[8] A. Lovell, Usp. Fiz. Nauk 61, 9 (1950).

Translated by L. B. Leder
318

Concerning the Temperature Dependence of the Photoelectromotive Force

F. F. KODZHESPIROV

(Submitted to JETP editor November 10, 1956)
J. Exptl. Theoret. Phys. (U.S.S.R.) 32, 1593-1594
(June, 1957)

EXPERIMENTAL INVESTIGATIONS of the crystal photoeffect[1] and photoelectromotive force, occurring when the capacitor method is used to investigate semiconductors,[2] show that these effects have a maximum with respect to temperature. This maximum, however, is difficult to explain on the basis of the proposed theoretical formulas.

Lashkarev and Kosonogova[3] have shown that the dependence of the non-barrier-layer photoelectric force in copper oxide on the intensity of light is described by the formula

$$V = (kT/e)\ln(1 + BJ). \tag{1}$$

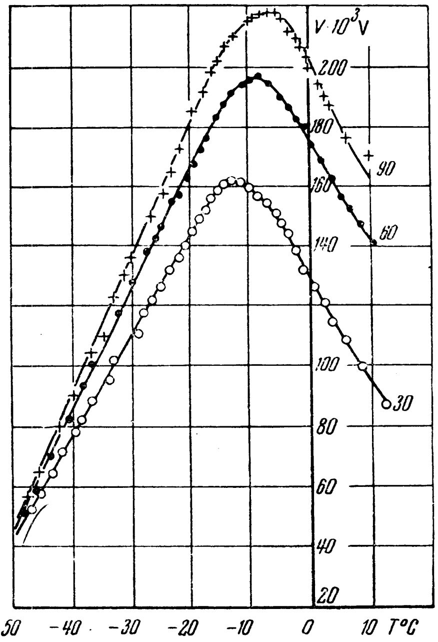
By comparing (1) for small intensity with the theoretical formulas obtained by Lashkarev[4] it is possible to assume that for the crystal photoeffect $BJ \approx \Delta\sigma_{-}/\sigma_{\mathrm{T}}$.

Thus both effects (non-barrier photoelectromotive force and photoelectric force in the capacitor method) may be described by relations (1) of like form but of somewhat different content. It is essential that in the case of the crystal photoeffect $\Delta\sigma_{-}$ (light-induced increment of conductivity at the base of the anti-barrier layer or on the boundary of the neutral contact) is due to the minority carriers, while in the capacitor method there is no need for restriction to the minority carriers.

The experimenter usually deals with samples of finite thickness, and therefore (1) can be written more precisely as

$$V = (kT/e)\left[\ln(1 + B_1J) - \ln(1 + B_2J)\right]. \tag{2}$$

But since the factor B_2, which must take into account the absorption of light in the sample and possibly also the diffusion of the minority carriers toward the second electrode, is very small, the second logarithm in Eq. (2) does not exert a notable influence on the intensity dependence of the photoelectromotive force. In this case Eq. (1) is satisfied to a good degree.



Matters are different in temperature investigations. It is shown in Refs. 1 and 2 that Eq. (1) cannot give even a qualitative explanation of the existence of a maximum in the photoelectromotive force *vs.* temperature curve. Ryvkin,[2] to reconcile the experimental data with Eq. (1) makes assumptions that are far from obvious concerning the mechanism of recombination at low temperatures. The need for such a reconciliation between the experimental data and the theoretical ones disappears if one takes into account the finite thickness of the sample. Making the same assumptions concerning the temperature dependence of σ_{T} and $\Delta\sigma$ it is possible to rewrite Eq. (2) in the form

$$\vartheta = T\ln\frac{1 + a_1x}{1 + a_2x}, \tag{3}$$

where

$$\vartheta = Ve/k,\ a_{1,2} = \mathrm{const}(T),\ b = W/k,\ x = e^{b/T},\ a_1 > a_2.$$

