from 2 to 2' is shown in Fig. 2b. When the sign of the field is reversed, only the polarity of the registered signal changes.

Since the intensity of the field in the gap was approximately half the breakdown value for air under normal conditions, a saturation current, determined by the number of carriers from the "precursor," was flowing through the circuit at each instant. This made it possible to estimate the value of the charge σ diffusing from the free surface into the gap upon approach of the SWF: $\sigma \sim 10^{-10}$ C/cm^2 (or 10^9 carriers/cm^2).

The fact that the registered signal had a negative polarity in the experiments made with the setup of Fig. 1a indicates that the carriers moving in front of the SWF in bismuth are negative, apparently electrons.

[1] R. Y. Eichelberger and G. E. Hanver, in: Les Ondes de Detonation (Editions du Centre National de la Recherche Scientifique), Paris, 1962, pp. 363-381.
[2] A. G. Ivanov, E. Z. Novitskii, V. N. Mineev, Yu. V. Lisitsyn, Yu. N. Tyunyaev, and G. I. Bezrukov, Zh. Eksp. Teor. Fiz. 53, 41 (1967) [Sov. Phys.-JETP 26, 28 (1968)].
[3] V. N. Mineev, A. G. Ivanov, E. Z. Novitskii, Yu. N. Tyunyaev, and Yu. V. Lisitsyn, ZhETF Pis. Red. 5, 296 (1967) [JETP Lett. 5, 244 (1967)].
[4] L. V. Al'tshuler, M. N. Pavlovskii, L. V. Kuleshova, and G. V. Simakov, Fiz. Tverd. Tela 5, 279 (1963) [Sov. Phys.-Solid State 5, 203 (1963)].
[5] R. G. McQueen and S. P. Marsh, J. Appl. Phys. 31, 1253 (1960).
[6] H. D. Weymann, Phys. Fluids 3, 545 (1960).
[7] A. G. Ivanov, S. A. Novikov, and V. A. Sinitsyn, Fiz. Tverd. Tela 5, 269 (1963) [Sov. Phys.-Solid State 5, 196 (1963)].

* The transport of the ions of the metal is neglected, in view of the low mobility of the ions compared with that of the carriers.
** The instants t_1 and t_2 were determined by means of a reference signal.

ABSORPTION OF ENERGY OF HOT ELECTRONS BY SEMICONDUCTOR SURFACE

A. I. Klimovskaya and O. V. Snitko
Semiconductor Institute, Ukrainian Academy of Sciences

It was shown in a number of theoretical and experimental papers [1] that the mobility of carriers decreases with decreasing thickness of the crystal. It was predicted theoretically in [2] that the situation may be reversed in strong electric fields, the carrier mobility increasing with increasing thickness. There is no experimental confirmation of such an effect. Investigations are known in which broadening of the region of validity of Ohm's law in thin layers was observed [3], but this might have been due either to the diffuse nature of the scattering [1] or to the cooling of the carriers on the surface [2].

The present study was undertaken to verify the conclusions of [2] experimentally. In this communication we present the results of an investigation of the thickness dependence of the current-voltage characteristics in thin surface layers of n-Si, from which we conclude that the energy of the hot electrons is absorbed by the surface of the semiconductor.

The investigations were made on n-Si single crystals ($\rho = 200$ ohm-cm) at two fixed temperatures (300 and 77°K). The resistance behavior of the contacts, which were prepared by the technology of [4], was monitored against the form of short current pulses flowing through the sample. To obtain thin surface layers we used the surface field effect [5] in
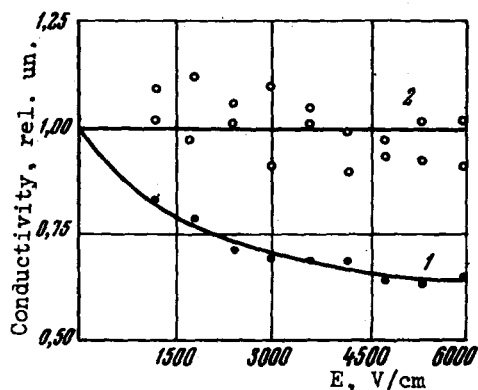
Fig. 1. Relative volume (curve 1) and surface (curve 2) conductivities vs. electric-field intensity.

in the enrichment mode and in the strong nonequilibrium depletion mode.

Figure 1 shows the relative changes of the volume and surface conductivities as functions of the drawing electric field applied to the sample (300°K). The surface conductivity was produced by an external transverse field in the enrichment mode and was determined from a comparison of the theoretical [5] and experimental dependences of the surface conductivity on the induced charge. It is seen from Fig. 1 that, accurate to 10%, the conductivity of the surface layer does not depend on the applied electric field up to fields of 6 kV/cm. At the same time, the volume conductivity depends noticeably on the field intensity, and a decrease by 10% is obwerved already at 1.5 kV/cm, i.e., the critical field for electron heating on the surface and inside the volume differ by not less than a factor of 4.

