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Abstract

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PHYSICS

Academician of the Academy of Sciences of the Uzbek SSR É. I. ADIROVICH,
V. M. RUBINOV, Yu. M. YUABOV

THE AFN EFFECT IN MONOCHROMATIC LIGHT

1. A number of authors (¹⁻⁵), including ourselves (⁶), have investigated the effect of anomalously large photovoltages in semiconductor films under illumination with monochromatic light. However, all these investigations had as their purpose the study of the spectral distribution of V_{afn} , and the experiment in monochromatic light was not regarded as an *experimentum crucis* capable of deciding the question of the physical nature of the AFN effect. We shall show that, by carrying out investigations of the angular dependences of V_{afn} at different wavelengths of the exciting light, it is possible to give an unambiguous and exhaustive answer to this fundamental question in the theory of the AFN effect.
2. In works (^{7, 8}) it was established that the AFN effect is due either to photovoltaic or to photodiffusion processes occurring in the microphotoelements that make up AFN films.

In the first case such microphotoelements are $p-n$ junctions; in the second, they are regions homogeneous in conductivity type in which the Dember effect arises. Orienting considerations as to which of these two possible mechanisms operates in a given semiconductor material may be expressed on the basis of an analysis of lux-volt characteristics: sublinearity at relatively low light intensities speaks in favor of a photovoltaic nature. Much more definite conclusions can be drawn from the dependence of V_{afn} on the angle of incidence of the light. Reversal of the sign of V_{afn} within the range from 0 to 180° unambiguously indicates a photodiffusion (Dember) mechanism of the AFN effect. However, if, when the angle of incidence of the light is varied within these limits, the sign of the photovoltage does not change, the AFN effect may be due both to $p-n$ junctions and to Dember microphotoelements. In other words, in this case the angular experiment does not lead to an unambiguous conclusion about the nature of the AFN effect.

The reason for the ambiguity of a possible interpretation of the angular dependences in the absence of reversal of the sign of V_{afn} within the range $0 \div 180^\circ$ is connected with the fact that, along with the normal Dember effect, an anomalous Dember effect may arise under certain conditions (^{2, 9}). In the latter case

the sign of the Dember effect is not connected with the direction of the light beam, but is determined by the difference in the rates of surface recombination at different faces. Therefore, in the anomalous Dember effect, as in the photovoltaic effect at $p-n$ junctions, V_{afn} does not change sign when the angle of incidence of the light is varied.

3. An experiment carried out on a large number of AFN films, the results of which were partially presented in ⁽⁸⁾, showed that in all cadmium telluride films without exception V_{afn} does not change sign when the angle of incidence of the light is varied from 0 to 180°. In films of germanium, silicon, and gallium arsenide, however, the results proved to be considerably more complex. For each of these materials there were films on whose angular diagrams, in the interval 0 ÷ 180°, reversal of the sign of V_{afn} was observed, as well as films with angular diagrams without reversal. Taken together, these results can be explained by a Dember effect occurring in some films under normal conditions and in others under anomalous conditions. However, when

the results of experiments on a single film, as a rule, remain uncertain. This uncertainty is removed when experiments are carried out in monochromatic light.

The anomalous Dember effect occurs when the rate of surface recombination on the illuminated face is sufficiently large, while on the shaded face it is small. With weak absorption of light ($\chi d < 1$), the gradients of the concentrations of nonequilibrium charge carriers and the bipolar-diffusion current are directed not along the light flux but against it, as a result of which the sign of the Dember photovoltage is anomalous. If, however, one passes from excitation by long-wavelength light to the short-wavelength region, then, owing to the increase in the absorption coefficient χ , generation of electron-hole pairs will occur only near the illuminated surface; the direction of the bipolar-diffusion current will become independent of the rates of surface recombination, and instead of the anomalous Dember effect, which occurred at long wavelengths, a normal Dember effect will arise. Consequently, if the afn effect is due to the photodiffusion mechanism, then, upon generation of photovoltages by sufficiently short-wavelength light, an inversion of the sign of V_{afn} must necessarily occur in the upper part of the angular diagram. Conversely, in the photovoltaic mechanism the angular diagram in monochromatic light must remain noninverted within 0 ÷ 180° for any wavelength of the exciting light.

It follows from these considerations that the mechanism of the afn effect can be determined unambiguously by studying the angular dependences of V_{afn} in monochromatic light.

4. In our experiments the specimen was rotated about an axis lying in the plane of the film, perpendicular to the interelectrode direction. An OI-24 illuminator with a set of interference light filters served as the source of monochromatic light beams. In measurements of photovoltages in the

Figure 1. Typical dependence of V_{aph} on the illumination angle in CdTe films ($d = 0.38 \mu$). *a*—white light; *b*— $\lambda = 800 \text{ m}\mu$; *c*— $720 \text{ m}\mu$; *d*— $619 \text{ m}\mu$; *e*— $534 \text{ m}\mu$; *f*— $400 \text{ m}\mu$.

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short-wavelength region of the spectrum, an additional light filter was placed in series with the interference light filter, cutting off the second long-wavelength interference maximum. The photovoltage was measured with a V2-5 millivoltmeter-electrometer. The value of V_{afn} , measured at a given fixed angle of illumination, was normalized according to the cosine law.

Typical experimental angular diagrams are shown in Figs. 1, 2, and 3. The mean values of the film thickness d , measured on an MII-4 microinterferometer, are also indicated there.

