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SURFACE SCATTERING MECHANISMS ON GERMANIUM

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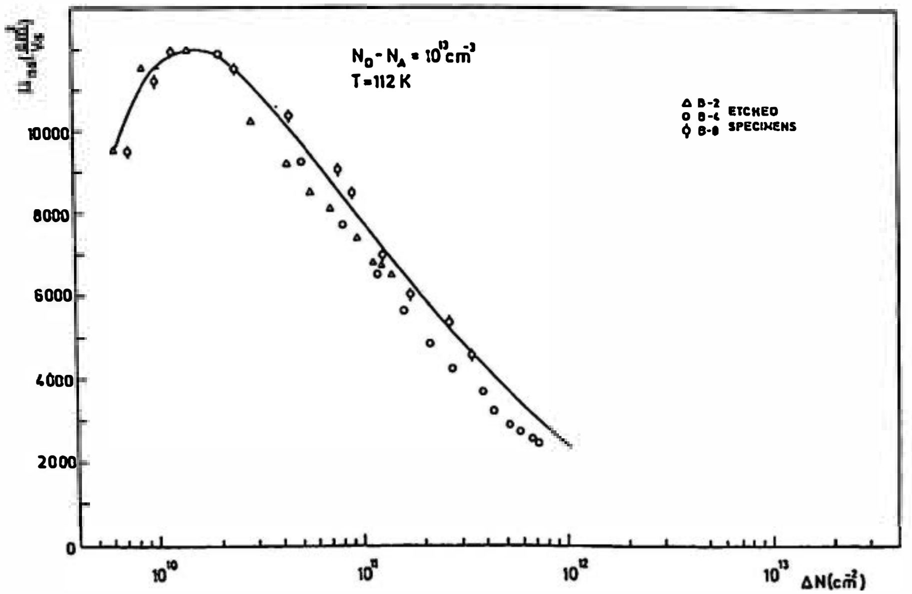
Abstract: Surface mobilities of electrons have been obtained by combined measurements of the electrical conductivity and Hall effect on near intrinsic n-type germanium at reduced temperatures. Mobility data plotted as a function of surface excess density of electrons are fitted with a semi-empirical expression which takes into account the following surface scattering mechanisms: ionized impurities, lattice vibrations and surface irregularities at the interface.

1.Introduction

Scattering of free carriers at semiconductor surfaces has been investigated for a number of years both theoretically and experimentally. With the advent of Si MOS technology in 1960s, large amount of work has been performed on this system. Various mechanisms of surface scattering have been postulated for the interpretation of data[1]. Semiconductors like Ge, InSb, InAs, GaAs and some others have also been investigated. Surface transport phenomena on Ge were investigated at the time when surface mobility theory had been developed by solving the Boltzmann equation[2,3,4,5]. Experimental results[6,7,8,9,10] had been compared with the above mentioned theory showing that germanium surfaces acted neither as completely diffuse nor completely specular scatterers. In this work we have made combined measurements of conductivity and Hall effect on etched germanium surfaces at reduced temperatures. Surface mobility data obtained for electrons in accumulation layers are fitted with an expression that takes in account scattering mechanisms on ionized impurities, lattice vibrations and surface irregularities at the interface.

