Vol. A57 (1980) ACTA PHYSICA POLONICA No 6

THE PHENOMENON OF PHOTOEMISSION MODULATION BY INFRARED ILLUMINATION

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(Received July 9, 1979; revised version received October 15, 1979)

The influence of additional excitement of the monocrystals, GaAs, with infrared on external photoemission was investigated. Under the influence of infrared the shifting of current-voltage characteristics to the right for samples of the n-type was observed while a smaller shifting to the left for samples of the p-type was found. It was shown also that the saturation photocurrents of some samples of the n-type were slightly larger under the influence of infrared illumination. An attempt to interprete the influence of additional illumination on the change in the hight of the surface band bending was made.

1. *Introduction*

The modulation of the current-voltage characteristics of photoemission can be obtained by the Schottky effect or by treatment with such radiation that does not induce photoemission but only causes a shift of carriers near surfaces of semiconductors. This second effect in semiconductors having a large energy gap is distinct. This was studied at first by Szuba [1] in monocrystals of CdS and later by Łagowski and collaborators [2] in a somewhat different way but also using CdS crystals.

In this paper a number of GaAs samples excited by ultraviolet and infrared radiation were subjected simultaneously.

The energies from additional illumination were not less than the width of the energy gap of the semiconductors that is, for CdS of 2.5 eV and for GaAs this was 1.4 eV. The author also observed a phenomenon in GaAs monocrystals of the n and p-types using as a source of infrared radiation a 750 W Tungsram lamp covered by an 802 filter having a maximal transmission of 802 nm and with a half width ~150 Å.

The measurements of photoemission currents with additional illumination from two GaAs samples of the n-type with an orientation (100) for five values of the ultraviolet photon energy were performed, and from two GaAs (111)-oriented samples for three photon energies. Also some samples of the p-type having orientations (111) and (113) as well as a polycrystal were investigated.

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2. *Experimental method and the results*

The current-voltage, photoemissive characteristics were measured in a spherical capacitor [1, 3]. The retarding potential method was used. The capacitor was evacuated and the pressure during the experiments did not exceed $2 \cdot 10^{-8}$ Torr.

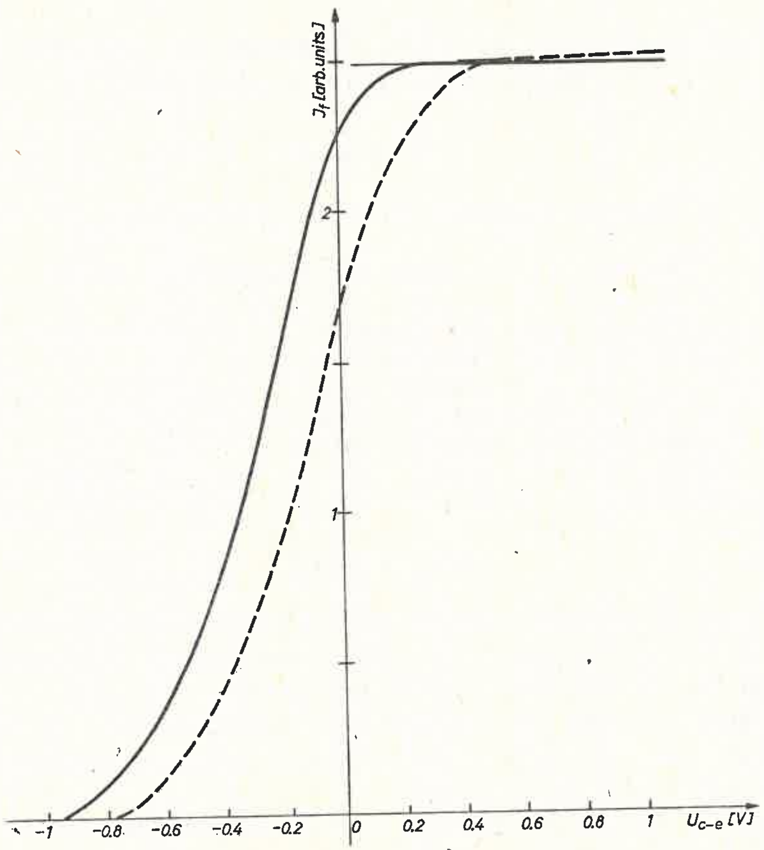


Fig. 1. Shift of the current-voltage photoemissive characteristics under the influence of additional illumination ($h\nu$ = 4.89 eV) of the n-type GaAs sample with orientation (100). The dashed line is the characteristic for infrared irradiation