Let us test Eq. (3) for an extremum. It is necessary for us to determine the temperature for which

$$\frac{d\vartheta}{dT} = \ln\frac{1 + a_1x}{1 + a_2x} - \frac{(a_1 - a_2)\,x\ln x}{(1 + a_1x)(1 + a_2x)} = f(x) - \varphi(x) = 0. \tag{4}$$

Since $a_1 > a_2$ and $x \geq 1$, then $f(x) > 0$ and $\varphi(x) \geq 0$. The function $f(x)$ increases monotonically and is different from zero over the entire range of variation of x, while $\varphi(x)$ vanishes at the end of the interval. Equation (4) is satisfied for two values of x, corresponding to two extremal points of Eq. (3). The character of the extremum (sign of the second derivative) depends on the sign of the difference $(1 - a_1 a_2 x^2)$.

Since Eq. (4) in its general form is not solvable, we attempt to approximate it. Solving Eq. (4) for specific values of a_1 and a_2 shows that an intersection of $f(x)$ and $\varphi(x)$ takes place for $a_{1,2}x \ll 1$ and $a_1 x \gg 1$; $a_2 x > 1$. In the first case Eq. (4) yields approximately $\ln x_1 \approx 1$. Near the second root, with satisfactory approximation, it is possible to represent Eq. (4) as

$$\ln (a_1 / a_2) - (a_1 - a_2) \ln x_2 / a_1 a_2 x_2 = 0.$$

Subject to a certain error, it is possible to assume that $\ln x_2 \approx - \ln a_2$ and $a_1 \gg a_2$, whence

$$x_2 = 1 / [a_2 (1 - \ln a_1 / \ln a_2)].$$

The root $x = x_1$ corresponds to a minimum of the function $\vartheta(T)$ and the root $x = x_2$ to a maximum.

The temperature maximum (T_M) and minimum (T_m) are determined from the relation

$$T_{M,m} = W / k \ln x_{2,1}, \tag{5}$$

i.e., for low temperatures we have a maximum, for high ones a minimum. The position of the maximum depends on the thickness of the sample and on the intensity of the illumination. With increase in the thickness of the specimen, a_2 quickly decreases, and the maximum moves towards the lower temperatures.

It is possible to obtain the dependence of the position of the maximum on the illumination intensity by assuming $a_{1,2} = a'_{1,2}J$. We then obtain for the shift of the maximum ΔT

$$\Delta T = cT_1^2 / (1 - cT_1), \; c = (k_2 / W) \ln (J_2 / J_1), \tag{6}$$

T_1 is the temperature of the maximum for intensity J_1. With increase in intensity $[\ln (J_2/J_1) > 0]$ the maximum moves to the side of higher temperatures.

It has been established by us[5] that when amorphous selenium is exposed to x-rays there is developed an electromotive force similar to the crystal-photoeffect and described by relation (2). The figure shows the temperature dependence of the emf for different intensities of x-ray exposure of amorphous selenium (the number under the curve gives the intensity of radiation in dosimeter pulses per second). With change in temperature we actually observe a maximum whose position moves to the side of higher temperature with increasing intensity, as follows from Eq. (6).

---

[1] A. V. Ioffe and A. F. Ioffe, J. Tech. Phys. (U.S.S.R.) **5**, 111 (1935).

[2] S. M. Ryvkin, J. Tech. Phys. (U.S.S.R.) **18**, 1521 (1948).

[3] V. E. Lashkarev and K. M. Kosonogov, J. Exptl. Theoret. Phys. (U.S.S.R.) **18**, 927 (1948).

[4] V. E. Lashkarev, J. Exptl. Theoret. Phys. (U.S.S.R.) **18**, 917 (1948).

[5] F. I. Kolomoitsev and F. F. Kodzhespirov, J. Tech. Phys. (U.S.S.R.) **27**, 5 (1947).

Translated by L. B. Leder
319