NEW TYPE OF CURRENT INSTABILITY IN n-GERMANIUM

A. A. Kastal'skii and S. M. Ryvkin
A. F. Ioffe Physico-technical Institute, USSR Academy of Sciences
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In [1] we calculated the current-voltage characteristic of n-Ge with low density of shallow donor states for the case of an electric field applied along the crystallographic [111] axis. It turned out that at low experimental temperatures the current-voltage curve should have a rather deep negative-resistance section. The effect is due to the non-equivalent conditions for different valleys, occurring at the indicated field direction, from the point of view of the electron heating in them, and consequently to the different intervalley transition probabilities.

Intervalley transitions of electrons occur in germanium both as a result of generation or absorption of a longitudinal short-wave acoustic phonon, and via scattering by impurities [2]. In the case of low density of the impurities capable of changing the electron momentum, the intervalley transitions are determined by the phonon scattering. With decreasing temperature the probability of the phonon transition decreases exponentially both as a result of the smaller number of phonons needed for the intervalley transfers, and as a result of the decreased number of electrons having an energy larger than that of the required phonon. In this case, the heating of the electrons by the electric field can greatly intensify the intervalley transitions accompanied by phonon generation.

However, when the field is along the [111] axis, the electrons in the valley that is elongated in this direction will be heated much less than in the three other valleys, which are "turned" by the small effective mass towards the direction of the field. Therefore the strongly heated electrons have a much greater probability of intervalley scattering with phonon emission that the weakly heated ones, and this brings about an increase in the intensity of the transitions from the three "hot" valleys to the one "cold" valley, where the

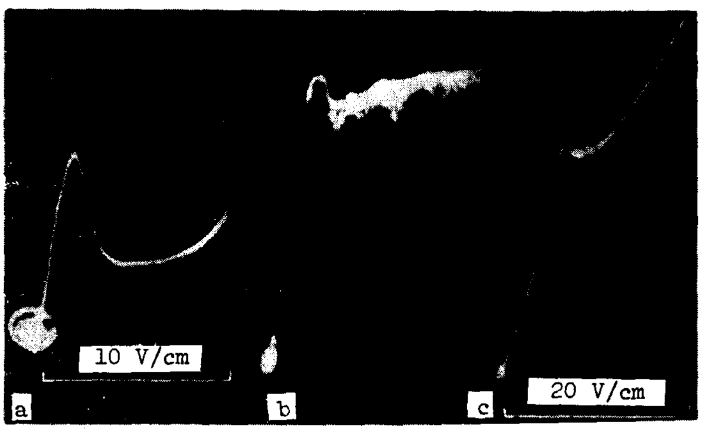

Fig. 1. Current-voltage characteristics of n-Ge with shallow-donor density 3×10^{12} cm^{-3} at 4.2°K (a), 20°K (b), and 30°K (c).

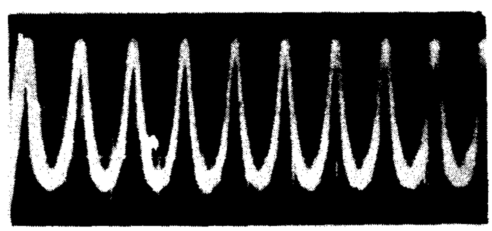

Fig. 2. Typical oscillogram of current oscillations.

electrons move under the influence of the field with a larger effective mass.

The resultant "diffusion" of the carriers in k-space decreases the current with increasing voltage, and thereby ensures the existence of a negative-resistance section on the current-voltage curve; this leads in turn to the appearance of a domain-drift instability of the current (just as in the Gunn effect).

However, inasmuch as the intervalley impurity scattering is not as critical to electron heating and is approximately the same for all valleys, it will tend to equalize the electron densities in the valleys.

Thus, the effect of negative resistance under consideration can arise only at low lattice temperatures and low impurity density (and electron density, since the electron-electron interaction will equalize the "temperatures" of the carriers in the valleys).

The effect was calculated for a shallow-donor density, $\sim 10^{12}$ cm^{-3}, at a temperature 20°K, inasmuch as at this temperature the overwhelming number of electrons are thermally ionized in the conduction band, whereas at lower temperatures the electrons are captured by the donor centers and the impurity breakdown process is superimposed on the investigated effect. In addition, it turned out that at T = 40°K there was no decreasing section of the calculated current-voltage curve.