A. Samples of the n-type

In figures 1, 2 some of the curves for samples of the n-type with orientations (100) and (111) are shown. Many results concerning the photoemission modulation were published previously [3]. The curves suggest the following:

a) after additional illumination a parallel shift in the current-voltage photoemission characteristics to the right occurs,
b) an increase in the contact voltage collector-emitter arises,
c) a small increase in the saturation current occurs on subjecting it to infrared radiation.

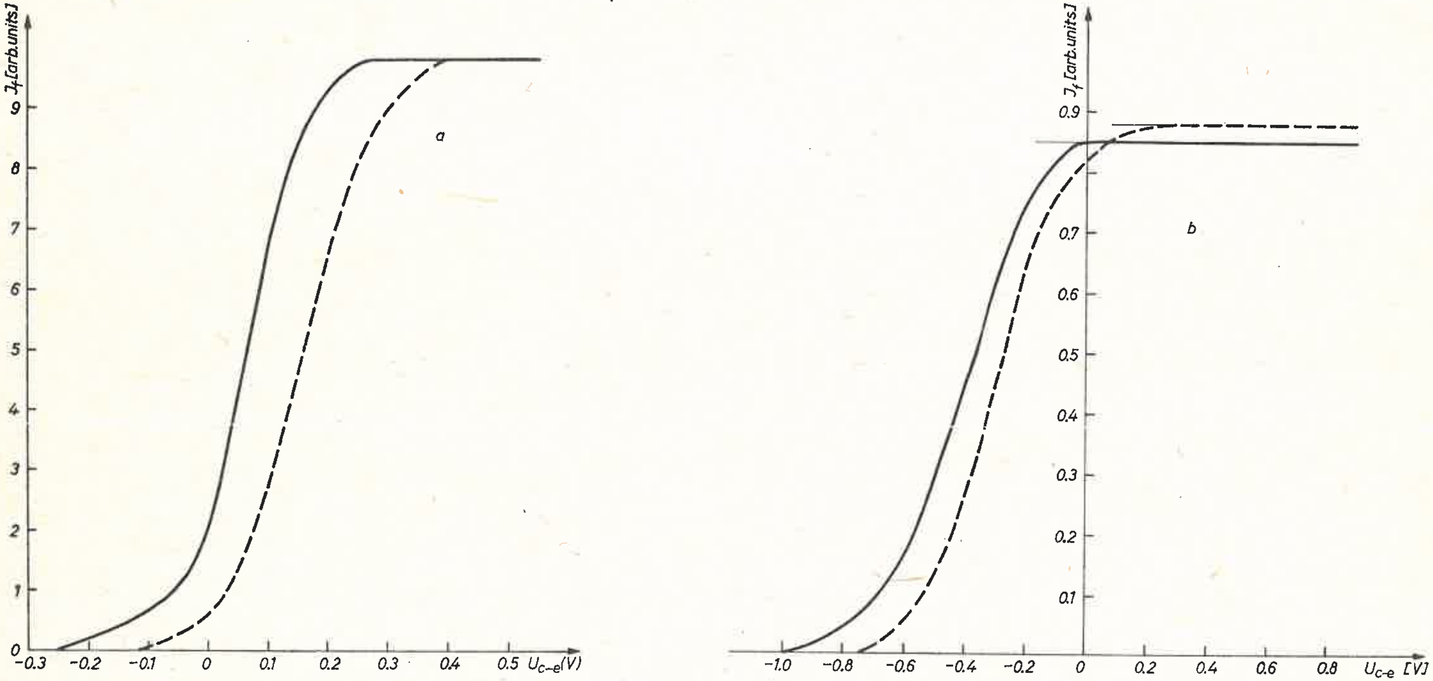
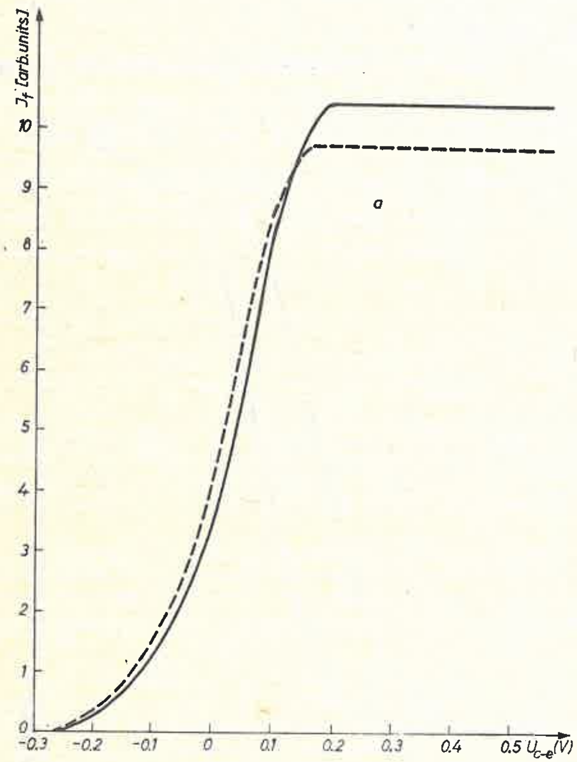


