nature. The obtained data do not make it possible as yet to determine the contributions of these phenomena to the polarization of CCl_4 in reflected waves. This question calls for further study.

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PHENOMENON OF EXCHANGE DETECTION IN n-InSb AT LIQUID-NITROGEN TEMPERATURE

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It was observed that if samples of n-InSb at liquid-nitrogen temperature are irradiated with millimeter and meter waves modulated at a frequency higher than 1 kHz, then an alternating voltage proportional to the envelope of the radiation incident on the sample is produced on contacts soldered to opposite faces of the sample and lying in a plane parallel to the irradiated face of the InSb sample (Fig. 1a). The magnitude of this voltage depends also on the constant bias field applied to the sample. Figure 1 shows plots of the resultant voltage (response) and the conductivity of the sample on the bias field at three sample temperatures. The dependence of the response on the bias field has a maximum which occurs at bias fields from 2 to 30 V/cm in different samples. In the best samples the response at the maximum is characterized by a volt-watt sensitivity ~1 V/W (referred to the power of the

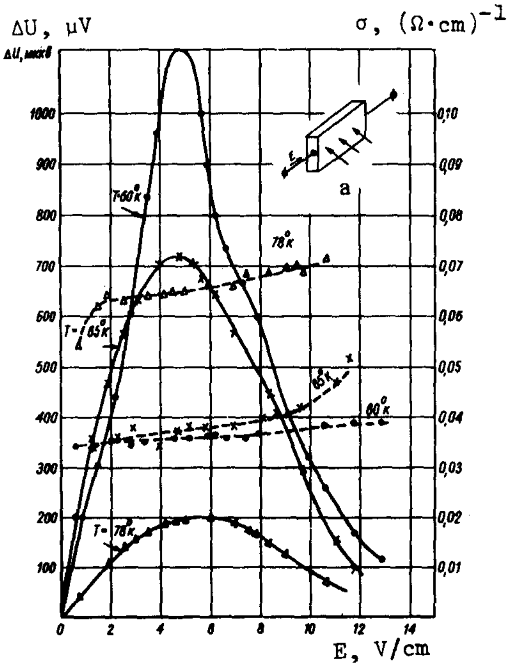

Fig. 1. Response (solid curves) and conductivity of the sample (dashed curves) vs. the applied bias field at temperatures 78, 65, and 60°K; sample dimensions 7.25 × 2.75 × 1.25 mm, $n = 3.4 \times 10^{12}$ cm^{-3}, $\mu = 1.2 \times 10^5$ cm^2/V-sec.

radiation incident on the sample). With decreasing sample temperature, the response increases and at ~60° it is 10 - 30 times larger than the response at 78°K. In the study of the spectral characteristic of the detection phenomenon, no appreciable change in the volt-watt sensitivity was observed in the wavelength range from 10 to 0.8 mm. In a number of samples, a response was produced also in the absence of a constant bias, although in this case the sensitivity was 10^{-4} - 10^{-3} V/W.

By increasing the frequency of the amplitude modulation of the radiation, we investigated the inertia of the observed detection phenomenon. No inertia was observed in the effects up to a modulation frequency 35 MHz. Mixing of two electromagnetic waves of the 8-mm band in an n-InSb sample at 78°K yielded an intermediate frequency of 2000 MHz. These experiments show that the time lag of detection in n-InSb at 78°K does not exceed 10^{-10} sec.

We observed a dependence of the response on the relative orientation of the intensity of the bias field $\vec{E}_0$ and of the electric vector of the electromagnetic wave $\vec{E}_\sim$. In the case when $\vec{E}_0 \parallel \vec{E}_\sim$ the response is 1.3 - 2.5 larger than when $\vec{E}_0 \perp \vec{E}_\sim$.

An investigation of the influence of the constant magnetic field $\vec{B}$ on the detection in n-InSb revealed a strong dependence of the response on the magnetic field and on its orientation relative to the vectors $\vec{E}_0$ and $\vec{E}_\sim$. In the case when $\vec{B} \parallel \vec{E}_0 \parallel \vec{E}_\sim$, the response increases with increasing magnetic field (Fig. 2). On the other hand, if the magnetic field is perpendicular to $\vec{E}_0$ or $\vec{E}_\sim$, then the response decreases with increasing $\vec{B}$, down to a certain minimum value, after which it oscillates. The position of this minimum depends on the radiation wavelength.