It should be noted that the large depth of the produced negative section at T = 20°K makes it possible to investigate this phenomenon under conditions of constant illumination (i.e., in the presence of a hole component of the conductivity). In this case the experiment can be performed at a lower temperature (say 4.2°K) and with samples of both n- and p-type. Here, however, it is necessary that the photoconductivity of the electrons be at least not smaller than the photoconductivity of the holes.

The purest of the samples selected for the experiment contained a total density of shallow acceptor and donor impurities on the order of (5 - 6) x 10^{12} cm^{-3} with an approximate differential density (1 - 3) x 10^{12} cm^{-3}, and had both p- and n-type conductivity at liquid-nitrogen temperature. samples in which the main contribution to the photocurrent is made by electrons were selected in preliminary photopiezoresistance experiments.

Figure 1 shows typical oscillograms of the current-voltage characteristics of an n-type sample for temperatures

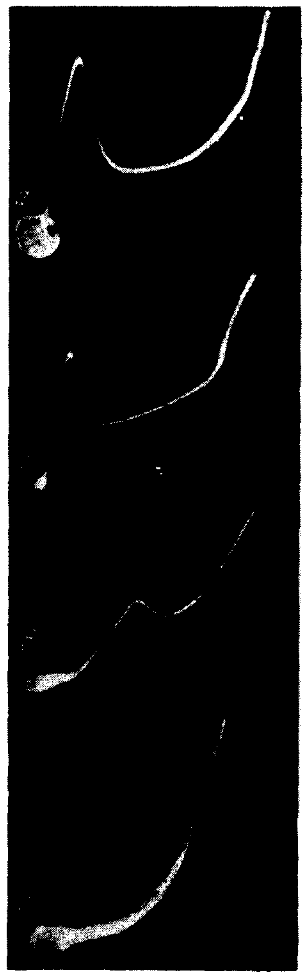

Fig. 3. Current-voltage curve as a function of uniaxial compression along the [111] axis at T = 4.2°K: P = 0 (a), P = 50 kg/cm^2 (b), P = 100 kg/cm^2 (c), P = 300 kg/cm^2 (d).

4.2°K (1,a), 20°K (1,b), and 30°K (1,c) in the case of a field acting along the [111] axis. A negative-resistance section is clearly seen; it turns into a plateau at 30°K and vanishes with further increase of temperature. In the case of liquid-helium temperature, the carriers were produced by weak constant illumination in the main absorption region. The abrupt increase of the current at 10 V/cm corresponds to the start of the impurity breakdown. At higher experimental temperatures, no constant illumination was used. At 20°K there is a section of periodic instability, occurring in the region 2 - 8 V/cm. An oscillogram of the oscillations is shown in Fig. 2. The frequency of the oscillations corresponds approximately to the ratio of the carrier drift velocity to the sample length. At 4.2°K the increase of the illumination intensity led to a decrease of the depth of the negative section and to the appearance of current oscillations. The oscillations had frequently an irregular character.

Uniaxial compression along the field direction led to a sharp decrease of the maximum on the current-voltage curve (Fig. 3). At a pressure 200 - 300 kg/cm^2 (at $T = 4.2°K$) the negative section disappears completely. Such changes can be readily explained from the point of view of the investigated effect, since a pressure in the [111] direction splits the conduction band into three valleys and one [3], and when the field and compression directions coincide the lowest energy position is assumed by the "cold" valley, in which the electrons accumulate in the absence of a field. In this case the carrier heating does not lead to an increase of the resistance.

When the field acts along the [100] axis (this is not accompanied by a change in the valley population), no singularities are observed on the current-voltage characteristic .

Thus, the results of the experiment offer evidence that the observed effect is due to intervalley redistribution of the electrons as they become heated.

In conclusion, the authors thank L. E. Vorob'ev for help with the experiment and for a discussion of the results.

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ANOMALOUS TEMPERATURE DEPENDENCE OF SPIN DENSITY IN PrF_3 SINGLE CRYSTALS

M. L. Afanas'ev, S. P. Gabuda, and A. G. Lundin
Physics Institute, Siberian Division, USSR Academy of Sciences
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During the course of an investigation of a number of paramagnetic single crystals, we observed an unusual temperature dependence of the shift of one of the components of the NMR of F^{19} in single-crystal PrF_3.

Whereas lowering of the temperature of the previously-investigated paramagnets leads only to an increase of the total width of the spectrum, leaving the relative positions of the components unchanged, in the case of PrF_3 the position of one of the components relative to the remaining lines in the NMR spectrum of F^{19} varies continuously with temperature.