Fig. 2. The shift of the photoemissive characteristics under the influence of additional irradiation of the n-type GaAs with an orientation (111): a) sample No 4 ($h\nu = 4.89$ eV), b) sample No 34 ($h\nu = 5.80$ eV)



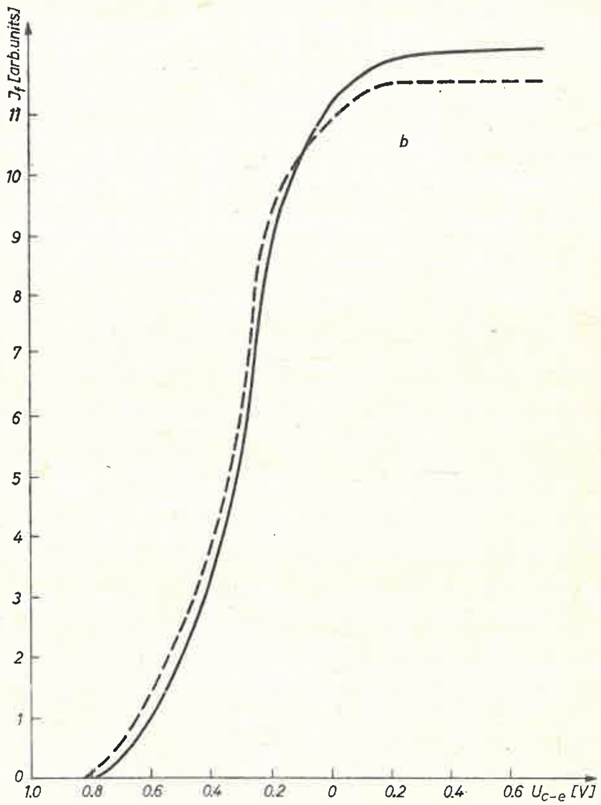


Fig. 3. Current-voltage characteristics of p-type GaAs with and without infrared excitation: a) sample orientation (111), $h\nu = 4.89$ eV, b) sample orientation (113), $h\nu = 5.48$ eV

In addition it was studied whether a change in the yield of spectral distributions might be caused by the additional illumination and it was concluded that the curves $Y = f(h\nu)$ for samples of the n-type as well as the value of the photoelectric threshold do not change.

B. Samples of the p-type

Several current-voltage characteristics were obtained from the surface of the monocrystals (111) and (113) and from polycrystals for ultraviolet energies of 4.89, 5.20 and 5.48 eV. The shift effect of the characteristics in crystals of the p-type GaAs observed (Fig. 3a and b) is much smaller and is an opposite direction than in samples of the n-type. A decrease in the saturation currents takes place with additional illumination.