At low temperatures, a thickness dependence of the current-voltage characteristics was observed during the time interval when the equilibrium was restored after the nonequilibrium depletion of the majority carriers from the sample. Assuming uniform distribution of the carriers in the conducting channel (which is valid if the channel thickness d exceeds the screening length L_d), it is possible to set in correspondence a channel thickness with each
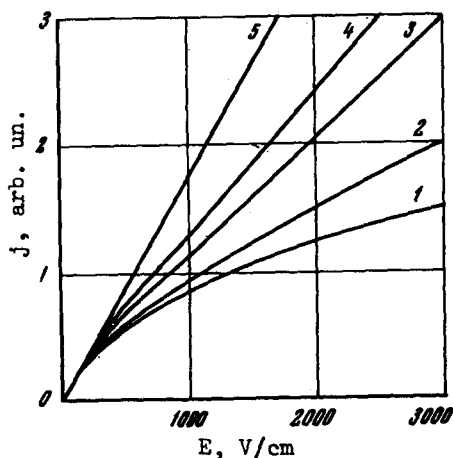

Fig. 2. Dependence of the current density on the electric field intensity for different conducting-layer thicknesses: 1) d = 100 μ, 2) d = 17 μ, 3) d = 12 μ, 4) d = 10 μ. Curve 5 was obtained at an ohmic resistance equal to the resistivity of the sample.

150

resistance of the sample. Figure 2 shows the current densities j as function of the electric field E for different thicknesses of the conducting layer. Curve 1 corresponds to the volume characteristic, and the curves above it were obtained for thicknesses $< 30 \mu$. We see that with decreasing thickness of the conducting channel and increase is observed in the current density, and also a decrease in the curvature of the characteristics, as a result of which they become close to linear at thicknesses $< 10 \mu$. Further decrease of the thickness leads to an appreciable change in the character of the current-voltage characteristics, but it has been established that this change is due to the inhomogeneity of the thin ($\sim 1 \mu$) layers.

Possible causes of the validity of Ohm's law in thin layers may be: 1) the diffuse scattering of the carriers from the surface, leading to a decrease in the mobility and to an increase of the critical field necessary for the start of heating (influence of the surface on the momentum relaxation time [1]); 2) inelasticity of the collisions of the carriers with the surface, leading to cooling of the carriers and consequently to an increase in the mobility in strong fields (influence of the surface on the energy relaxation time [2]).

The mean free path ℓ, calculated from the mobility, was 2.4×10^{-6} cm at room temperature and 2.3×10^{-5} cm at nitrogen temperature. Comparison of ℓ with the thicknesses of the layers whose current-voltage characteristics were close to linear (see Figs. 1 and 2) shows that the thicknesses of such layers exceeds the mean free path, so that, in accordance with [1], the corrections for the decrease in the mobility are small and do not explain the observed phenomenon.

Thus, the effect of the rectification of the current-voltage characteristics at small thicknesses of the conducting channels can be attributed to inelastic collisions between the electrons and the surface. It is obvious that in thin silicon layers ($< 1 \mu$ at $300°K$ and $< 10 \mu$ at $77°K$) a situation is realized wherein the carrier momentum is scattered by volume acoustic phonons and the energy is scattered predominantly from the surface. Consequently, the effect predicted in [2] is observed in thin layers of silicon.

An investigation of the cooling of the carriers on the surface will possibly yield, first, the volume parameter, namely the electron cooling length, and second, explain the micromechanism of the interaction between the carriers and the surface. In spite of the large number of investigations [6] devoted to scattering in surface layers, the description of this mechanism has so far only a phenomenological character.

[1]   Fuchs, Cambridge Philos. Soc. 34, 100 (1938); G. R. Schriffer, Phys. Rev. 97, 641 (1955); R. L. Petritz and J. V. Zemel, ibid. 110, 1254 (1958); R. L. Petritz and J. V. Zemel, ibid. 110, 1263 (1958); R. F. Green, D. R. Franke, and J. V. Zemel, ibid. 118, 967 (1960).
[2]   V. I. Mel'nikov, Z. G. Gribnikov, and T. S. Sorokina, Fiz. Tverd. Tela 8, 3379 (1966) [Sov. Phys.-Solid State 8, 2669 (1967)].
[3]   S. Martinuzzi, J. Phys. 25, No. 6, Suppl., 108 (1964); S. Kal'venas and Yu. K. Pozhela, Fiz. Tverd. Tela 9, 1270 (1967) [Sov. Phys.-Solid State 9, 997 (1967)].
[4]   B. L. Boichenko, PTE No. 2, 177 (1964).
[5]   D. Many, J. Goldstein, and N. B. Grover, Semiconductor Surface, North Holland, Amsterdam, 1965.
[6]   R. M. Greene, Surf. Sci. 2, 101 (1964).