Journal of Science and Technology
ISSN: 2456-5660 Volume 5, Issue 06 (November – December 2020)
www.jst.org.in *DOI:https://doi.org/10.46243/jst.2020.v5.i06.pp175 - 177*

On the Universality of Inversion Layer Mobility in Si MOSFET's: Part I-Effects of Substrate Impurity Concentration

S. Leelashyam, G Shobha, L. Hari Prasad
Assistant Professor[1], Associate Professor[2,3,]
Department of ECE
vkalyani.ece@anurag.ac.in, gshobha.ece@anurag.ac.in, lhariprasad.ece@anurag.ac.in
Anurag Engineering College, Kodada, Telangana

To Cite this Article
S. Leelashyam, G Shobha, L. Hari Prasad, **On the Universality of Inversion Layer Mobility in Si MOSFET's: Part I-Effects of Substrate Impurity Concentration"** *Journal of Science and Technology, Vol. 05, Issue 06,November- December 2021, pp175-177*
Article Info
Received: 23-10-20210 *Revised: 8-11-2020* *Accepted: 17-12-2020* *Published: 29-12-2020*

Abstract

Channel electron and hole mobilities in MOSFETs have been extracted in terms of the eRective vertical field for several substrate biases. After ascertaining that the 2-D drift–diRusion numerical device simulator is reproducing the substrate charge variation in the MOSFET with respect to the gate voltage, obtained from C–V data, the mobility versus eRective field behavior is extracted by comparing the simulated and measured Id–Vgs characteristics. A simple model has been constructed to fit the extracted mobility data in weak and strong inversion, for inversion-layer electrons and holes in n-MOSFET and p-MOSFET, respectively.

Keywovds: MOSFET; Mobility extraction; Modeling; ERective field; Drain current; Gate voltage

Introduction

The mobility of inversion-layer carriers is one of the key parameters underlying the MOSFET operation. The carrier mobility determines the drain current (Id) drive, the transconductance (gm), and the speed of the transistor, and is dependent on both the longitudi- nal (horizontal) and transverse (vertical) electric fields. RF circuits prefer to have MOSFETs operating in the moderate to weak inversion regions so that higher current e@ciency (higher gm/Id) can be achieved [l]. Therefore, a need exists for a mobility model that can be used not only in the strong inversion region but also in the weak and moderate inversion regions. There are models which fit the mobility data in the low and high vertical field regions [2–5]. However, these models are complex and not suitable for incorporation into circuit simulators. This paper reports a simple model which accurately describes mobility in the low- and high-field regions and can be readily incorporated into existing circuit simulation programs.

In the next two sections, we present extraction of electron and hole mobilities versus eRective vertical electric field and subsequent model development. A2-D device simulator, MEDICI, which includes both the drift and diRusion components of the drain current (hence it works in weak and moderate inversion regions as well), is used to reproduce the extracted substrate charge. Moreover, the simulator takes into account Fermi–Dirac statistics and quantum mechanical eRects, which are important in modern MOSFETs. Mobility values are then adjusted using MEDICI to fit the mea- sured Id–Vgs data. Two separate functions are used to fit the extracted mobility data for each carrier.

Electron mobility extraction and modeling

2.l. Electvon mobility extvaction

The mobility extraction technique used in our present work can be divided into two parts. First, the total semi- conductor charge density (QS) calculated from the mea- sured capacitance–voltage (C–V) behavior is compared with that obtained from MEDICI.

ISSN: 2456-5660 Volume 5, Issue 06 (November – December 2020)
www.jst.org.in *DOI:https://doi.org/10.46243/jst.2020.v5.i06.pp175 - 177*

extracted using MEDICI by comparing the simulated Id–Vgs of the n-MOSFET with its measured counterpart. I–V data are then taken on MOSFETs with W /L = 20 µm/l0 µm. Since the capacitance values of these de- vices are quite low and cannot be accurately determined using our LCR meter, we perform C–V measurements on large-area MOSFETs (269 ll09 µm2) from the same wafer. The extracted parameters from the C–V data are independent of device size.

The C–V measurement on a large-area n-MOSFET is taken between the gate and the substrate with the source and drain both connected to ground. Thus the measured capacitance reflects total charge variation in the semi- conductor. The l0 kHz C–V curve for a 269 × ll09 µm2 n-MOSFET is shown in the inset of Fig. l. Oxide thickness is calculated from the maximum capacitance in the accumulation region. The doping concentration is estimated from the slope of the l/C2 versus the gate voltage (Vg) curve in the depletion region. The flat-band voltage is then obtained from the extracted flat-band capacitance. The values of oxide thickness, doping con- centration, and flat-band voltage obtained are 72.25 A˚, 2.6283 l0l7 cm—3, and 0.99 V, respectively.

The variation of QS with respect to Vg is obtained by integrating the l0 kHz C–V curve. This extracted charge is then compared with the simulated QS using MEDICI and the result is shown in Fig. l. For computing QS with MEDICI, the parameters extracted from the C–V curve (oxide thickness, substrate doping, and flat-band volt- age) are used. In addition, Fermi–Dirac statistics and quantum-mechanical eRects are included in running MEDICI for optimal matching with QS from the C–V data. The quantum-mechanical model proposed by Van

Dort et al. [6] is used in this simulation. The resulting match as shown in Fig. l is excellent.

