Surface mobility of carriers in indium antimonide

E. V. Vlasenko, R. A. Suris, A. M. Filachev, and B. I. Fuks

(Submitted 24 September 1979; resubmitted 14 November 1979)
Pis'ma Zh. Eksp. Teor. Fiz. **31**, No. 1, 49–52 (5 January 1980)

The surface mobility of electrons and holes in an MDS-structure of InSb was measured for the first time as a function of their surface concentration. The effect of quantization of the motion of electrons on their mobility is discussed.

PACS numbers: 73.25. + i

The surface mobility of carriers in semiconductors μ_s is now investigated mainly in metal-dielectric-semiconductor (MDS) structures that contain a Si-SiO$_2$ system. Of much greater interest is the MDS structure of InSb. The effective mass of electrons is much smaller in InSb than in Si and, therefore, the effect of quantization of motion of free carriers on their surface mobility is strong in InSb. However, the surface mobility in InSb heretofore has not been measured. This is apparently due to the fact that measurement of the latter by the usual methods has not been successful. These methods are based on the use of an MDS-transistor,[1] and such InSb transistor has not been developed.

0021-3640/80/010044-04$00.60

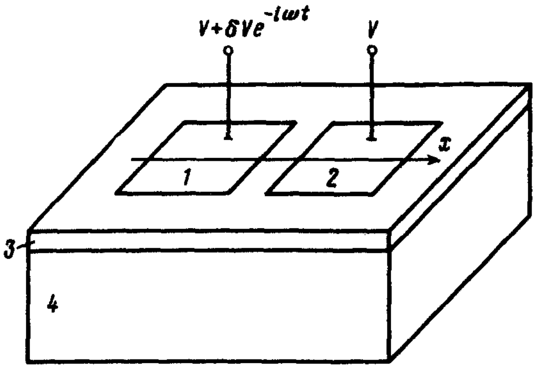

FIG. 1. Schematic representation of the investigated structure: 1 and 2—electrodes; 3—dielectric; 4—semiconductor.

We overcame this difficulty and, as far as we know, measured the surface mobility in InSb for the first time by using a new method[2] based on the measurement of the frequency dispersion of the low-signal admittance of the structure, which contained two closely spaced MDS capacitators (Fig. 1). If we apply a constant voltage V to electrodes 1 and 2, which generates a potential well at the semiconductor surface for the minority carriers, and a small harmonic signal $\delta V e^{-i\omega t}$ is applied to electrode 1, then the minority carriers collected near the semiconductor surface will periodically flow from one electrode to the other. The carriers are delayed longer the larger is ω and the smaller is μ_s, which determines the characteristic frequency dependence of the admittance of such structure:

$$Y(\omega) = -\frac{iC\omega}{2}\left(1 + \frac{i}{\omega\tau}\right)^{-1} \frac{\operatorname{th}\sqrt{\frac{\omega i L^2}{\mu_s V}\left(1 + \frac{L}{\omega\tau}\right)^{-1}}}{\sqrt{\frac{\omega i L^2}{\mu_s V}\left(1 + \frac{i}{\omega\tau}\right)^{-1}}} .$$

Here C is the capacitance of one MDS capacitator and L is its size in the direction of the carrier flow. The difference between this equation and that obtained in Ref. 2 is in the substitution $\omega \rightarrow \omega(1 + i/\omega\tau)^{-1}$, since we now take into account the generation of carriers in the near-surface depleted layer whose characteristic time is τ.

The results of the measurements are shown in Figs. 2 and 3. We note the following important differences between the hole μ_s^p and the electron μ_s^n mobilities: (1) μ_s^p has a maximum at the surface concentration of the holes $N_s = 5\times10^{11}$ cm^{-2}, whereas μ_s^n has no maximum in the investigated range of N_s, (2) μ_s^n exceeds μ_s^p by more than two orders of magnitude, (3) μ_s^p to the right of the maximum decreases approximately as N_s^{-1}, while μ_s^n decreases faster than N_s^{-2}. Below we give the reasons showing that these differences give evidence of the important role of the quantum nature of the motion of electrons, which are much lighter than holes, along the semiconductors surface and in the direction normal to it.

The reason for the appearance of a maximum in μ_s is as follows. The dielectric in the MDS structure is an amorphous substance that contains randomly distributed

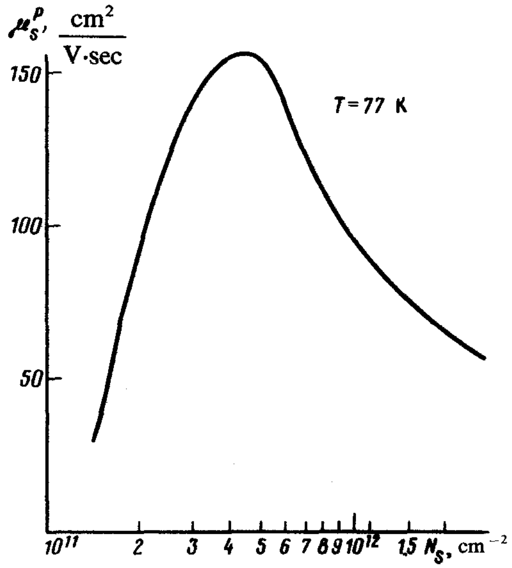

FIG. 2.