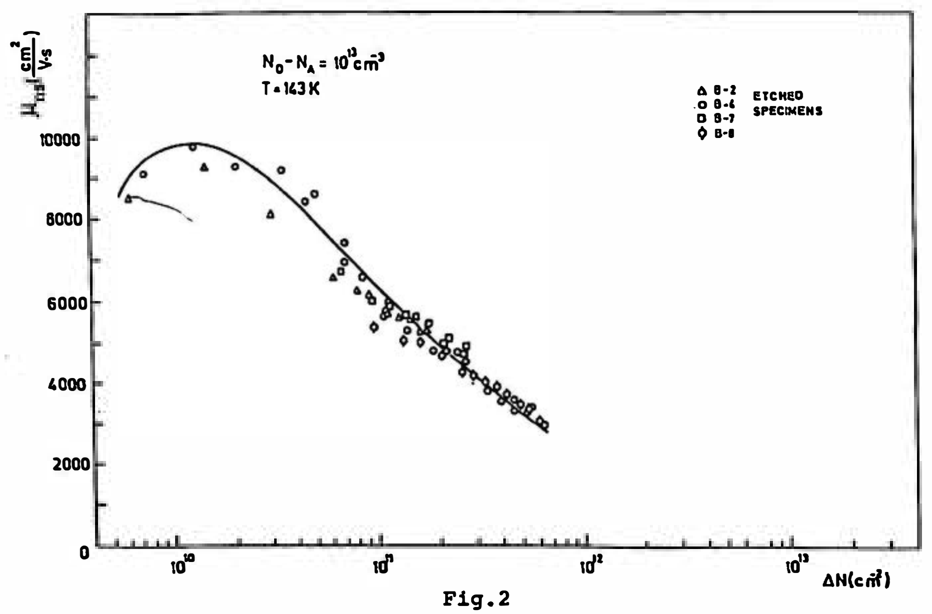
2.Experiments

Specimens have been prepared from single crystal slices of near intrinsic n-type germanium. They received the usual treatments of polishing and etching in CP-4A. All specimens were supplied with excentrically placed side arms[7]. Measurements were made in the temperature range between 112 and 203 K. In this temperature range slow surface states relaxations were absent. Conductivity and Hall effect changes were produced by the field effect at several fixed temperatures. Hall effect measurements were made at magnetic field strength of 0,3 T. Linear dependence of Hall voltage on magnetic field had been checked at the field free point. By employing the procedure suggested by Petritz[6], surface Hall mobilities of electrons in accumulation layers have been obtained. They are plotted as a function of the excess surface carrier density ΔN. These results are shown on figs. 1,2 and 3. Their common feature is the mobility drop with increasing excess carrier density, preceeded by a maximum at lower densities.



$N_D - N_A = 10^{13}$ cm^{-3}
T = 112 K
△ B-2
○ B-4 ETCHED
◊ B-8 SPECIMENS
10000
8000
6000
4000
2000
0
10^{10}
10^{11}
10^{12}
10^{13}
ΔN(cm^{-2})

Fig.1



μ_{HS} ($\frac{cm^2}{V \cdot s}$)
$N_D - N_A = 10^{13}$ cm^{-3}
T = 143 K
△ B-2
○ B-4 ETCHED
□ B-7 SPECIMENS
◊ B-8
10000
8000
6000
4000
2000
0
10^{10}
10^{11}
10^{12}
10^{13}
ΔN(cm^{-2})

Fig.2

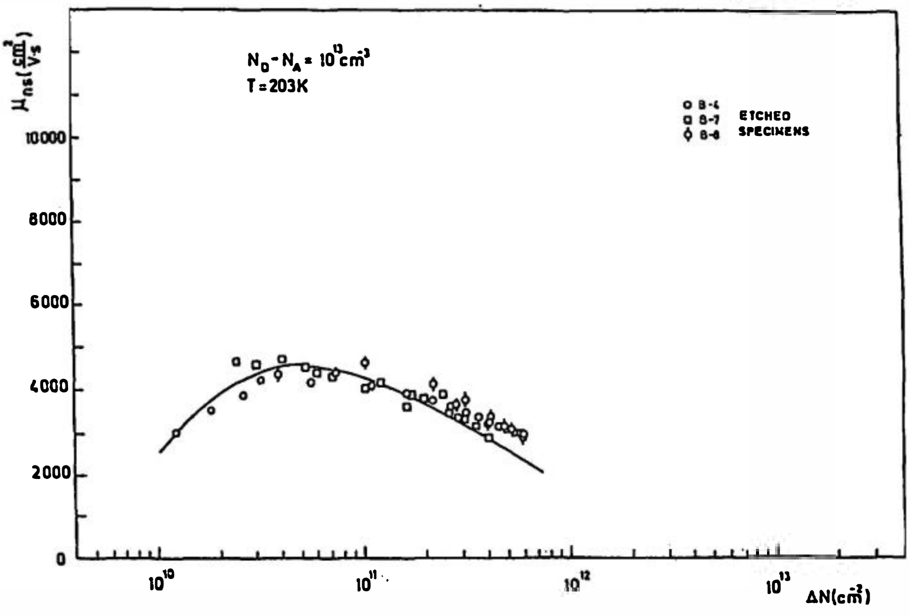


Fig.3

3.Discussion

In the analysis of our results we neglect the difference between Hall and drift mobilities, since this point has not been so far adequately covered in the surface transport theory. We have interpreted our surface mobility data with a tree term semi-empirical expression used by Rico et al.[12] for Si MOS structure. This approach is based on an assumption that several scattering mechanisms act simultaneosly and independently, so that the resulting mobility can be combined according to the Mathiessen's rule, that is

