooth out the difference between the crystal lattice constants of silicon and cadmium sulfide. It was proved by electron Auger spectroscopy that all obtained cadmium sulfide films have n-type conductivity.

Keywords. Injection, current, photodiodes, cadmium.

INTRODUCTION

High integral and spectral photosensitivity of photodiodes in the transmission direction has been found in diodes made of germanium with an admixture of gold (Ge(Au)) at liquid nitrogen temperature [1-3]. The base resistance of the p^+-i-n^+ structure decreases when illuminated by light. And this in structures leads to redistribution of applied bias voltage. At the p-n junction the voltage increases, the injection of charge carriers into the base increases, which further reduces its resistance. The current transfer mechanism for injection amplification consists precisely in this, which amplifies the primary photocurrent due to the implementation of positive feedback (PFF). In injection photodiodes, there is another photocurrent amplification mechanism [4-9], the so-called parametric amplification. A nonequilibrium plasma of electrons and holes inhomogeneously distributed in space is created by the injection of charge carriers into the volume of a compensated semiconductor (semi-insulator) [10]. When the illumination power increases, the concentration of charge carriers increases, illumination and affects the parameters determining their distribution in the base region (lifetime, bipolar drift mobility, bipolar diffusion coefficient, etc.). Lifetime, mobility, and diffusion coefficient depend on the intensity of impurity illumination, which directly changes the filling of impurity centers. Therefore, the conductivity of the base region changes, there is a redistribution of voltage between the base and the p-n junction, an additional increase in injection, etc. It is this effect that makes the main contribution to enhancing the primary photocurrent in injection photodiodes made from germanium, silicon, and gallium arsenide.

Industry produces a large number of types of photodetectors with high sensitivity, for example, avalanche photodiodes [6]. However, their spectral range of sensitivity is limited by the intrinsic photosensitivity of the materials from which they are made. For the detection of light signals in the infrared regions of the spectrum, along with narrow-band semiconductors, impurity semiconductors are widely used. Practically only photoresistors are receivers of radiation exhibiting sensitivity in the impurity region of the spectrum. Hence, it follows that exactly IFDs, which can be represented as photoresistors controlled by injection from contacts, can be photodetectors with high sensitivity in the spectral range, from the ultraviolet (UV) to the far infrared (IR) region.

METHODS AND RESULTS

This paper presents the results of studies of $n^+CdS-nCdS-nSi$ structures. Such heterostructures were created by sputtering CdS powders in a quasi-closed system in a vacuum of 10^{-5} torr onto the surface of an n- and p-type silicon wafer with a thickness of 300-400 μm . These studies with the MII-4 microscope show that the CdS films consist of columnar crystallites (grains). A heavily doped n^+CdS layer with a thickness in the order of 500 \AA was formed by vacuum deposition of indium(In) atoms on the surface of the CdS film.

The lattice constants a , of cadmium sulfide and silicon with hexagonal modification ($a_{CdS}=5.84\text{\AA}$) and Si ($a_{Si}=5.43\text{\AA}$) differ by almost 7%, and to obtain heterojunction with low density of surface states their difference should not exceed 4% [11]. However, the above experimental facts indicate that there are low density surface states at the interface of contacting semiconductor materials. When obtaining a film of cadmium sulfide on the surface of silicon, it is assumed that an intermediate layer is formed between these layers, which helps smooth out the difference between the crystal lattice constants of silicon and cadmium sulfide. Therefore, in order to know the composition of this layer we investigated the distribution of chemical elements of the $n^+CdS-nCdS-nSi$ structure on the thickness of the film, which was carried out on its chipping. The measurement was carried out on the microanalytical complex Jeol - JXA - 8900 with EDS LINK ISIS (energy dispersion spectrometer); the error of measurements was $\pm 2.0\%$ (Figure 1).

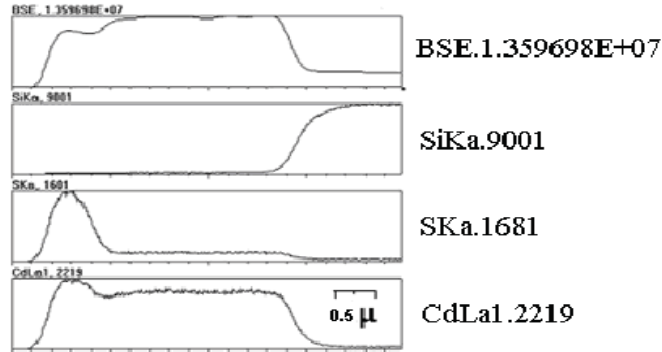


FIGURE 1. Chemical element distribution of $n^+CdS-nCdS-nSi$ structure

Measurement conditions: $V=20$ kV, $I=10$ nA. Standards: native Cd, and Si, for S - synthetic FeS. Measurement results and microphotography show that the elements of Cd, S and Si at the interface decrease sharply to almost zero at a distance of $\approx 1\mu m$ across the film thickness. It follows that there is an intermediate layer between cadmium sulfide and silicon of the order of one micrometer thickness. Determination of the components of this solid solution is the object of further research.