In cadmium telluride (Fig. 1), the angular diagrams in white light, as well as in monochromatic light at $\lambda = 800$; 720 ; 619 ; 534 and $400 \text{ m}\mu$, have one and the same form; when the film is illuminated at any angles within $0 \div 180^\circ$, the polarity of the photovoltage does not change. As in [8], in these diagrams the value of V_{afn} at a given illumination angle is plotted from the zero circle, shown by a dashed line. For that polarity of V_{afn} at which the potential at the thick end of the film is higher than the potential at the thin end, the values of V_{afn} are plotted outside the zero circle; for the opposite polarity, they are plotted inside the zero circle. The form of the angular diagrams in the interval $180 \div 360^\circ$, corresponding to illumination of the film through the substrate, is not discussed here, since it has no bearing on distinguishing the two possible mechanisms of the afn effect.

The angular diagrams in gallium arsenide films change quite differently upon transition to short-wavelength excitation (Figs. 2 and 3). In sufficiently long-wavelength monochromatic light, the angular diagram does not differ qualitatively from the angular diagram in white light. Then, at smaller λ , in the middle part of the diagram the polarity of V_{afn} changes, with inversion of the sign of the photovoltage occurring under illumination at an angle close to the deposition angle of the film, as follows from the considerations developed in [8].

Fig. 1. Typical dependence of V_{aph} on the illumination angle in CdTe films ($d = 0.38 \mu$).
a—white light; *b*— $\lambda = 800 \text{ m}\mu$; *c*— $720 \text{ m}\mu$; *d*— $619 \text{ m}\mu$; *e*— $534 \text{ m}\mu$; *f*— $400 \text{ m}\mu$.

Fig. 2. Dependence of V_{aph} on the illumination angle in a GaAs film ($d = 0.09 \mu$).
a—white light; *b*— $\lambda = 684 \text{ m}\mu$; *c*— $637 \text{ m}\mu$; *d*— $637 \text{ m}\mu$, scale of V_{aph} enlarged; *e*— $534 \text{ m}\mu$.

Figure 2. Dependence of V_{aph} on the illumination angle in a GaAs film ($d = 0.09 \mu$). *a*—white light; *b*— $\lambda = 684 \text{ m}\mu$; *c*— $637 \text{ m}\mu$; *d*— $637 \text{ m}\mu$, scale of V_{aph} enlarged; *e*— $534 \text{ m}\mu$.

Figure 2: Figure 2. Dependence of V_{aph} on the illumination angle in a GaAs film ($d = 0.09 \mu$). *a*—white light; *b*— $\lambda = 684 \text{ m}\mu$; *c*— $637 \text{ m}\mu$; *d*— $637 \text{ m}\mu$, scale of V_{aph} enlarged; *e*— $534 \text{ m}\mu$.

Figure 3. Dependence of V_{aph} on the illumination angle in a GaAs film ($d = 0.04 \mu$). *a*—white light; *b*— $\lambda = 534 \text{ m}\mu$; *c*— $438 \text{ m}\mu$; *d*— $438 \text{ m}\mu$, scale of V_{aph} enlarged; *e*— $400 \text{ m}\mu$.

Figure 3: Figure 3. Dependence of V_{aph} on the illumination angle in a GaAs film ($d = 0.04 \mu$). *a*—white light; *b*— $\lambda = 534 \text{ m}\mu$; *c*— $438 \text{ m}\mu$; *d*— $438 \text{ m}\mu$, scale of V_{aph} enlarged; *e*— $400 \text{ m}\mu$.

Fig. 3. Dependence of V_{aph} on the illumination angle in a GaAs film ($d = 0.04 \mu$). *a*—white light; *b*— $\lambda = 534 \text{ m}\mu$; *c*— $438 \text{ m}\mu$; *d*— $438 \text{ m}\mu$, scale of V_{aph} enlarged; *e*— $400 \text{ m}\mu$.

It is interesting to note that upon excitation with still shorter-wavelength light the inversion effect is enhanced, but the inversion angle decreases. It is possible that the decrease in the inversion angle is due to the fact that the true relief of the film surface is considerably more complex than the schematic drawing used as the basis for the discussion in work (8). When AFN films are deposited, the dimensions of the substrates were commensurate with the distance from the deposition source. Therefore the orientation of the microphotoelements changes along the film (Fig. 4). It may be supposed that the shift of the inversion angle with decreasing wavelength of the exciting light is connected with the fact that the microphotoelements at the thin end of the film are oriented at smaller angles to the plane of the substrate, and it is precisely they that make the largest contribution to the photovoltage at small wavelengths.

Fig. 4. Schematic arrangement of microcrystals on the substrate

The experimental results obtained confirm the statements made earlier that the AFN effect in cadmium telluride is due to micro-*p-n* junctions, and in gallium arsenide to Dember microregions. They also show that experiments in monochromatic light lead to an unambiguous conclusion about the nature of the AFN effect in a given semiconductor material even in those cases where recording angular dependences in white light does not solve this problem.

Fig. 4. Arrangement of microcrystals on the substrate

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**Physico-Technical Institute
Academy of Sciences of the Uzbek SSR**

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CITED LITERATURE

1. V. M. Lyubin, G. A. Fedorova, DAN, **135**, 883 (1960).
2. H. Kallman, V. Kramer et al., J. Electrochem. Soc., **108**, 247 (1961).
3. I. A. Karpovich, M. V. Shilova, FTT, **5**, 3560 (1963).
4. P. P. Konorov, K. I. Lyubits, FTT, **6**, 71 (1964).
5. M. I. Korsunskii, V. M. Fridman, FTT, **8**, 263 (1966).
6. E. I. Adirovich, V. M. Rubinov, Yu. M. Yuabov, FTT, **6**, 3480 (1964).
7. E. I. Adirovich, V. M. Rubinov, Yu. M. Yuabov, DAN, **164**, 529 (1965).
8. E. I. Adirovich, V. M. Rubinov, Yu. M. Yuabov, DAN, **168**, No. 5, 1037 (1966).
9. E. I. Adirovich, DAN, **150**, 1252 (1963).

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