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THE INFLUENCE OF THE CARRIER DISTRIBUTION ON THE HALL MOBILITY OF A THIN SEMICONDUCTOR IN A DEEP DEPLETION IGFET

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The Petritz expressions are used to calculate the Hall mobility and conductivity dependence on the gate voltage of a thin semiconductor in a deep depletion IGFET. It is shown that, by using a suitable spatial variation and an exact carrier distribution and by fitting the surface scattering parameters and surface states density, it is possible to obtain good agreement with the experiments of another author[3].

It has been experimentally shown[1,2,3,4] that the Hall mobility of a thin semiconductor in a deep depletion IGFET essentially depends on the gate voltage. This is due to the spatial variation of mobility $\mu(x)$ (where x is the "thickness" coordinate) caused either by scattering centres spatially distributed in the bulk of the semiconductor, or by surface scattering, or by both. It follows from the one-electron Petritz formula[5]

$$\mu_H = \left(\int_0^{d_s} \mu_n^2(x) n(x) dx \right) / \left(\int_0^{d_s} \mu_n(x) n(x) dx \right) \qquad (1)$$

that Hall mobility μ_H depends on the carrier distribution. d_s in (1) is the thickness of the semiconductor. Because the n(x) distribution is determined by V_G (the gate voltage), μ_H depends on V_G.

The purpose of this paper is to obtain the theoretical $\mu_H(V_G)$ dependence starting from (1) and to fit it to experiments. To do so, it is first of all necessary to know the spetial variation of $\mu_n(x)$. We shall adopt

$$\mu_n(x) = \mu_0 / \left(1 + \frac{|E(x)|}{E_c} \right) \qquad (2)$$

for $\mu_n(x)$ where E(x) is the electric field distribution in the semiconductor and E_c is a scattering parameter[6]. Expression (2) is not entirely empirical. Namely, on the basis of the Schrieffer theory[7] the following approximate expression may be obtained

$$\mu_{ns} = \mu_0 / \left(1 + \frac{|E_s|}{E_0} \right) \qquad (3)$$

for the effective surface mobility of excess surface carriers. In (3), E_s is the surface electric field while E_0 is a parameter which characterizes both the surface (the coefficient of surface reflectivity, surface states, etc) and the bulk of the semiconductor. Expression (2) has otherwise been used earlier but for other purposes[8].

Generally, due to the spatial distribution of scattering centres in the bulk, μ_0 depends linearly[2] or exponentially[9] on x, decreasing from the upper (semiconductor-gate insulator interface) to the rear (semiconductor - insulating substrate interface) surface of the semiconductor. However, we shall not take this into consideration and shall assume that $\mu_0 \neq \mu_0(x)$.

By solving the Poisson equation one-dimensionally[6,11] and using non-degenerate statistics ($n(x) = n_0 \exp(e\Psi(x)/kT)$), it is possible to express E(x) as a function of Ψ only. This, then enables us to express (1) as

$$\mu_H(V_G) = \frac{\int_{\Psi_1}^{\Psi_2} \mu_n^2(\Psi) n_0 \exp(e\Psi/kT) d\Psi/E(\Psi)}{\int_{\Psi_1}^{\Psi_2} \mu_n(\Psi)\; n_0 \exp(e\Psi/kT) d\Psi/E(\Psi)} \; ; \; \mu_n(\Psi) = \frac{\mu_0}{1 + \frac{|E(\Psi)|}{E_c}} \quad (4)$$

We can see from (4), that in this case the $\Psi(x)$ potential distribution does not have to be known. Only $\Psi_1(V_G)$ and $\Psi_2(V_G)$ have to be known, where Ψ_1 and Ψ_2 are the potentials at the upper and rear surface, respectively. We have, by suitably choosing boundary conditions, already[6] derived expressions which enable the numerical calculation of $\Psi_1(V_G)$ and $\Psi_2(V_G)$:

As has been already mentioned above, E_c is due to surface scattering. Hence, E_c must be different for the upper (E_{c1}) and rear (E_{c2}) surface. We also have to bear in mind the specific characteristics of the various types of potential distributions:

a. If the gate voltage accumulates both the upper and rear surface (CH distribution $\Psi_1 . \Psi_2 > 0$, $E_1 . E_2 < 0$) we then separate the integrals in (4) into two integrals with boundaries Ψ_1, Ψ_0 with $E_c = E_{c1}$ and Ψ_2, Ψ_0 with $E_c = E_{c2}$.

b. In the case of a SH^+ distribution ($E_1 . E_2 > 0$, $\Psi_1 \cdot \Psi_2 < 0$) and a n-type semiconductor we consider two cases: 1^0 $\Psi_2 < 0$,

$E_c=E_{c1}$ 2^o $\Psi_2>0$, $E_c=E_{c2}$ for the whole interval of integration Ψ_1,Ψ_2. This actually means that the scattering at the accumulated surface is considered more dominant than the scattering at the depleted surface.