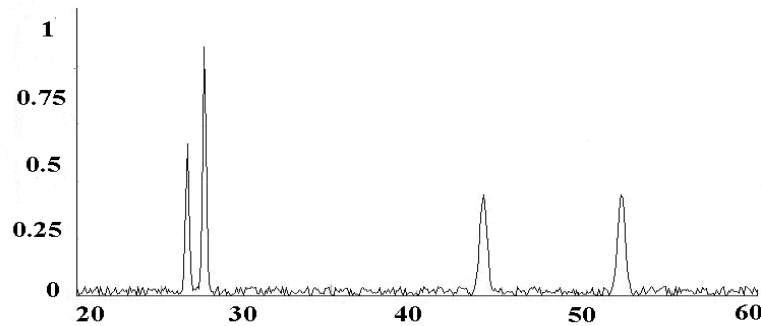


FIGURE 2. Structure composition of cadmium sulfide films.

To, find out the composition of the structure X-ray analysis and chemical composition for n⁺CdS-nCdS-pSi structure was investigated. Structural studies of the grown CdS films were performed on a diffractometer $CuK\alpha$ ($\lambda = 1,54 \text{ \AA}$). The experimental data show that the cadmium sulfide films, without the impurity composition of indium, contain 4 peaks, which, as follows from [12], are characteristic of the CdS hexagonal phase (Figure 2).

Experimental data of cadmium sulfide films, with an admixture of indium, contains 6 peaks (Fig.3.). According to the literature data [12], peaks 1, 2, 5, and 6 are characteristic of cadmium sulfide, peak 3 corresponds to the compound CdO (111) [12]. And the fourth peak is characteristic for compound SiO.

When obtaining vacuum-sprayed cadmium sulfide films, the CdS film may contain inclusions of cadmium oxide and silicon oxide.

To find out what chemical elements cadmium sulfide films contain when obtained on the surface of silicon, we investigated the chemical composition of CdS by electron Auger spectroscopy. Experimental data shows that the surface of CdS films for all samples was identical, and the different intensities of the spectrum is due to differences in the concentration of chemical elements included in the film.

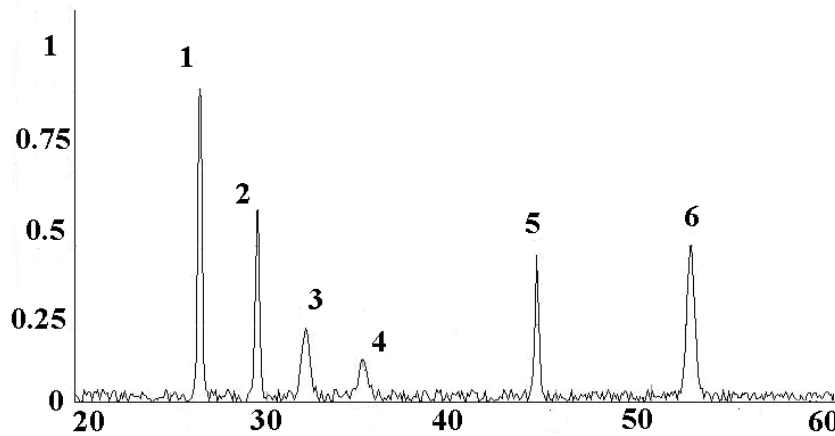


FIGURE 3. X-ray analysis of the surface of CdS films containing In impurity.

The In impurity was registered in the spectra of samples 1 and 2 when obtaining the top contact on the surface of cadmium sulfide films. What in the samples the concentration of In was below the sensitivity limit of Auger spectrometer.

On the basis of the obtained experimental data by Auger spectrometer method we calculated atomic concentrations of chemical elements S, Cd, Cl, C, O, In included in CdS film (Table 1).

TABLE 1. Atomic concentrations of chemical elements in CdS films.

Sample number	Atomic concentration, %					
	Cd	S	Cl	C	O	In
1	36.9	45.9	10.6	4.1	1.8	0.7
2	40.8	46.5	6.1	4.2	1.6	0.8

CONCLUSION

These data show that all samples have excessive concentration of sulfur with respect to cadmium. According to [13] the opposite situation should be observed for CdS: the presence of sulfur vacancies and an excess of cadmium. This is the reason for the n-type conductivity of CdS [13]. The observed situation can be explained by the fact that the method of electron Auger spectroscopy fixes the chemical composition of the film and does not give an answer to the question what share of impurity is electrically active. Since the obtained CdS films on all samples have n-type conductivity, it can be assumed that not all of the observed sulfur impurity is electrically active. The

excess of sulfur could be due to the presence in the CdS film of intermediate reaction products that were not removed during the etching and washing of the samples.

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