Having obtained the semiconductor charge, the only unknown parameter left which determines the drain current is the carrier mobility. Mobility is extracted from MEDICI by adjusting its values to fit the measured Id–Vgs data for an n-MOSFET having W /L = 20 µm/ l0µm, with Vds = 40 mV and Vbs = 0.3, 0, —l, and —2 V. Fig. 2 shows the mobility versus eRective field behavior for Vbs = 0.3, 0, —l, and —2 V. The magnitude of the eRective vertical field is calculated using Eeff = (Qi/2 ‡ b /ss [7,8], where i is the inversion-layer charge den- sity and Qb is the depletion layer charge density. From Fig. 2, it is clear that mobility increases with Eeff , reaches a maximum, and then decreases. The mobility behavior in the higher electric field regime, which is known as the universal part, has been attributed mainly to pho- non scattering and surface roughness scattering, while the mobility fall-oR in the lower field region, the non- universal part, is due primarily to coulomb scattering from ionized impurities and other carriers [2,4]. It can be seen from Fig. 2 that in the lowest electric field re- gion (weak inversion), the mobility is either leveling oR or starting to bend upwards. In this region, the small channel carrier concentration probably results in en- hanced mobility, as the scattering due to other carriers is minimal in the inversion layer.

We have extracted mobility data for two diRerent drain voltages, namely, Vds = 40 and 50 mV. There is no significant diRerence in the mobility data extracted between these two Vds values, even for low Eeff . This is due to the fact that a long-channel device (L = l0 µm) is used for the extraction. For such a device, the lateral field is negligibly small even at Vds 40 mV, compared to Eeff in weak inversion. Thus the error introduced by the use of this Vds value is expected to be insignificant.

K. Remashan et al. / kolid-ktate Electvonics 46 (2DD2) l53–l56 l55

2.2. Model genevation fov electvon mobility

We now construct a simple empirical model to fit the mobility data. Two expressions are employed, one for the universal part, μ_{uni} [5], and the other for the non- universal part, $\mu_{non-uni}$ [9]. Using the Matthiessen-rule, the resulting fitted mobility is given by

μ

N_i is the electron concentration per unit area in the in- version layer. The mobility limit of 600 cm^2/Vs in Eq.
(2) is consistent with the bulk value for the extracted doping. The calculated mobilities for the substrate biases 0.3, 0, —l, and —2 V using Eqs. (l)–(3) are also shown in Fig. 2. It can be seen that the match between the ex- tracted data and the empirical model is quite good. In our case, the extracted mobility shows a slight depen- dence of μ_{uni} on V_{bs}, which is not evident in Ref. [8]. We attribute this dependency to our assumption that the substrate doping is uniform.

Hole mobility extraction and modeling

Ni is the hole concentration per unit area in the inversion layer. As in electrons, Eq. (4) yields the correct bulk hole mobility value. The comparison between extracted mo- bilities and those calculated using the above model is given in Fig. 4. It can be seen that the match between the extracted data and the model is also reasonable.
The Eqs. (2)–(5) are simple closed-form representa- tions of mobility for both electrons and holes in the low- and high-field regions, which can be incorporated into compact device models used in circuit simulators. Our model captures mobility data (from weak inversion to strong inversion) with two simple expressions as com- pared to complex expressions employed in Refs. [2,4]. Models given in those papers were intended primarily for device simulators. Also, the empirical formulas for µuni given by Eqs. (2) and (4) include both phonon and surface roughness scattering.

Conclusion

Inversion-layer mobility versus eRective vertical electric field behavior has been examined for both elec- trons and holes with the help of a 2-D drift and diRu- sion device simulator, MEDICI, in conjunction with C–V and I–V characteristics of the MOSFETs. An em- pirical model for each carrier mobility versus eRective field behavior is obtained, yielding reasonable fits to extracted data for all regions of MOSFET operation. The universal part of each carrier mobility model yields the correct bulk value, while the non-universal part shows some promise that coulomb scattering can be modeled accurately. Further investigation into substrate doping and substrate bias dependencies is in progress. In the low electric field or weak inversion regime, the anoma- lous behavior is attributed to reduction in carrier–carrier scattering in the inversion layer.

Acknowledgements

The authors gratefully acknowledge Professor k. Lee and Dr. N.D. Arora for their helpful advice and guid- ance.

References

[l] Enz C. RF MOS transistor modeling. 2000 FSA Design Modeling Work Shop. 2000. p. l– 20.
Villa S, Lacaita AL, Perron LM, Bez R. A physically-based model of the eRective mobility in heavily-doped n-MOS- FETs. IEEE Trans Electron Dev l998;45:ll0–5.
Mujtaba SA, Dutton RW, Scharfetter DL. Semi-empirical local NMOS mobility model for a 2-D device simulation in- corporating screened minority impurity scattering. NUPAD V l994:3–6.
Shin S. Model for roll-oR behaviour of electron eRective mobility from universal curve. Electron Lett l995;3l:l789– 9l.
Chen k, Wann HC, ko Pk, Hu C. The impact of device scaling and power supply change on CMOS gate perfor- mance. IEEE Electron Dev Lett l996;l7:202–4.
Van Dort MJ, Woerlee PH, Walker J. A simple model for quantization eRects in heavily-doped silicon MOSFETs at inversion conditions. Solid State Electron l994;37: 4ll–4.
Sun SC, Plummer JD. Electron mobility in inversion and accumulation layers on thermally oxidized silicon surface. IEEE Trans Electron Dev l980;27:l497–508.
Takagi S, Toriumi A, Iwase M, Tango H. On the univer- sality of inversion layer mobility in Si MOSFETs: Part I. ERects of substrate doping concentration. IEEE Trans Electron Dev l994;4l:2357–68.
Suetake M, Suematsu k, Nagakura H, Miura-Mattausch M, Mattausch HJ, kumashiro S, Yamaguchi T, Odanaka S, Nakayama N. HiSIM: A drift–diRusion-based advanced MOSFET model for circuit simulation with easy parameter extraction. SISPAD 2000:26l–4.