An analytic mobility model for two dimensional electron gas layers and the implementation in a device simulator.

Andras Poppe Wim Schoenmaker Wim Magnus Cristiano Sala
Rudi Vankemmel Kristin De Meyer
IMEC, 75 Kapeldreef, 3001 Leuven, Belgium

February 4, 1991

1 Introduction

The ongoing miniaturization of semiconductor devices will result into increasing simulation errors, provided that one is limited to the classical approximations of the Boltzmann transport equation. Hot electron effects are now incorporated by the use of higher moments but quantization effects at inversion layers are still outside the scope of existing general purpose device simulators, although there exist programs which solve the Poisson and Schrödinger equations simultaneously. However, these programs are usually dedicated to a very particular layout of the device or are restricted to a one-dimensional analysis. In this work we will discuss the fusion of such a dedicated simultaneous Poisson/Schrödinger solver and a 2D device simulator.

2 The mobility model.

At IMEC a project was carried out to develop a method for a selfconsistent solution of the Schrödinger equation and Poisson's equation at inversion layers. This project resulted into SCALPEL [1] [1]. With SCALPEL one can calculate the energies, wavefunctions and populations of quantum states in two-dimensional electron gas (2DEG) layers. In order to solve the transport problem [2] another program, SPACETRAM [2] was developed which relies on SCALPEL. The program SPACETRAM can be used to calculate the drift velocity in 2DEG layers. For an GaAs/AlGaAs heterojunction, the transport problem is solved by incorporation of a non-parabolic band structure, LO phonon scattering, LO intervalley scattering, remote impurity scattering, the dependence on the spacer geometry, the screening effect and the bulk doping. With SPACETRAM we calculated the mobility of the electrons in the inversion layer for a wide variety of electric field strenghts. The inversion layer concentration varied from 10^9 to 5.0×10^{12} cm^{-2} . Our next objective was to represent the mobility for these different inputs in an analytic expression of which the parameters were determined by means of a fitting program SIMPAR [3].

Our first observation was that the well-known bulk formula for the drift velocity

$$v_d(E) = \frac{\mu_0 E + v_s \left(\frac{E}{E_{crit}}\right)^4}{1 + \left(\frac{E}{E_{crit}}\right)^4} \tag{1}$$

was not suitable for describing the transport in 2DEG layers. Instead, we could fit the drift velocities with the following expression

$$v_d(E) = \frac{\mu_0 E v_s \exp\left(\frac{E_0}{E+E_1}\right)}{\mu_0 E + v_s \exp\left(\frac{E_0}{E+E_1}\right)} \tag{2}$$

where v_s is the saturation velocity, μ_0 the low field mobility, and E_0 and E_1 characterize the overshoot and saturation regions. All the 'parameters' v_s, μ_0, E_0, E_1 are still dependent on the surface concentration, N_S. The dependence has been determined also empirically. Our findings are summarized below. The low field mobility is

$$\mu_0(N_S) = \frac{\mu_{00}}{\left(A + \frac{N_S}{N_0}\right)^n} + \frac{\mu_\infty}{1 + \exp\left(\frac{\frac{N_S}{N_0} - B}{C}\right)} \tag{3}$$

---

[1] Self- Consistent Algorithm for Population and Energy Levels

[2] SPatially Confined Electrons TRAnsport Module

[3] SIMulation of PARameters

$\mu_{00} = 33078 cm^2/V sec$
$\mu_{\infty} = 5859 cm^2/V sec$
$A = 3.1083 \times 10^{-3}, B = 5.7809$
$C = 1.0713, n = 0.4879$

The saturation velocity is

$$v_s(N_S) = v_a \exp\left(-\frac{N_S}{N_1}\right) + \frac{v_b}{\left(A + \frac{N_S}{N_0}\right)^n} \quad (4)$$

$v_a = 3.985 \times 10^6 cm/sec$
$v_b = 1.012 \times 10^6 cm/sec$
$N_1 = 15.745 \times 10^{12} cm^{-2}, A = 9.7400 \times 10^{-3}$,
$n = 0.31444$

The peak field is

$$E_0(N_S) = \frac{E_{00}}{\left(A + \frac{N_S}{N_0}\right)^n} + \frac{E_{\infty}}{1 + \exp\left(\frac{\frac{N_S}{N_0} - B}{C}\right)} \quad (5)$$

$E_{00} = 17035 V/cm$
$E_{\infty} = 5391 V/cm$
$A = 8.2642 \times 10^{-4}, B = 5.2142$
$C = 1.8406, n = 0.67614$

Finally, the N_S dependence of E_1 is

$$E_1(N_S) = \frac{E_{10}}{\left(A + \frac{N_S}{N_0}\right)^n} \quad (6)$$

$E_{10} = 6509.2 \frac{V}{cm}$
$A = 1.5321 \times 10^{-3}, n = 0.83990$
In all equations we have $N_0 = 10^{12} cm^{-2}$.

3 The Implementation.

In order to implement the analytic mobility model in the device simulator PRISM [4], we have defined a new type of material, named DEG2, in which the new mobility model of the two dimensional electron gas should be valid. Since this is a thin layer, we represent this layer with one layer of elements as is shown in Fig.1 . In each element we can easily detect the interface nodes and the surface charge is taken to be the charge lumped in these nodes. Furthermore, the mobility is calculated for each *side* of the element, see Fig.2, because the new mobility model is only applicable for the drift velocity component which is tangential to the interface. We take for the bulk mobility the formula of Mawby, Snowden and Morgan [3].

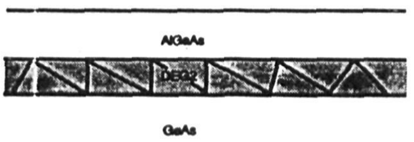

Fig.1 Location of the 'material' DEG2 at the GaAs/AlGaAs heterojunction, and its covering with meshing elements.

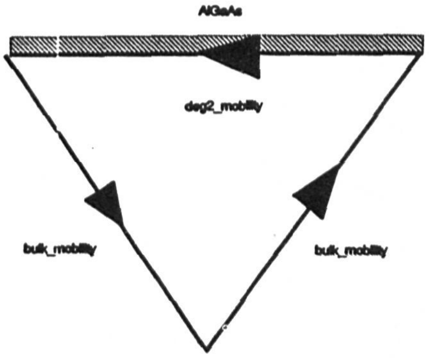

Fig.2 Assignment of the mobilities to the links inside an element.

4 Conclusion

We have presented a method to incorporate two-dimensional quantum layer effects into a two-dimensional device simulator. Simulations of GaAs/AlGaAs mesfets are now under consideration.

References

[1] W.Magnus, C.Sala and K. De Meyer *Phys.Rev. B41 5197 (1990)*

[2] C.Sala, W. Magnus and K De Meyer *to appear in Journ. of App. Phys.*

[3] P.A.Mawby, C.M.Snowden and D.V.Morgan *Simulations of Semiconductor Devices and Processes Vol 2 Proc. 2nd International Conference held at Univ. of Swansea, U.K. (1986) Ed. K.Board and D.Owen,Pineridge Press.*

---

[4] PRogram for Investigating Semiconductor Models