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High-Temperature Dependent Data Extraction and Modeling of Effective Channel Mobility in MOSFETs Using Measured S-Parameters

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1. Introduction

Effective channel mobility(μ_{eff}) is the most important parameter for MOSFET modeling and characterization. The temperature-dependent μ_{eff} modeling plays an important role for high temperature IC design. Conventionally, a simple temperature-dependent μ_{eff} model is used for SPICE simulation, but its validity is limited in the narrow range of temperature. Until now, various μ_{eff} extraction data have been reported [1], but mainly performed at temperatures less than 125°C. In reality, μ_{eff} values at much higher temperatures are also important for special IC applications.

Thus, in this paper, the high temperature dependent μ_{eff} data up to 250°C have been newly extracted using an improved RF method based on S-parameter measurements at V_{DS}=0V. Using the extracted data, a new temperature dependent model is developed to remove the inaccuracy of the conventional SPICE one.

2. An improved extraction method

To obtain reliable mobility values, an accurate extraction method should be used. Recently, several RF measurement based methods for μ_{eff} extraction [2, 3] using measured S-parameters have been reported to overcome inaccuracy and complexity of typical DC or CV measurement based techniques. However, Lee's method [2] still requires extra DC measurements to extract total drain-source resistance, and another method [3] requires the additional extraction of bias-dependent parasitic capacitance, the series resistance and effective channel length.

To reduce such extraction complexities of the conventional RF methods, the following RF technique is developed for μ_{eff} extraction in this work.

Using [2], μ_{eff} is determined by:

$$\mu_{eff} = 1/(AC) \qquad (1)$$

where A and C are slopes of the total drain-source resistance R_{tot} and total gate charge q_{in} versus the mask gate length L_{msk}, respectively. In a conventional method [2], R_{tot} is obtained from the DC measurements for obtaining the slope A in (1). To eliminate complexity and mismatch due to the extra DC measurement, the following equation with low-frequency (LF) data of Y_{22}-parameter converted from measured S-parameter at V_{DS}=0V is used.

$$R_{tot} \approx 1/\mathrm{Real}(Y_{22})_{LF} \qquad (2)$$

To obtain the slope C, q_{in} is determined by :

$$q_{in}=\int_{V_{TH}}^{V_{GS}} C_G(V')dV' \qquad (3)$$

where the measured gate capacitance C_G is determined by $(-2/\omega)\mathrm{Imag}(Y_{12})$ under the assumption of $C_{gd} = C_{gs}$ at V_{DS}=0V [3].

3. Results and Verification

S-parameters were measured and de-embedded for extract ing C_G and R_{tot} in the frequency range up to 10GHz on multi finger n-MOSFETs of 16 x 2.5μm gate width at V_{DS}=0V with increasing temperatures of 27 to 250°C. The values of R_{tot} are determined using the low-frequency data of Figs. 1 and 2 obtained from (2). In Fig. 3, extracted values for C_G are plotted as a function of frequency and seem to be nearly frequency-independent up to 10GHz, verifying the accuracy of the parameter extraction. In Figs. 4 and 5, the measured data of R_{tot} vs. L_{msk} are plotted with varying V_{GS} and T, respectively. The q_{in} data obtained using (3) are plotted as a function of L_{msk} at several V_{GS} in Fig. 6. Fig. 7 shows V_{GS}–dependent curves of extracted μ_{eff} data at various high temperatures. Fig. 8 shows the temperature dependent curves of extracted μ_{eff} data with gradually decreasing behaviors. In order to model the temperature-dependence of μ_{eff}, the following equation is conventionally used in SPICE model [4].

$$\mu_{eff} = u_0(T/T_{nom})^{U_T} \qquad (4)$$

where u_0 is a mobility value at $T=T_{nom}$ and u_T is a mobility temperature exponent. However, this conventional equation produces inaccuracy in modeling μ_{eff} data in the broad range of T up to 250°C in Fig. 8. Thus, in order to model the μ_{eff} data accurately, the new equation with a constant value u_b is proposed as follows :

$$\mu_{eff} = u_a(T/T_{nom})^{V_T} + u_b \qquad (5)$$

As shown in Fig. 8, much better agreement with extracted data is achieved using the new equation of (5) than the conventional one of (4), verifying the superiority of (5).

4. Conclusions

The accurate high temperature-dependent data of electron mobility with varying V_{GS} have been newly measured using an improved RF method based on measured S-parameters. To reduce the error of the conventional SPICE model, the new temperature dependent μ_{eff} equation has been proposed and its accuracy has been verified in the wide temperature range up to 250°C.

Acknowledgement

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References

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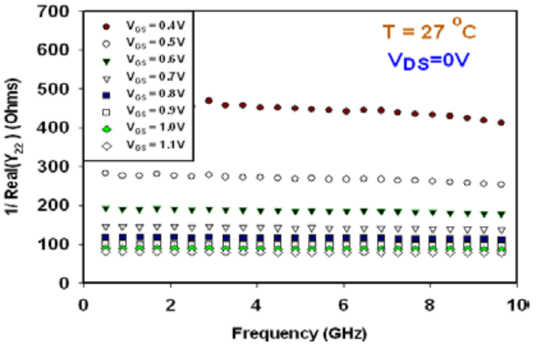

Fig. 1 Measured data of 1/Re(Y_{22}) vs. frequency at different V_{GS}.