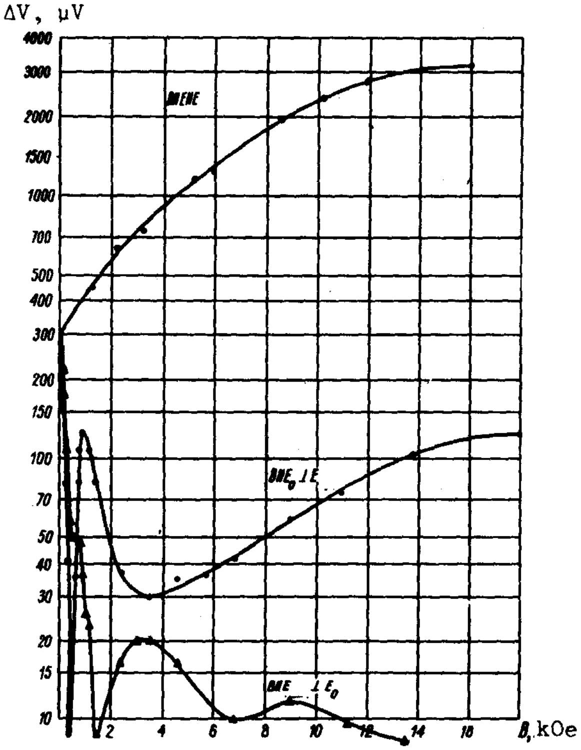

Fig. 2. Response vs. magnetic field at different orientations of the fields $\vec{B}$, $\vec{E}_0$, and $\vec{E}_\sim$; sample dimensions 2.4 × 2.1 × 0.4 mm, $n = 2.5 \times 10^{12}$ cm-3, and $\mu = 3.1 \times 10^5$ cm^2/V-sec.

The employed InSb samples had a free-electron density $n \sim 10^{10}$ - 10^{13} cm^{-3} and a mobility ~1×10^5 - 4.5×10^5 cm^2/V-sec. An investigation of several samples known to be compensated with germanium has shown that the total density of the ionized impurities is 5×10^{14} - 10^{16} cm^{-3}. We note that the electron mobility in the investigated InSb samples is determined by scattering from ionized impurities; this follows, for example, from Fig. 1. If we assume that the response is due to variation of σ, then its magnitude and polarity are determined by the expression:

$$\Delta V = -\ell E_0 \Delta\sigma/\sigma_0 \tag{1}$$

(ℓ is the length of the sample). The measured polarity of the response agrees with the polarity determined from (1).

Under the conditions of the described experiment, the response can be due either to a change in the electron mobility when heated by the incident radiation (mechanism I), or to a change of the electron concentration as a result of ionization of the impurity atoms (mechanism II). One of the characteristic features of the observed response is its dependence on the radiation polarization. As shown by Yu. V. Gulyaev [1], such a dependence should occur in both mechanisms. However, it is impossible to explain on the basis of mechanism I the experimental dependence of the response on the magnetic field, say in the case when $\vec{E}_\sim \parallel \vec{E}_0 \parallel \vec{B}$. In addition, if it is assumed that $\sigma = \sigma_0(1 + \beta E^2 + \gamma E^4)$ when $\beta > 0$ and $\gamma > 0$, then the functional dependence of the response on E_0, which follows from formula (1) of [1], does not coincide with the experimentally observed one.

A satisfactory explanation of the observed phenomenon can be obtained apparently on the basis of mechanism II. Owing to the low energy of the microwave quantum in the millimeter band, the photoeffect can take place here only from shallow levels, the existence of which in n-InSb was indicated in [2,3]. Inasmuch as at nitrogen temperatures $n \ll N_a < N_d$ in the investigated samples (N_a and N_d are the densities of the donor and acceptor impurities) and there is no degeneracy, it is easy to find that the density of the electrons at the donor levels is given by

$$n_{0d} \simeq (N_d - N_a)\left[1 + \frac{\beta N_c}{N_d} \exp\left(-\frac{\epsilon_d}{kT}\right)\right]^{-1}. \tag{2}$$

Recognizing that in InSb at 78°K we have $\beta N_c = 2.5 \times 10^{15}$ cm^{-3} and $\epsilon_d/kT \ll 1$, it is easy to verify that the number of electrons at the donor levels is of the same order as the number of electrons in the conduction band. The partial overlap of the impurity states leads to the formation of an impurity band for which the conductivity will be smaller than for the conduction band. The transition of the electrons to the conduction band as a result of the photoeffect leads to an increase of σ and to the appearance of a response. On the basis of mechanism II in the samples under consideration it is possible to explain satisfactorily [1] the dependence of the photoresponse on the mutual orientation of the fields $\vec{E}_\sim$ and $\vec{E}_0$ and on the value of E_0. In view of the low binding energy of the electrons at the impurity levels, even very small magnetic fields will strongly influence the state of the electrons; this can explain the observed dependence of the response on the magnetic field.

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