Features of the electrical properties of ZnO:Al/ZnS/*n*-CdTe heterojunctions

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Introduction

Efficient thin-film solar cells based on Cu(In,Ga)Se_2 (CIGS), Cu_2ZnSnS_4 (CZTS), and CdTe are obtained by using a thin CdS buffer layer [1]. One of the alternative semiconductors for the buffer layer is zinc sulfide (ZnS) [2]. This is due to such properties as non-toxicity, wide band gap E_g=3.6 - 3.8 eV, high refractive index (n = 2.35), high transmittance T = 85 %. This paper presents the results of a study of the electrical properties of ZnO:Al/ZnS/*n*-CdTe heterojunction structures obtained by depositing thin films of ZnO:Al and ZnS onto crystalline *n*-CdTe by high-frequency magnetron sputtering.

Experimental technique

For the fabrication of heterostructures, plane-parallel plates of the CdTe base material (thickness $d \approx 1$ mm) were used, which were made by chipping from ingots obtained by the vertical Bridgman method. The crystals were characterized by the electronic type of conductivity. They had kinetic parameters (at T = 300 K): electrical conductivity $\sigma \approx 50\ \Omega^{-1}\cdot cm^{-1}$, electron concentration $n = 4\cdot10^{17}\ cm^{-3}$ and their Hall mobility $\mu_H = 760\ cm^2\cdot V^{-1}\cdot s^{-1}$. Heterostructures were produced by sequential sputtering of thin films of ZnS (thickness ~ 0.2 μm) and ZnO:Al (thickness ~ 0.1 – 0.15 μm) on the surface of *n*-CdTe plates. Sputtering was carried out in a Leybold-Heraeus L560 universal vacuum unit by high-frequency magnetron sputtering of zinc sulfide and aluminum-doped zinc oxide targets in an argon atmosphere. Current-voltage characteristics (IVC) of heterostructures were measured using a hardware-software complex implemented on the basis of the Arduino platform, an Agilent 34410A digital multimeter, and a Siglent SPD3303X programmable power source. Capacitance-voltage characteristics (CVC) were measured using an LCR Meter BR2876.

Experimental results and their discussion

The current-voltage characteristics of the ZnO:Al/ZnS/*n*-CdTe heterojunction structures (obtained at forward and reverse voltages in the temperature range T = 294 – 337 K) showed their rectifying properties (Fig. 1). The series resistance of the structures $R_S = 1.8\cdot10^3$ Ohm is due to the formation of a CdS_xTe_{1-x} solid solution in the near-surface region of cadmium telluride. The linear nature of the forward branches of the *I-V*-characteristics $I \sim V^m$ (obtained on a double logarithmic scale) is typical for space-charge-limited currents (SCLC) (Fig. 2). Such currents appear in high-resistance semiconductors and dielectrics due to the injection of minor charge carriers when their concentration exceeds the concentration of equilibrium charge carriers. In the studied ZnO:Al/ZnS/*n*-CdTe heterostructures, the manifestation of such a current transfer mechanism is due to the presence of a high-resistance CdS_xTe_{1-x} layer. The decrease in the value of m observed with increasing temperature is explained by an increase in the intensity of thermal generation of charge carriers from shallow traps to the corresponding zone.

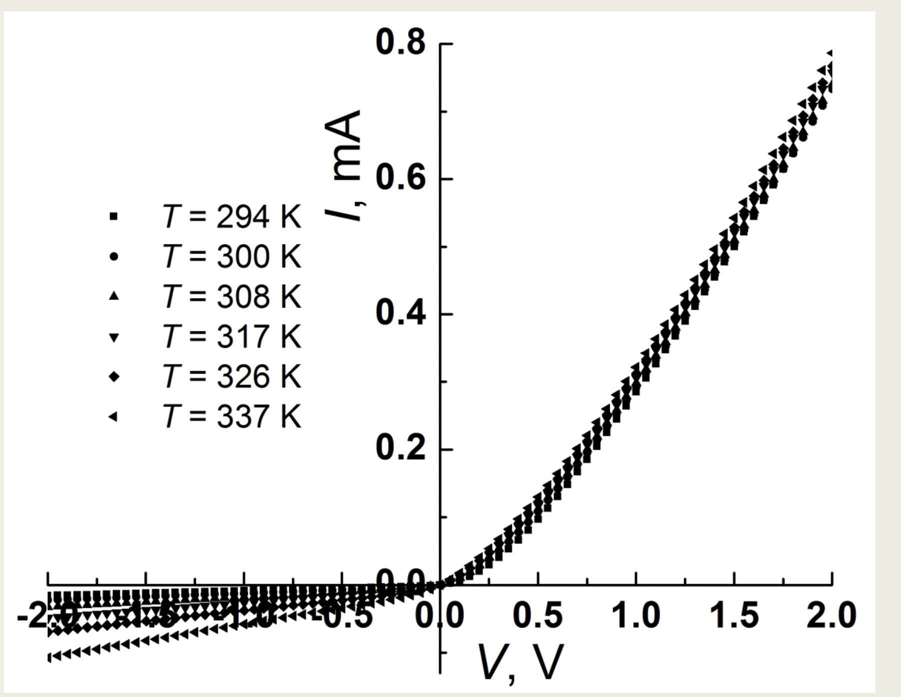

Fig. 1. *I-V*-characteristics of the isotype ZnO:Al/ZnS/*n*-CdTe heterostructure in the temperature range from 294 K to 337 K.