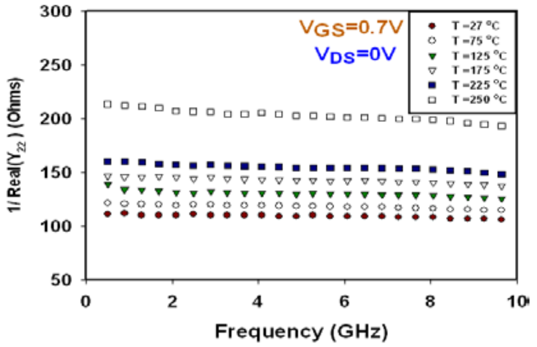

Fig. 2 Measured data of 1/Re(Y_{22}) vs. frequency at different T.

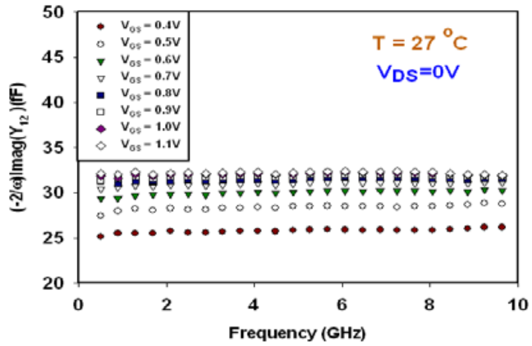

Fig. 3 The extracted data of C_G as a function of frequency.

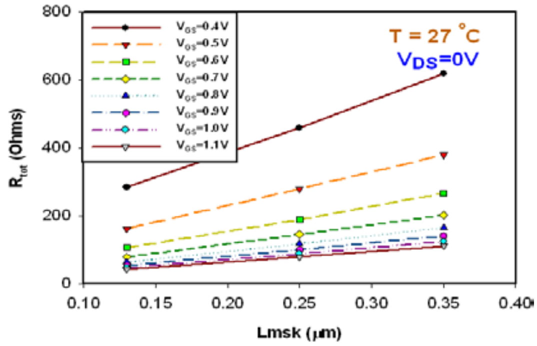

Fig. 4 The measured data of R_{tot} vs. L_{msk} with varying V_{GS}.

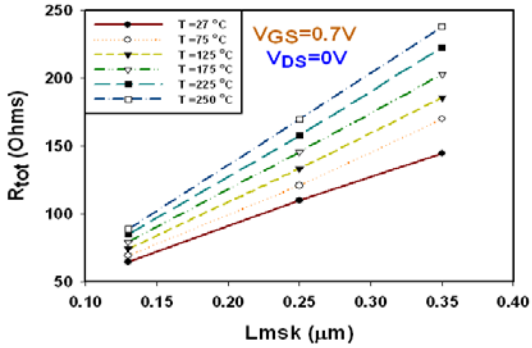

Fig. 5 The measured data of R_{tot} vs. L_{msk} with varying T.

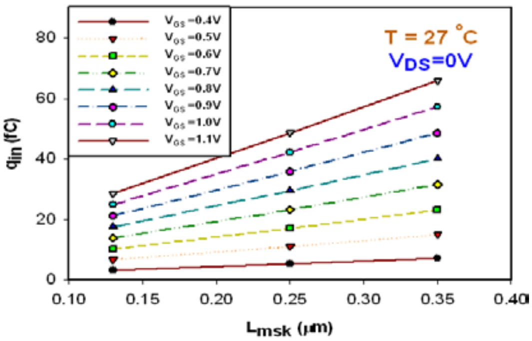

Fig. 6 The extracted data of q_{in} vs. L_{msk} with varying V_{GS}.

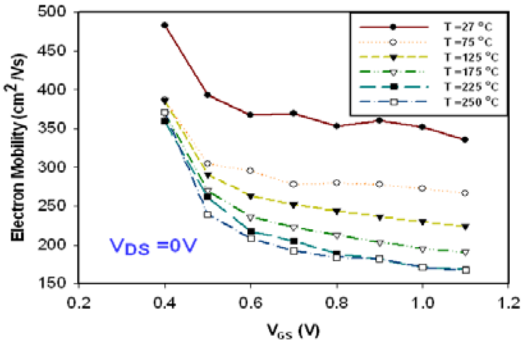

Fig. 7 The V_{GS}-dependence of extracted electron mobility data at various high temperatures.

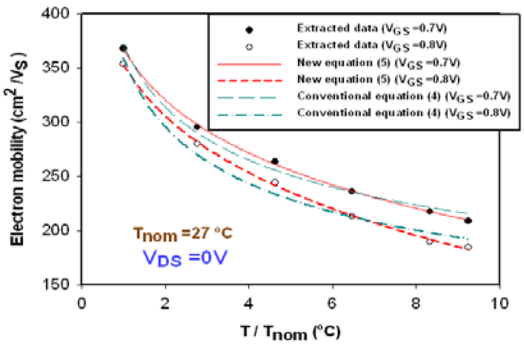

Fig. 8 The temperature dependence of extracted electron mobility data and modeled curves using new and conventional equations.