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Analytical Study of Mobility Extraction of MOSFET

Anil Kumar[1], Rakesh Kumar Singh[2], A.K. Jaiswal[3]

Assistant Professor, Department of Electronics and Comm. Engg., SHIATS-DU, Allahabad, India [1]
Research Student, Department of Electronics and Comm. Engg., SHIATS-DU, Allahabad, India [2]
Professor, Department of Electronics and Comm. Engg., SHIATS-DU, Allahabad, India [3]

Abstract: A mobility extraction method for Si MOSFETs, is presented. An accurate mobility extraction is obtained from the linear drain current by excluding the parasitic source/drain resistance and the parasitic gate capacitance Direct extraction of each parameter using a linear regression approach is performed by -parameter analysis on the proposed equivalent circuit of the MOSFET for high-frequency operation. The extracted results are physically meaningful and good agreement has been obtained between the simulation results of the equivalent circuit and measured data without any optimization. Also, the extracted parameters, such as and ds, match very well with those obtained by dc measurement.

Keywords: MOSFET, Structure, Mobility, Electric Field.

I. INTRODUCTION

Today, MOSFET simulation and modelling has left its infancy and has reached a level whereby high agreement is reached with experimental characteristics. At the same time, by building in temperature dependent physical models, it is possible to predict the low temperature operation in an accurate way [l]-[4]. In principle, one could thus restrict the actual low-temperature device characterisation to the absolute minimum and rely on numerical parameter calculations. In practice, however, the situation is more complex. For instance, for MOSFETs operating in the freeze-out regime, which typically occurs below 50 K or so, some new physical phenomena start to play a role, which are generally less well understood and require a detailed study of the underlying mechanism. Furthermore, upon down-scaling the device dimensions to the submicron and the nano scale, the device parasitic become prominent and start to affect the I-V characteristics. This is the more true for low temperature operation, which can increase the mobility degradation and the series resistance [5]. At the same time, high transverse and high lateral field effects become important [6] and carrier velocity saturation limit the drive current [7]. So from a practical and a more fundamental viewpoint there is still a need for detailed MOSFET studies at temperatures and hence for parameter extraction methods., in order to unravel the temperature dependence of physically relevant properties like the charge threshold voltage Vt, the subthreshold swing S, the effective mobility (μeff), the source-drain series resistance R_{SD} and the effective device length L_{eff}. As will be seen, most methods rely on an input curve (I_D versus Vgs) registered in linear operation, i.e. for low drain voltage V_{DS}. It will become clear that traditional room temperature, mobility parameter extraction need important.

II. STRUCTURE OF MOSFET

Figure-1 is the structure of the MOSFET transistor which has oxide thickness (tox) 30nm, intrinsic concentration (Ni)$1.4*10^{10}cm^{-3}$, Impurity atoms (Na)$2*10^{15}$,width of the channel (W) 3µm, channel length(L)1µm,and the threshold voltage (Vt) is the 0.75v.

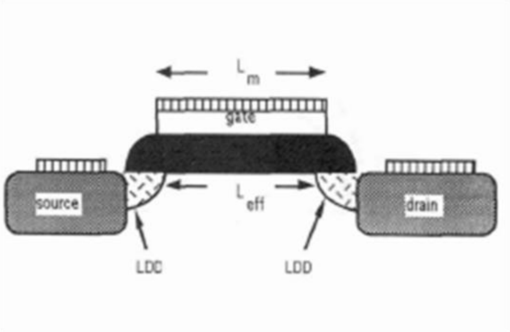

FIGURE-1: STUCTURE OF MOSFET

III. MOBILITY

Effective mobility at moderate transverse electric field

The extraction and physical modelling of the inversion layer mobility has attracted a lot of attention in the past two decades, both at room temperature [8]. At room temperature, the effective mobility μ_{eff} , which is defined as:

$$\mu_{eff} = \frac{L_{eff}}{W_{eff}} \frac{g(Vgs)}{qNs(Vgs)} \qquad (1)$$

$$\mu_{eff} = \frac{L_{eff}}{W_{eff}} \frac{Id}{Cox\ (Vgs - Vt)Vds} \qquad (2)$$

takes the form:

$$\mu_{eff} = \frac{\mu_0}{1+\theta^{\#}(Vgs - Vt)} \qquad (3)$$

in strong inversion. Hereby is g_d the channel conductance ($\partial Id/\partial Vds$), Ns the inversion layer carrier surface density and μ_0 is the zero-field mobility. The generalised mobility attenuation factor $\theta^{\#}$ is given by [9]:

$$\theta^{\#} = \theta + \frac{Cox\ W_{eff}\, Rsd\ \mu_0}{L_{eff}} \tag{4}$$

and is a measure of the reduction of the effective mobility with increasing normal field. The latter is physically due to the increasing contribution of surface roughness scattering to the carrier mobility. From eqs. (3) and (4) it is assumed that the source-drain series resistance is constant with Vgs-Vt (non-LDD type of MOSFETs) and that the gate overdrive voltage Vgs-Vt >>IdRsd/2. As pointed out earlier [10]-[11], the extraction of μ_{eff} from a linear input curve an accurate modeling of the device characteristics, in case of the μ_{eff} dependence on the normal field. This implies that most of the extraction methods which have been proposed recently [12]-[14] are rather complex and require numerical treatment of the measurement data. In many cases, they are applicable only in a restricted temperature regime generally from 77 K. extraction of the electron mobility in inversion and accumulation layers [15], to SOI MOSFETs [16] and to n- and p-MOSFETs with nitrided oxide gates [17]. The principle of the extraction method is based on the empirical relationship between the function I^2 d/g_m and the gate overdrive voltage Vgs-Vt.

$$\frac{Id^2}{g_m} = \beta(Vgs - Vt)^n \tag{5}$$

whereby the coefficient β depends on $\theta^{\#}$. Physically acceptable values for the empirical exponent 'n' are in the range 2 (300 K) to 3 (4.2 K). The effective mobility is shown to be [10]:

$$\mu_{eff} = \mu_g \frac{X^{n-2}}{1+X^{n-1}} \tag{6}$$

with x=θ(Vgs-Vt) and μ_g proportional to the maximum effective mobility through the relationship:

$$\mu_{maxf} = \mu_g \frac{(n-2)^{\frac{n-2}{n-1}}}{n-1} \tag{7}$$

At the same time, the charge threshold voltage Vt at any temperature in the range 4.2 to 300 K can be derived from:

$$V_{Text} = V_t \frac{1}{\theta^{\#}} \left[\frac{n-2}{n}\right]^{\frac{n}{n-1}} \tag{8}$$

Where $\theta^{\#}$ is obtained from:

$$\theta^{\#} = \left(\frac{n-2}{n}\right)^{\frac{n}{n-1}} \frac{1}{Vgs\ max\ - Vt} \tag{9}$$

Vgs max is the gate voltage which corresponds to the maximum transconductance $g_{m\ max}$. Since $\theta^{\#}$ is a positive number and 'n' becomes larger than 2 upon cooling, from eqs (8) and (9) follows that the linear extrapolated threshold voltage V_{Text} is slightly larger than the actual Vt at low Temprature. In practice, it turns out that the exponent 'n' starts to increase in the range between roughly 100 K and 200 K for n-channel devices, depending on the technology, while for p-MOSFETs, the change from 2 to 3 occurs between 20 K and 4.2 K. The mobility μ_{eff} is an explicit function of the inversion charge Q, which in its most general form is represented by [11]:

$$\frac{1}{\mu_{eff}} = \frac{A}{{Q_j}^{n-2}} + BQ_i \tag{10}$$

Where by the coefficient A is a Coulomb scattering parameter and B a surface roughness scattering parameter. Although this method is quite general and powerful, there exists a number of limitations. This implies that the technique is not applicable to short-channel LDD devices at low Temperature, probably because of the series resistance. Of course, it has been demonstrated that the function represented by eq. (4) is independent of R_{SD} and therefore also the determination of 'n' and Vt [10], [18]], which is, however, only valid if R_{SD} is indeed independent of Vgs-Vt. This fact has to be taken into account if the above extraction method is to be used for short-channel LDD MOSFETs. The same analysis can be applied to the case of p-MOSFETs fabricated on high-resistivity Si substrates (HR-CMOS)[19]. Another important point related to the mobility extraction is the universal electric field dependence of the effective mobility for n-channel [20] and p-channel devices [21]. It turns out that if μ_{eff} is related to the effective normal electric field, given by:

$$E_{eff} = \frac{\eta Q_i + Q_d}{\varepsilon_{si}\,\varepsilon_0} \tag{11}$$

a universal curve is obtained, which is independent of substrate doping density, or substrate bias. Hereby is the empirical factor **η**=1/2 for electrons and 1/3 for holes. The resulting effective mobility then reads:

$$\mu_{eff} = \frac{\mu_{00}}{1+\frac{E_{eff}}{E_c}} \tag{12}$$

with μ_{00} the zero field maximum mobility and Ec is a critical electric field. Early low-temperature studies revealed already that the parameter **η** is not a constant with temperature [22], [23], [24], but lies somewhere between 1/3 and 1, which points towards a change in dominant scattering mechanism upon cooling. And doping density dependence of the low temperature μ_{eff} [25]-[27], both for n- and for p-channel devices.

Effective mobility at high transverse electric field

Already in the mid sixties, it was found that the transconductance at large gate overdrive voltages[26]. This has more recently been confirmed for both n-channel and p-channel devices[27]-[29] and for MOSFETs with nitrided oxides[20]. It turns out that the critical field for zero g_m is in the range 2.2-2.6 mv/crn for n-MOSFETs at 77 K and increases up to 7 to 8 mv/cm for p-MOSFETs, depending on e.g. the gate oxide thickness [27]. In physical terms, this means that at low temperature, a change in scattering mechanism occurs at high normal fields. Empirically, this is modelled by introducing a second attenuation factor [30]-[31].

$$\mu_{eff} = \frac{\mu_0}{1+\Theta(Vgs-Vt)+\Theta_2(Vgs-Vt)^2} \qquad (13)$$

The extraction of this second attenuation factor at low temperatures is in detailed discussed in[28]. The inversion layer mobility is dominated by phonon scattering for low effective fields and by surface roughness scattering at high fields. At 77 K and 4.2 K, Coulomb scattering dominates the phonon scattering at low fields, while a much stronger E_{eff} dependence is observed at higher fields than at 300 K.

IV. RESULT AND DISCUSSION

The Figure-2 shown below is the characteristics of mobility and gate to source voltage for different parameter of mosfet structure. It is clear that at low gate to source voltage the mobility is high for P-Channel MOSFET and when gate to sources voltage increased the mobility is nonlinearly decreased. The variation of mobility, at gate to source voltage upto 1.25v is decrased very fast and after that its decrement is very slow. From figure-3 the characteristics of Mobility and drain to source voltage. This characteristic represents the mobility is inversely to to the drain to source voltage for different gate to source voltages. It is clear that each gate voltages their mobility is different and the drain voltage up to 1.25v the decrement of mobility is very fast while beyond of that there is slow decrement of mobility.From figure-4 that is the relationship of drain to source current and drain to source voltage for the same structure. In this figure when gate to source voltage is low then the accumulation of charges are less under the gate so that current flows low and after increasing the gate to source voltage the current increased.