c. A SH^+ potential distribution means that the whole semiconductor is either fully enriched or fully depleted ($E_1 \cdot E_2>0$, $\Psi_1 . \Psi_2>0$). In the case of a fully enriched semiconductor a value of E_c which corresponds to a more accumulated surface is used for the whole integration interval whereas in the fully depleted case a value of E_c for the less depleted surface is used. Thus, for a n- type semiconductor, we have

$$1^o\ \Psi_1,\Psi_2>0\quad \begin{matrix}\Psi_1>\Psi_2\rightarrow E_c=E_{c1}\\ \Psi_1<\Psi_2\rightarrow E_c=E_{c2}\end{matrix}\qquad 2^o\ \Psi_1,\Psi_2<0\quad \begin{matrix}|\Psi_1|<|\Psi_2|\rightarrow E_c=E_{c1}\\ |\Psi_1|>|\Psi_2|\rightarrow E_c=E_{c2}\end{matrix}$$

In this paper we have fitted our numerical results for (4) to the $\mu_H(V_G)$ experimental dependence for a silicon-on-saphire (SOS) IGFET in which $n_o=10^{16}cm^{-3}$, of semiconductor thickness $d_s=1$ μm and gate insulator thickness 0.11μm [3]. Since surface states were not measured in[3], we had to fit them as well. At the rear surface we have only considered the slow positively charged states with a density of N_{SS2}. Namely, for the above mentioned values of n_o and d_s, the semiconductor behaves as if it were "thick". Due to this, the change of rear surface states cannot change with gate voltage even in the presence of fast surface states[6]. At the upper surface both slow (density N_{SS1}) and fast (density N_{SB1}) states must be fitted. As is usually the case, we have used the δ- function for the energy distribution of fast surface states with the acceptor level at $W_{ta1}=0.15$ eV and the donor level $W_{td1}=0.90$ eV below the bottom of the conduction band. μ_o does not have to be fitted because it appears in $\mu_H(V_G)$ as a multiplicative factor only.

Apart from Hall mobility, we have also calculated the conductivity of the semiconductor using

$$\sigma(V_G) = \frac{e}{d_s}\int_0^{d_s}\mu_n(x)n(x)dx = \frac{e}{d_s}\int_{\Psi_1}^{\Psi_2}\mu_n(\Psi)n_o\exp(e\Psi/kT)d\Psi/E(\Psi) \qquad (5)$$

with $\mu_n(\Psi)$ being from (4).

The results of the theoretical calculation are shown in Fig. 1. It can be seen that our theory and the experiment presented in [3] are in good agreement, this being especially so for mobility. The discrepancy is only significant for the $\sigma(V_G)$ dependence.

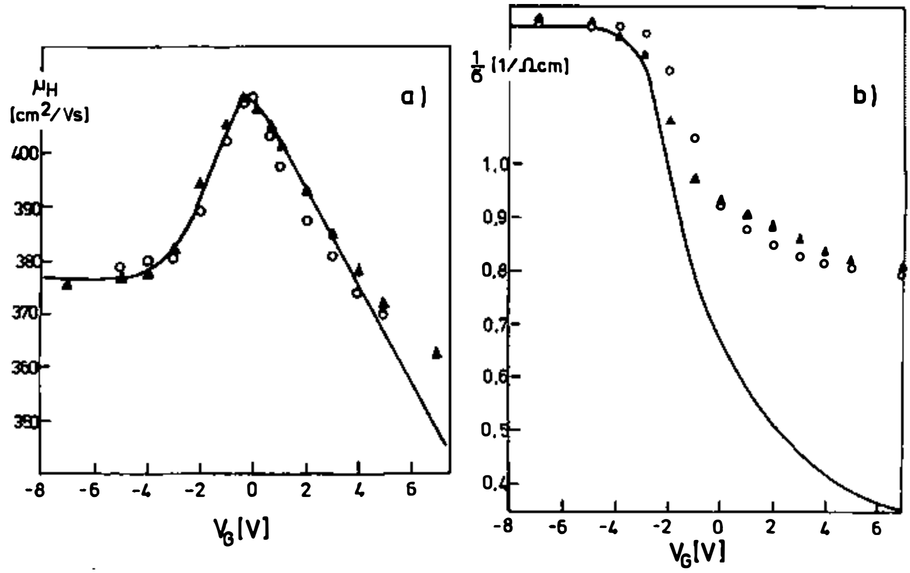

Fig. 1. Experimental (full line)[3] and theoretical (o, ▲) dependence of (a) Hall mobility μ_H ; (b) conductivity σ on the gate voltage of a thin semiconductor in a SOS IGFET structure. The value of the parameters used are $n_o = 10^{16}$ cm^{-3}, $d_s = 1\ \mu$m, $N_{SS2} = 2 \cdot 10^{12}$ cm^{-2}, $\mu_o = 510$ cm^2/Vs, $E_{c1} = E_{c2} = 1.8 \cdot 10^4$ V/cm. o denotes the case without surface states at the upper surface ($N_{SS1} = 0$, $N_{SB1} = 0$) and ▲ the case with optimal fitting values of the surface states density ($N_{SS1} = 5 \cdot 10^{11}$ cm^{-2}, $N_{SB1} = 4 \cdot 10^{11}$ cm^{-2}).

The agreement of our theory with experiment is somewhat better when the surface states (slow and fast) at the upper surface are taken into account (sign ▲ in Fig. 1).

In Fig. 1 we have taken $E_{c1}=E_{c2}$. Somewhat lower value of E_{c1} (= $1.6\cdot 1o^{4}$V/cm) gives better agreement with the experiment in the inversion region (flat part of $\mu_H(V_G)$ curve) when the surface states of the upper surface arenot included. This is not shown in Fig. 1.

The results of our theory for high resistivity semiconductor will be published later.

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