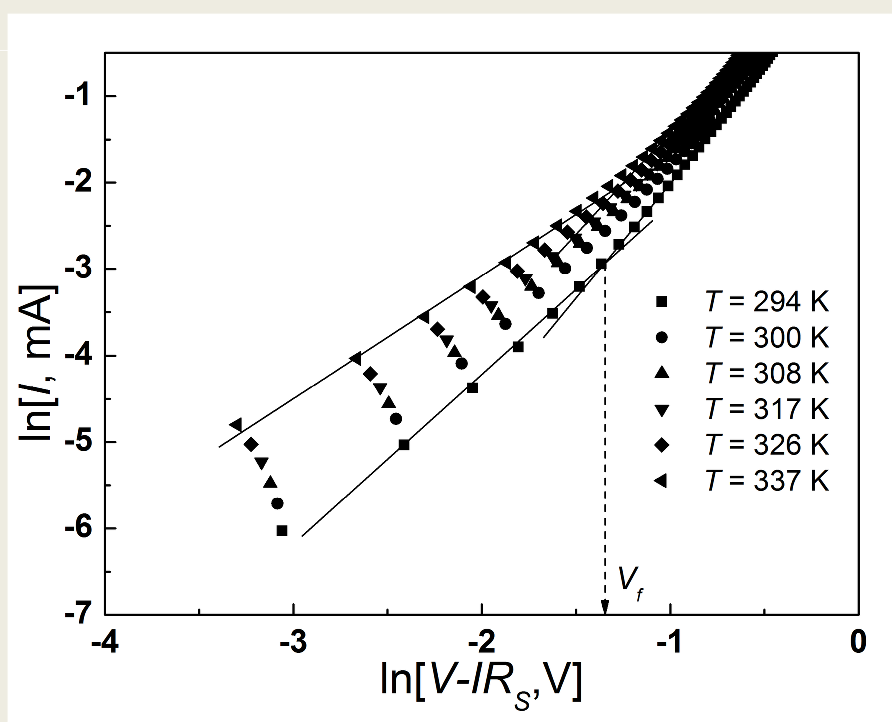

Fig. 2. Forward *I-V*-characteristic's branches of the ZnO:Al/ZnS/*n*-CdTe heterostructure on a double logarithmic scale

The height of the potential barrier $q\varphi_b$ (estimated from the *I-V*-characteristic by the cut-off voltage) was 0.72 eV. $q\varphi_b$ decreased linearly with increasing temperature. The temperature coefficient was $d(q\varphi_b)/dT = -2.8\cdot10^{-3}$ eV/K. The energy diagram of the ZnO:Al/ZnS/*n*-CdTe heterostructure in the state of thermodynamic equilibrium (Fig. 3) is built on the basis of the experimental $q\varphi_b$ value and the energy parameters of the contacting materials. The energy states at the ZnS/*n*-CdTe heterojunction interface play a decisive role in the appearance of the electron-depleted region in *n*-CdTe and the formation of the energy barrier.