positive and negative fixed charges bound either to the impurity atoms or to the broken chemical bonds. In the near-surface layer of the semiconductor, the field of these charges generates a fluctuating potential whose wells contain the minority carriers. Only the carriers with greater energy than the flow level contribute to the conductivity along the surface. The higher is the N_s, the stronger is the screening of the fluctuating potential and the lower is the flow level. Thus, μ_s increases with increasing

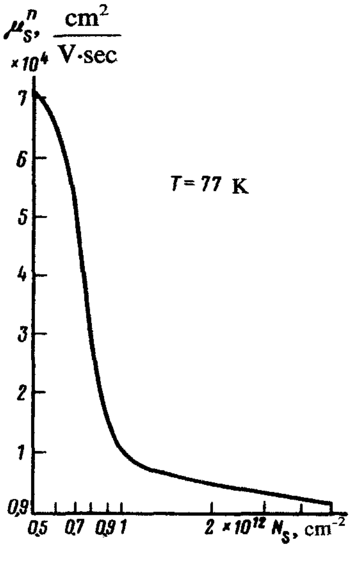

FIG. 3.

N_s. For a specific value of $N_s^{\max}$, the excitation energy at the flow level is zero, and as N_s increases further the mobility decreases, since the increase of N_s is associated with an increase in the electric field E_s normal to the surface, which presses the carriers against it and increases the role of surface scattering.

The lighter is the carrier, the more important is the quantum delocalization, the lower is the flow level, and the smaller is $N_s^{\max}$. The results[4] allow us to connect $N_s^{\max}$ to the *total* surface density of the positive and negative charges embedded in the dielectric, σ_s. For heavy carriers whose effective Bohr radius $a_B = \hbar^2\epsilon/me^2$ is so small that $\sigma_s a_B^2 \ll 1$, $N_s^{\max} \sim \sigma_s$. If the carriers are light and $\sigma_s a_B^2 \gg 1$, then $N_s^{\max} \sim \sigma_s/(\sigma_s a_B^2)^{1/2}$. In InSb, a_B is approximately 30 times larger for electrons than for holes, and is about 500 Å. If $\sigma_s \sim 10^{12}$ cm^{-2} (for a typical dielectric thickness of $\sim$ 1000 Å, this corresponds to a volume density of the charged defects of 10^{17} cm^{-3}), then for electrons $\sigma_s a_B^2 \sim 10$–100, and $N_s^{\max}$ should be several times smaller than for the holes for which $\sigma_s a_B^2 \sim 10^{-2} - 10^{-1}$.

The differences between μ_s^n and μ_s^p at points 2 and 3 are evidence in favor of the quantization of the electron motion in the direction normal to the surface. In the absence of quantization, the carrier mobility under the conditions of their diffusion scattering by the surface is $\mu_s = v_T/E_s$ [5] (v_T is the thermal velocity and E_s is the field at the surface proportional to N_s) and decreases as as N_s^{-1}. (This is true when E_s is so large that the length of the carrier localization at the surface kT/eE_s is much shorter than the free path in the volume.) Between our experimental values beyond the maximum are in good agreement with this expression.

If μ_s^n could be described by a similar expression, then it would exceed μ_s^p by a factor of $\sqrt{m_p/m_n} \sim 5$. We can see from a comparison of Figs. 2 and 3 that this ratio is much larger, and a decrease in μ_s^n with N_s occurs much faster than according to the law N_s^{-1}. It is known[3] that the quantum localization of the carriers on the one hand decreases the role of surface scattering, and on the other band it leads, in the limiting quantum case, to a sharper dependence of the mobility on $N_s (\mu_s \sim N_s^{-2})$. Figure 3 shows that the rate of decrease of μ_s^n is even faster. We attribute this effect to the "loading" of the electrons as a result of their localization because of the nonparabolicity of the dispersion law. The evaluation shows that in InSb for a surface charge of 10^{12} e/cm^2 the ground-state level of the electrons is separated by $\sim$0.1 eV from the bottom of the conduction band. At such energies the nonparabolicity of the dispersion law for the electrons is large.

[1] A.V. Rzhanova, ed., Svoĭstva struktur metall-dielektrik-poluprovodnik (Properties of Metal-Dielectric-Semiconductor Structures), Nauka, Moscow (1976).
[2] E.V. Vlasenko, R.A. Suris, and B.I. Fuks, Fiz. Tekh. Poluprovodn. **11**, 1112 (1977) [Sov. Phys. Semicond. **11**, 657 (1977)].
[3] F. Stern, in: Surface Science: Recent Progress and Perspectives, T.S. Jayadevaiah and R. van Selow, eds., CRC Press, Inc., Cleveland (1974).
[4] V.A. Gergel' and R.A. Suris, Zh. Eksp. Teor. Fiz. **75**, 191 (1978) [Sov. Phys. JETP **48**, 95 (1978)].
[5] J.R. Schrieffer, Semiconductor Surface Physics, R.H. Kingstone, ed., Univ. of Pennsylvania Press, Philadelphia (1957).