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PHOTO-EFFECTS IN In/p–$CuInSe_2$ SCHOTTKY-TYPE JUNCTION *

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The voltage-dependent photocurrent and the short-circuit photocurrent generated by the modulated light in the In/p–$CuInSe_2$ junction were measured. The results suggest that the recombination of carriers occurs in the metal–semiconductor interface as well as in the recombination centres present in the space charge region of the junction. Both the interface recombination and the recombination in the centres can be modified by illumination of the junction.

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Many researches reported the results of studies of various physical properties of $CuInSe_2$ and its application possibilities (e.g. [1–4]). Some electric and photovoltaic properties of the In/p–$CuInSe_2$ Schottky barrier junctions were reported in [5–8]. In this paper the results of study of the collection efficiency of the In/p–$CuInSe_2$ junction are presented for the first time. The crystals used for fabrication of the junctions were grown by the Bridgman method [9]. Monocrystalline plates of sizes $3 \times 3 \times 0.1\,\mathrm{mm}$ were cut from ingot. They were polished mechanically and chemically in H_2SO_4:$K_2Cr_2O_7$ water solution. The rectifying In and ohmic Au contacts were made by vacuum evaporation of these metals onto opposite surfaces (planes (112)[10]) of the p–$CuInSe_2$ monocrystalline plate.

The measured dark current–voltage ($J - U$) characteristic for the typical junction obeys the law $J = J_0 \exp(qU/kT)$ for forward bias ($U > 2kT/q$), where the saturation current density $J_0 = 0.25\,\mathrm{mA\,cm^{-2}}$, and the diode quality factor $m = 1.7$ at room temperature (q is the electron charge).

In order to describe the photovoltaic properties of the p–n hetero-junction Rothwarf et al. [11, 12] developed theory of the "light" $J - U$ characteristic using new parameter called the collection efficiency of the junction. This parameter is assumed to be dependent on the interface recombination of carriers. The collection

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efficiency is defined by $\eta = J_L/J_{sc}$, where $J_L = J_D(U) - J(U)$ is voltage-dependent photocurrent, J_{sc} is the short-circuit photocurrent, $J_D(U)$ is the diode current under illumination, and $J(U)$ is the total diode current. The collection efficiency may be determined from the results of measurements of the currents J_L and J_{sc} generated by the modulated light [11, 12]. We assume that this theory, after its modification, can also be used for description of the electronic properties of the metal–semiconductor (m–s) Schottky-type junction. In order to determine the collection efficiency of the In/p–$CuInSe_2$ junction the measurements of the photocurrents J_L and J_{sc} generated with monochromatic and white light were performed. In the measurements we used a mechanical light chopper for the modulation of light intensity (L) and a phase sensitive detection system. The chopper frequency was 40 Hz. All measurements were done at room temperature ($T = 297$ K).

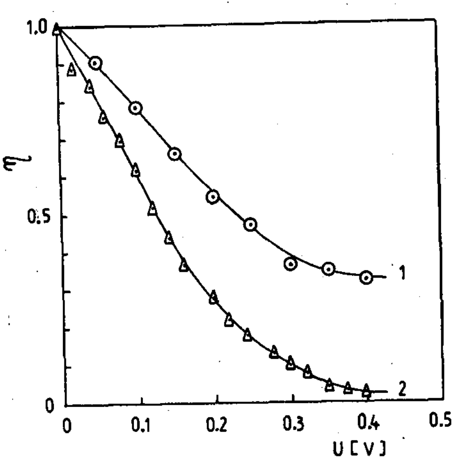

Fig. 1. Dependence of collection efficiency of a In/p–$CuInSe_2$ junction on voltage (forward bias) for (1) weak ($L = 0.75\,\mathrm{mW\,cm^{-2}}$) and (2) strong ($L = 60\,\mathrm{mW\,cm^{-2}}$) modulated illumination with white light.

Figure 1 shows the collection effeciency of the In/p–$CuInSe_2$ junction as a function of voltage for the weak and strong white light illumination. The collection effeciency decreases with increasing forward bias ($\eta = 0.67$ for $U = 0.15$ V and $L = 0.75\,\mathrm{mW\,cm^{-2}}$). Under the strong illumination of the junction the collection efficiency is reduced ($\eta = 0.41$ for $U = 0.15$ V and $L = 60\,\mathrm{mW\,cm^{-2}}$). The effects of voltage and strong illumination can be interpreted as the result of increase of the m–s interface recombination. According to the Rothwarf theory [11, 12] the collection efficiency decreases with voltage, when the increase of interface recombination is due to the change in charge on the p–n interface.

On the other hand, the results of measurements of the dependence of the short-circuit current (J_{sc}) of the junction on the white light illumination intensity (L) can not be explained by this theory. Namely, there is observed the supralineary

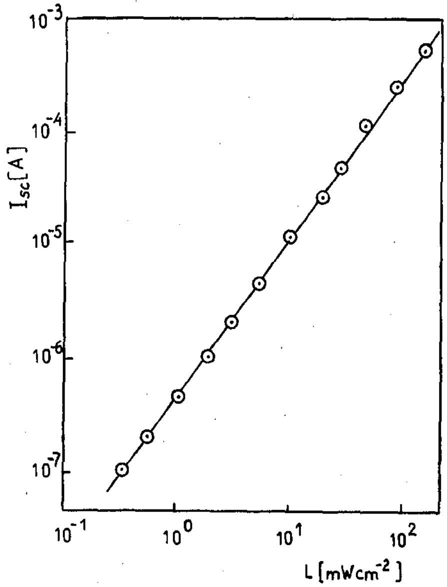

Fig. 2. Dependence of short-circuit photocurrent of a In/p–$CuInSe_2$ junction on white light intensity at room temperature.

dependence of the J_{sc} on L^{α} with $\alpha = 1.4$ (Fig. 2). This dependence shows that the minority carrier diffusion lenght (L_D), and , of course, the minority carrier life-time increase due to increasing illumination intensity of the junction (see theory of the dependence of J_{sc} on L and L_D for the m–s junction [2, 13]). In our opinion it can be understood as being the result of ionization of recombination centres in the crystal by photo-generated carriers. It should be noticed that our previous photo-capacitance measurements also provide indications on the photoionization of the centres in the space charge region of the In/p–$CuInSe_2$ junction [8]. In conclusion, the experimental results presented above show that the electronic properties of the interface layer and the space charge region in the In/p–$CuInSe_2$ junction can be modified by illumination.

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