Thermostimulated *p–n* junctions

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Thermostimulated diodes as a fundamentally new method of creating *p–n* junctions is considered.

Fusion and the diffusion of donor and acceptor impurities are the principal (and virtually the only) methods of creating *p–n* junctions in semiconductors. We discuss the question of whether there are fundamentally different methods of producing *p–n* junctions.

The basic idea of our approach is as follows. It is known that in doped semiconductors there is a change in spin of the Hall constant in the thermoelectromotive force at a certain temperature, characteristic of the given semiconducting material.[1] This temperature is called the inversion temperature T_i. Below T_i the Hall constant, the thermoelectromotive force, and hence the type of conductor have one sign, and above it they have the opposite sign. Suppose a temperature gradient is created across the sample, such that part of the sample is below T_i and the other part is above T_i. The part of the sample with $T < T_i$ will then have one type of conductivity (say, *p* type), while the other part with $T > T_i$ will have the other type (*n* type). In this way a *p–n* junction can be stimulated or induced in the sample. It is natural to call it a thermostimulated *p–n* junction. It will exist as long as the appropriate temperature gradient is maintained across the sample. In this sense a thermostimulated junction is a dynamical transition, since it appears and disappears together with the temperature gradient. In the fusing method this type of *p–n* junction can be considered as a thermostimulated diode or rectifier. In order to demonstrate experimentally that this is indeed the case, we measured the I-V characteristics for three variants of the experiment.

We created a temperature gradient, in which the entire sample was 1) below T_i [the purely donor region ($T_i > T_{\rm h} > T_{\rm c}$)]; 2) above T_i [the purely intrinsic region ($T_i < T_{\rm c} < T_{\rm h}$)]; 3) in the neighborhood of T_i ($T_{\rm c} < T_i < T_{\rm h}$). Only in the third case is a thermostimulated *p–n* junction possible. Here $T_{\rm h}$ is the heater temperature and $T_{\rm c}$ is the cooler temperature.

In addition, in the third variant of the experiment, the extent of the region occupied by a given type of conductivity in the sample can be controlled by an appropriate choice of the magnitude of the temperature gradient, which also controls the width of the *p–n* junction. The experiments were carried out with germanium ($T_i \approx 370$ K) and silicon ($T_i \approx 420$ K). The experimental methodology was described in Ref. 2 and is summarized briefly as follows.

A temperature gradient was created across the sample by means of wires connected to the ends of the sample. The I-V characteristic of the sample was recorded.

The results are shown in Fig. 1 for a dumbell-like sample of a hole-type germani-

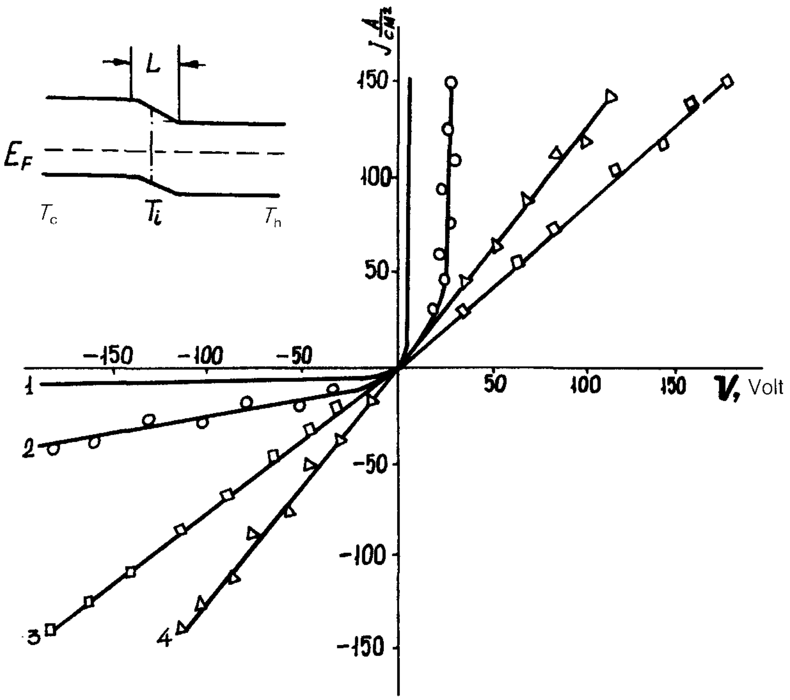

FIG. 1. Current-voltage characteristics: *1*—Theory, *2*—experiment for $T_c < T_i < T_h$, *3*—experiment in the purely donor region when $T_i > T_h > T_c$, *4*—experiment for the temperature region corresponding to purely intrinsic conductivity $T_i < T_h < T_c$. Inset: T_h—temperature of the heater; T_c—temperature of the cooler; T_i—inversion temperature corresponding to the change in sign of the Hall constant; *L*—width of the *p–n* junction.

um with $\rho = 50$ Ω·cm and dimensions $1\times1\times1.6$ mm. The temperature gradient was 10^3 deg/cm. The measured results for the first variant (curve 3) and the second variant (curve 4) of the experiment show a slight asymmetry on the I-V characteristic. In these two cases p^+–p and n^+–n junctions can arise. It is known, however, that these junctions result in practically no rectification. As expected, significant rectification occurred only in the third variant of the experiment (curve 2). Figure 1 also shows the I-V characteristic calculated theoretically using the diffusion theory for a germanium sample with a smooth *p–n* junction (curve 1).

The sign of the rectification also indicates the presence of a *p–n* junction: it corresponds to the case where a positive current source is applied to the cold *p* region and a negative current source is applied to the hot *n* region. The direct current was 1.6 A and the back current was 60 mA. The direct voltage was $V = 10$ V, while the back voltage was 150 V. In the pulse mode the direct current was equal to 3.2 A and the back current was 0.8 mA. Hence, the rectification coefficient reached values of up to 10^3–10^4, while the maximum current density in the working part of the best diodes was 10^3 A/cm^2, which exceeds the largest attainable current densities in ordinary *p–n* junctions by 1–2 orders of magnitude. All of these facts show that it is possible to create p–n junctions in wide-band semiconductors by means of a temperature gradient about T_i.

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[1] I. K. Kikoina (ed.), *Tables of Physical Quantities* [in Russian], Atomizdat, Moscow (1976); chs. 21 and 26.

[2] Kh. I. Amirkhanov, R. I. Bashirov, M. M. Gadzhialiev, and V. A. Elizarov, *Nonequilibrium Current Carriers in Semiconductors* [in Russian], Makhachkala (1982); p. 4.

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