$$\frac{1}{\mu} = \frac{1}{\mu_1} + \frac{1}{\mu_2} + \frac{1}{\mu_3} .$$

In this expression the first term is due to the carrier scattering on surface potential fluctuations. Spatial fluctuations of the surface potential are caused by ionized centers in the semiconductor oxide near the interface. For small carrier concentrations some carriers will be trapped in the deepest potential fluctuations and the resulting mobilities will be low. As the excess carrier density increases, ionized centers become screened and the mobility goes up. One can assume linear dependence of mobility on surface carriers excess for this scattering mechanism, namely

$$\mu_1 = A(T)\Delta N$$

where A(T) is a temperature dependent constant.
The second term in the mobility expression represents phonon scattering. For this term we used results of Sah et al.[13] and Kawaji[14]

$$\mu_2 = \frac{C}{T(\Delta N)^{1/3}}$$

The last term corresponds to the situation when all ionized centers are completely screened and energy bands at the surface are strongly bent. In this case quantization effects should set in leading to an increase of the mobility. However, there are surface irregularities (localized defects and lattice strains in the merging region of crystalline Ge and amorphous oxide) that will act as scattering centers and lead to a decrease of the mobility. Toscano-Rico describes this scattering with an expression similar to the results of Schrieffer[2]

$$\mu_3 = \frac{BT^{1/2}}{\Delta N}$$

To low mobility values in this region of carrier concentration correspond very short relaxation times and this fact leads, through the uncertainty relation for energy, to smearing of the quantized levels which is comparable to the distance between the twodimensional subbands.

As can be seen on Figs.1,2 and 3, which correspond to a temperature range of roughly 90 K, the three term expression gives a good fit to the experimental mobility data. We obtained the following values for the constants: $A(112K)=2{,}8\cdot10^{-6}$, $A(143K)=2{,}6\cdot10^{-6}$, $A(203K)=3{,}5\cdot10^{-7}$; $B=7{,}0\cdot10^{14}$ and $C=4{,}9\cdot10^{9}$. We have compared the value of our constant C with one computed from the theoretical expression for surface phonon scattering. The theory gives one order of magnitude larger value for C which might be due to the somewhat uncertain value of the surface deformation potential constant.

4.Conclusions

We have shown that the surface mobility of electrons in accumulation layers on etched germanium, presented as a function of surface excess carrier density, can be explained by a model which takes in account surface scattering on potential fluctuations, on surface phonons and on surface irregularities.

References:

1) Electronic Properties of Quasi-Two-Dimensional Systems, Surface Sci. 58(1976) 1 - 340 (References).

2) J.R.Schrieffer, Phys.Rev. 97 (1955) 641.

3) R.F.Greene, D.R.Frankl and J.N.Zemel, Phys.Rev. 118 (1960) 967.

4) N.B.Grover, Y.Goldstein and A.Many, J.Appl.Phys. 32 (1961) 2538.

5) Y.Goldstein, N.B.Grover, A.Many and R.F.Greene, J.Appl.Phys. 32 (1961) 2540.

6) R.L.Petritz, Phys.Rev. 110 (1958) 1254.

7) J.N.Zemel and R.L.Petritz, Phys.Rev. 110 (1958) 1263.

8) J.N.Zemel and R.L.Petritz, J.Phys.Chem.Solids 8 (1959) 102.

9) A.Many, N.B.Grover, Y.Goldstein and E.Harnik, J.Phys. Chem.Solids 14 (1960) 186.

10) A.V.Ržanov, V.P.Migalj i N.N.Migalj, Fiz. i Teh. poluprovodnikov 3 (1969) 231.

11) D.Čajkovski and T.Čajkovski, Fizika 3 (1971) 57.

12) A.Toscano-Rico and J.C.Pfister, Phys.Stat.Sol. (a) 5 (1971) 209.

13) C.T.Sah, T.H.Ning and L.L.Tschopp, Surface Sci. 32 (1972) 561.

14) S.Kawaji, J.Phys.Soc.Japan 27 (1969) 906.