3. *Discussion of the results*

It can be seen from the results obtained that most distinctively the effect of decreasing the electron work function from samples of the n-type occurs by subjecting them simultaneously to infrared and ultraviolet radiation. This effect could be caused by the following factors:

a) the filling of the surface states by the valence electrons excited by infrared,

b) the freeing of the pairs of carriers by the absorption of the infrared and, because of their different mobility, the change in the charge distribution in the near-surface layer Dember's effect [4–5]. In the author's opinion for the samples studied the second effect is dominant.

If the exciting radiation has an energy sufficient to generate the "electron-hole" pairs, then in the absorption depth the quantity of concentration of these carriers increases and in the state of stability the inequality, $\Delta n_e \neq \Delta n_h$, is observed caused by different mobilities and coefficients of diffusion.

In some near-surface region of a semiconductor an excess of a positive charge relative to the volume is formed which is responsible for Dember's voltage, and which for the homogeneous semiconductor is given by:

$$U_D = kT(\mu_e - \mu_h)\frac{\Delta n_h}{\sigma_0}, \qquad (1)$$

where Δn_h is the mean macroscopic increase in the concentration of the holes and σ_0 is the conduction of the sample without illumination.

When considering the excitation by ultraviolet and infrared radiation of a semiconductor it is important to know that the increment of density carriers appears in a region having a thickness of about 0.1 cm, the surface bendings of bands in the n-type GaAs samples are below 1000 Å and that the external photoelectrons come from a depth of $\leqslant$100 Å.

Let us consider the phenomena which take place in the last layer into which both the ultraviolet and infrared radiation penetrate. There the pairs of carriers are generated which cause an increase in the increments, Δn_e and Δn_h, of the concentration of electrons and holes. Since the mobilities of the latter are more than 10 times smaller, we can consider these holes as unmovable.

The leaving of the layer[1] by several angstroms of the excessive electrons can be caused either by the occupation of surface states or by the diffusion of carriers into the interior of the semiconductor or by both processes. The physical facts which we will discuss later suggest that the first process does not occur or is insignificant.

The diffusion of electrons from the nearest surface layers into the crystal interior is also hampered by the screening action of the large number of carriers which were generated in the region of 0.1 cm thickness. The deeper they are in the crystal the easier it is for the

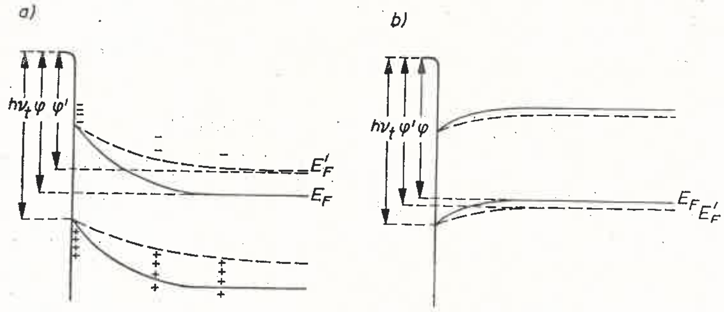


Fig. 4. Illustration of the change in surface energy models of GaAs after generating a pair of carriers by infrared photon energy: a) n-type crystal, b) p-type crystal

electrons to penetrate into the interior of the semiconductor. Hence, a potential gradient is produced in the surface layer, which has the effect of "flattening" the bending of the bands (Fig. 4).

In the region nearest the surface, because of the more difficult escape of electrons, one can assume that the densities of electrons and holes generated by infrared radiation are approximately the same. This explains the constancy of $h\nu_t$ and κ_S^2. The decrease of the surface bending of the energy bands must cause an upward shift in the Fermi-level, i.e., the voltage contact increase observed in the characteristics, without a change in the photoelectric threshold on the surface.

If a change in the surface charge had played a dominating role in this phenomenon, then the photoelectric thresholds near the surface and the photoelectric quantum yields would increase or decrease in a distinct manner depending on the filling of the surface states with electrons or holes.

However, the constancy of $h\nu_t$ and the coincidence of the characteristics of the photoelectric quantum yield, with or without additional illumination, indicate that the surface states are unchanged electrically. This is also confirmed by the lack of clear changes in the shape of the energy distributions of electrons obtained after illuminating with infrared radiation (Fig. 5). These changes should appear if there was an increase in the threshold emission which occurs from surface states.