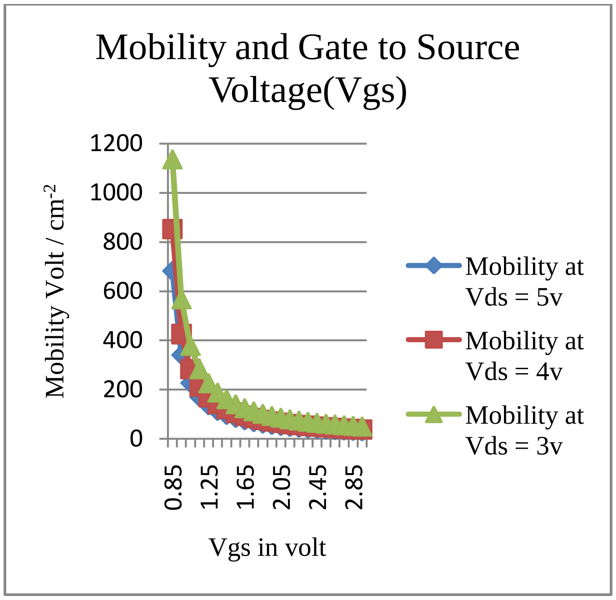

FIGURE-2: MOBILITY AND GATE TO SOURCE VOLTAGE CHARACTERISTICS

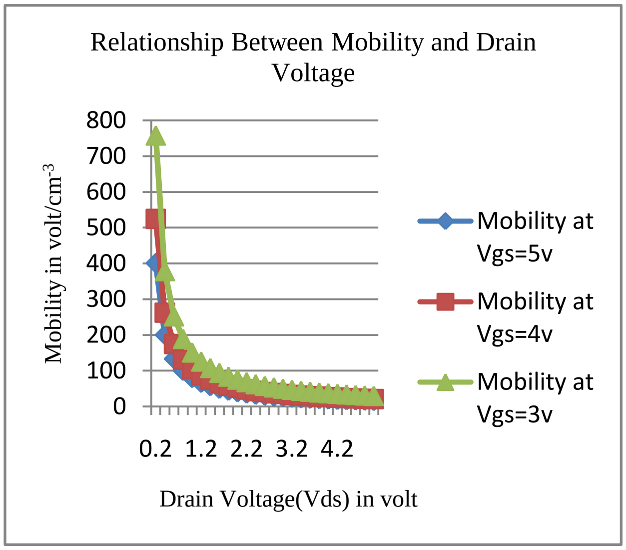

FIGURE-3: MOBILITY AND GATE TO SOURCE VOLTAGE CHARACTERISTICS

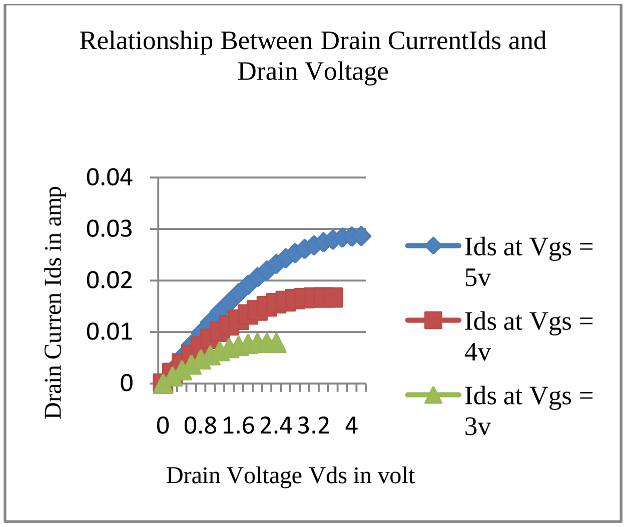

FIGURE-4: DRAIN CURRENT AND DRAIN VOLTAGE CHARACTERISTICS

V. CONCLUSION

From the above overview, it is clear that there is a necessity for mobility parameter extraction of MOSFETs is better option for scaling the device operated at different temperatures as well as I-V charecteristics. there are still some problem like areas, device parasitic which affects on gain by down-scaling the device dimensions.

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BIOGRAPHY

Anil Kumar is Asst. Prof. at SHIATS-DU Allahabad. He obtained B.E (MMMEC,Gorkhpur) in ECE, M.Tech. (IIT BHU Formerly IT B.H.U.) in Microelectronics Engg., and presently pursuing Ph.D. He guided various projects & research at undergraduate & postgraduate level. He published many research paper in different journals. He has more than 10 years teaching. experience and actively involved in research and publications. His area of interest includes Antenna, microwave, artificial neural network and VLSI.

Rakesh Kumar Singh is a M.Tech. student in Electronics And Communication Engineering SSET, SHIATS-DU Allahabad.

A.K. Jaiswal is Prof. and Head of ECE-Dept at SHIATS-DU Allahabad. He obtained M.Sc. in Electronic & Radio Engg. from Allahabad University in 1967. He guided various projects & research at undergraduate & postgraduate level. He has more than 40 years Industrial, research and Teaching experience and actively involved in research and publications. His area of interest includes Optical Networks and satellite communication.