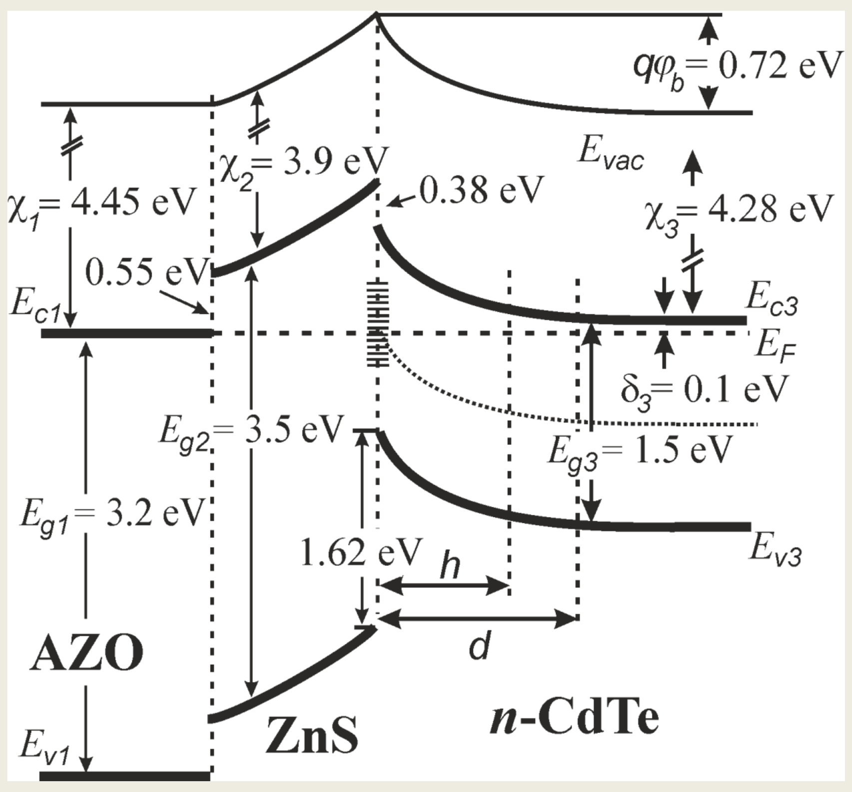

Fig. 3. Energy diagram of the isotype ZnO:Al/ZnS/*n*-CdTe heterostructure.

A feature of the *C-V*-characteristics of the ZnO:Al/ZnS/*n*-CdTe heterostructure is the independence of the capacitance from the value of the reverse voltage and the change in its value with a change in the frequency of the excitation signal (Fig. 4). The structure has an inversion layer at zero bias (Fig. 3), whose capacitance increases at reverse bias. The smaller capacitance of deep traps ΔE = 0.76 eV of the CdS_xTe_{1-x} layer (which determines the total capacitance at V < 0 V) is connected in series with the capacitance of the inversion layer. The shift of the minimum of the $C = f(V)$ dependence at forward voltages is due to the effect of charges in the ZnS film.

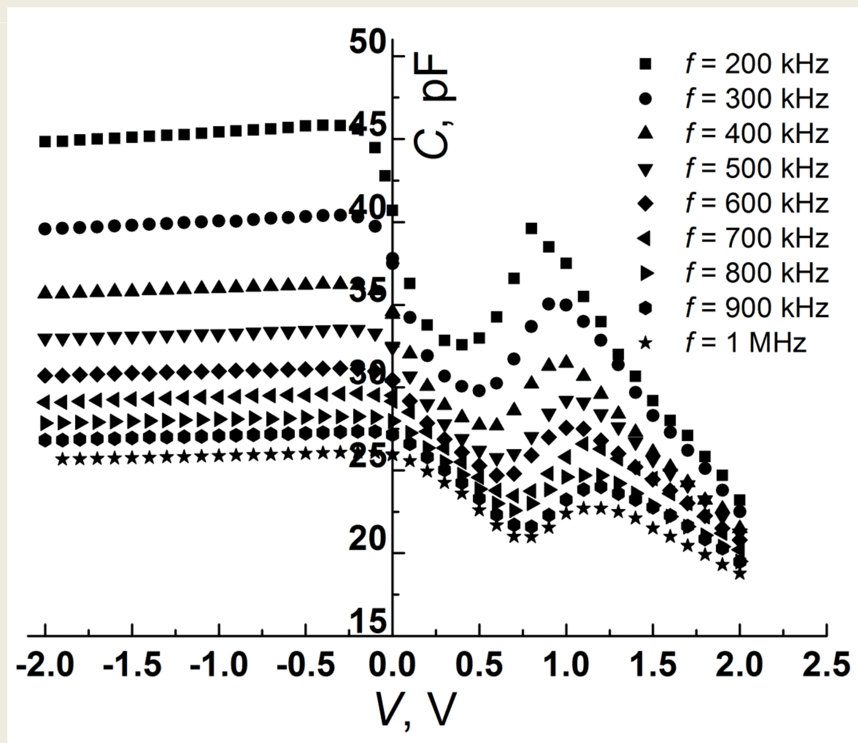

Fig. 4. *C-V*-characteristics of the ZnO:Al/ZnS/*n*-CdTe structure in the frequency range f = 200 – 1000 kHz.

Conclusions

ZnO:Al/ZnS/*n*-CdTe heterostructures are fabricated by successive deposition of ZnO:Al and ZnS thin films on the surface of freshly cleaved monocrystalline *n*-CdTe substrates by high-frequency magnetron sputtering and possess diode properties and contact potential difference of 0.72 V. The *I-V*-characteristics of the studied structures in the region of positive voltages agree well with the theory of space-charge-limited currents, the occurrence of which is due to the formation of CdS_xTe_{1-x} solid solutions with high resistance in the near-surface region of the base. The features of *C-V*-characteristics of the studied heterojunctions under reverse biases - the independence of the measured capacitance from the voltage value and the change in its value with a change in the frequency of the alternating signal are in satisfactory agreement with the effect of the high-resistance layer of the CdS_xTe_{1-x} solid solution formed in the ZnO:Al/ZnS/*n*-CdTe heterostructure during production.

References

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2. Syed Asfandyar Ali Kazmi, Aimal Daud Khan, Adnan Daud Khan, Abdul Rauf, Waqas Farooq, Muhammad Noman, Haider Ali, Efficient materials for thin−film CdTe solar cell based on back surface field and distributed Bragg reflector, Appl. Phys. A 126 (2020) 46.