[1] The surface band bending in these layers is smaller and reverses for the p-type GaAs samples compared to n-type samples.

[2] κ_S is the surface electron affinity.

The exchange of electrons seems to be between the surface layer and the surface of the n-type GaAs is negligible because of a constant value charge located on the surface as indicated by the large bending of bands in the surface layer. The calculation of this charge is:

$$Q_S = \left[\frac{1}{2\pi}\varepsilon e \Delta V n_e\right]^{1/2},$$

where ε is the dielectric constant, e, the electronic charge, ΔV, the bending of the surface band, and n_e denotes the excessive concentration. This gives the result that the filling of surface states in GaAs is close to maximum after vacuum thermal treatment. The small

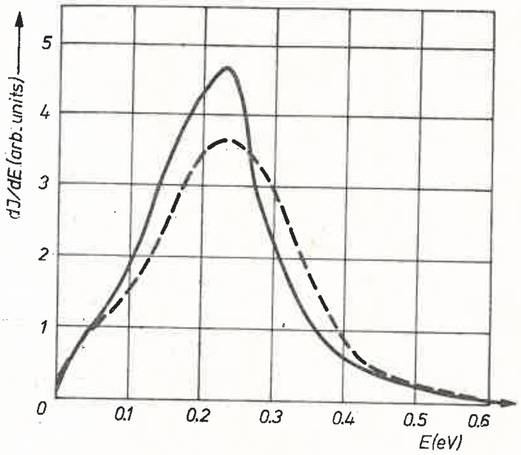


Fig. 5. A comparison of photoelectron energy distributions of the n-type GaAs sample with and without using additional illumination ($h\nu = 4.89$ eV)

increase in the saturation current after additional illumination of the n-type samples is caused by the Schottky effect (usually intervals of saturation currents slightly increase) rather than the change of the quantum yield of the samples.

In 1971 Dinar et al. [6] investigated the influence of additional illumination on photoemission from the surface (110) of the n-type GaAs single crystal and found as we did [3], the occurrence of effects a) and b). They also observed up to a 20% increase in the saturation current of samples after illumination. These authors [6] emphasize the coincidence of their results with those of Wojas [3] and agree with his interpretation based on the phenomenon of "flattening" of the bending of bands. The above literature explains the increase in the saturation current in n-type crystals by the "lowering of the barrier of photoelectrons". Since this barrier has not been described exactly, we suppose that it can be expressed as $h\nu_t$ or φ. Clearly, the latter value of φ decreases. However, the quantum yield depends on the threshold, $h\nu_t$. A decrease in the distance (E_V–E_F) cannot cause an increase in I_s, unless we have a considerable above-threshold emission. When samples with a preponderance of hole conduction are illuminated with infrared radiation the mechanism of this phenomenon is the same, flattening of band bending, although the generated increments, Δn_e and Δn_h, may be smaller because of the "emptying" of the tops of the valence bands of electrons.

The shifting of the characteristics of the p-type samples to the left shows that there is an increase in the energy distance, $(E_V - E_F)$, and hence an increase in the Fermi level near the surface (Fig. 4b).

4. *General conclusions*

1. The results obtained after the application of additional infrared illumination of GaAs samples differed distinctly only in the n-type and p-type samples.

2. For faces (100) and (111) of the n-type GaAs samples the effect of infrared illumination caused a considerable shift in the voltage-current characteristics to the right, while for p-type samples the shift was smaller and directed to the left.

3. The saturation photocurrents of the n-type samples were either unaffected by infrared illumination, or they increased only slightly. In p-type samples the saturation photocurrents decreased.

4. The positions of the maxima of the photoelectron energy distributions and the red photoemission thresholds from (100) and (111) faces, subjected or not to infrared illumination, did not show any measurable changes.

5. From studies of photoemission modulated by infrared radiation one can obtain some fundamental information as well as certain practical hints. For example:

a) one can determine the type of conductivity of unknown samples whenever it is necessary to establish the type of conductivity by contactless measurements,

b) by applying additional infrared excitation one can increase the emitter photosensitivity to required values,

c) one can modulate the height of band bending near the surface.

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