DEPENDENCE OF THE PHOTOCONDUCTIVITY OF SEMICONDUCTORS ON THE POLARIZATION OF THE INCIDENT RADIATION

Yu. V. Gulyaev
Institute of Radio Engineering and Electronics, USSR Academy of Sciences
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In measurements of the photoconductivity (PC) of semiconductors, there is usually a constant electric field E_0 in the sample. Thus, a certain direction is singled out even if the material is initially isotropic. Therefore when the sample is illuminated with polarized light, the photoresponse (PR) may be dependent on the angle γ between the alternating electric field vector $\vec{E}_\sim$ and the vector $\vec{E}_0$. In the present paper we discuss the possible mechanisms that bring about such a dependence.

In the case when the PC is due to a change in the mobility of the free electrons as they become heated by the incident radiation, the dependence in question is connected with the fact that the total power released in the nonlinear medium by two currents is in general dependent on the angle between them. In the electron-temperature approximation, assuming that $\omega\langle\tau\rangle \ll 1$ (ω - frequency of incident light wave, $\langle\tau\rangle$ - average relaxation time of electron momentum), and $\vec{E}_\sim \ll \vec{E}_0$, we obtain for the PR averaged over the period of the wave

$$\Delta V = -\frac{LE_0\overline{E_\sim^2}}{\sigma(E_0^2)}\left\{\frac{d\sigma(E_0^2)}{dE_0^2} + \frac{2\dfrac{d^2\sigma(E_0^2)}{d(E_0^2)^2}E_0^2\cos^2\gamma}{1+\omega^2\tau_9^2\left(1+\dfrac{d\ln\sigma(E_0^2)}{d\ln E_0^2}\right)^2}\right\}. \tag{1}$$

Here L is the sample length, $\sigma(E_0^2)$ its dark electric conductivity, and $\tau_e = \tau_e(E_0^2)$ is the characteristic relaxation time of the electron energy. It is seen from (1) that the considered "heating" mechanism of the dependence of ΔV on γ can be significant only when the field E_0 is sufficiently strong, the sample has a suitable current-voltage characteristic, and furthermore the frequency of the incident radiation is not too high.

We now consider the case of impurity PC. It is easy to see that the dependence of the PR on the radiation polarization, a dependence caused by the anisotropy of the wave functions of the coupled electrons (and "induced" by the constant field E_0), will be weak, to the extent that the Stark level splitting of the field E_0 is small, compared with the ionization energy or kT (for degenerate excited states of hydrogenlike impurities). However, in semiconductors, in which the lifetime τ_r of the photoelectrons "knocked out" of the impurities is comparable with their momentum relaxation time τ (these times depend, in general, on the electron energy ϵ), it is possible that the following mechanism of the dependence of the PR on the angle γ becomes significant.

It is known (see [1]) that the photoelectrons knocked out in the photoeffect from bound states characterized by more or less symmetrical wave functions are emitted predominantly along the direction of the vector $\vec{E}_\sim$. It is easy to see that the average time of flight of such a photoelectron until the first collision, as well as its average velocity, depend on the angle between the vector $\vec{V}_i$ of its initial velocity and the vector $\vec{E}_0$. This is connected with the acceleration of the electron in the field $\vec{E}_0$ and with the dependence of τ on the electron energy ϵ. Therefore the currents of the electrons emitted at acute and obtuse angles relative to the vector $\vec{E}_0$ do not cancel each other (see [2]) and a difference current is produced, which obviously depends on the angle γ and is proportional to E_0 in weak fields. Under the conditions of the PC measurement (sample connected in a current generator circuit), this effect will give rise to a PR superimposed on the ordinary PR, proportional to the change of the electric conductivity of the sample. If the photoelectron energy relaxation time is much longer than the electron lifetime, then the relative magnitude of these responses will be determined by the ratio $\tau(\epsilon_i)/\tau_r(\epsilon_i)$, where ϵ_i is the initial energy of the photoelectrons. In this case it is easy to obtain the following estimate for the total PR:

$$\Delta V = -LE_0 \frac{G\tau_r(\epsilon_i)}{n_0} \frac{\tau(\epsilon_i)}{<\tau>} \{1 + \frac{\tau(\epsilon_i)}{\tau_r(\epsilon_i)} \frac{d\ln\tau(\epsilon_i)}{d\ln\epsilon_i} \frac{12}{5} (\cos^2\gamma + \frac{1}{3}\sin^2\gamma)\}, \quad (2)$$

where G is the rate of photoelectron generation and n_0 is the density of the equilibrium electrons.

In compensated InSb samples with sufficiently high impurity density ($\sim 10^{14} - 10^{15}$ cm^{-3}) the lifetime of the knocked-out photoelectrons and the relaxation time of their momenta can turn out to be fully comparable. It is therefore perfectly possible that the strong dependence of the PR produced in such InSb samples by microwave irradiation in the millimeter range on the angle γ, observed in [3], is connected with the last mechanism considered. We note incidentally that the noticeable deformation of the wave functions of the electrons bound to shallow donors in InSb even in relatively weak magnetic fields (~100 Oe) uncovers possibilities for explaining the strong variation, noted in [3], of the PR with increasing magnetic field. However, at such impurity densities the question of the existence of the bound states themselves ceases to be trivial [4]. At any rate, owing to the random distribution of the impurities and of their interaction, we apparently cannot expect an abrupt frequency threshold in the PC under consideration.

In conclusion we note that the separation of the polarization-dependent part of the PR is greatly facilitated if the sample is illuminated with light having a variable polarization and the obtained modulated signal is then amplified.

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Equation (1) should read:

$$\Delta V = -\frac{LE_0E^2_{\sim}}{\sigma(E_0^2)}\left\{\frac{d\sigma(E_0^2)}{dE_0^2} + \frac{2\left(\frac{d\sigma(E_0^2)}{dE_0^2} + \frac{d^2\sigma(E_0^2)}{d(E_0^2)^2}E_0^2\right)\cos^2\gamma}{1+\omega^2\tau_e^2\left(1+\frac{d\ \ln\sigma\ (E_0^2)}{d\ \ln\ E_0^2}\right)^2}\right\}$$