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

Thus, in this paper, the high temperature dependent μeff data up to 250°C have been newly extracted using an improved RF method based on S-parameter measurements at VDS=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 μeff 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 μeff extraction in this work.

Using [2], μeff is determined by:

\[ \mu_{eff} = \frac{1}{(AC)} \]  

where A and C are slopes of the total drain-source resistance Rtot and total gate charge qin versus the mask gate length Lmsk, respectively. In a conventional method [2], Rtot 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 Y22-parameter converted from measured S-parameter at VDS=0V is used.

\[ R_{tot} \approx \frac{1}{\text{Real}(Y_{22})}_{LF} \]  

To obtain the slope C, qin is determined by:

\[ q_{in} = \int_{V_{TH}}^{V_{DS}} C_{G}(V') dV' \]  

where the measured gate capacitance CG is determined by (-2/ω) Imag(Y12) under the assumption of Cgs = Cgs at VDS=0V [3].

3. Results and Verification
S-parameters were measured and de-embedded for extracting CG and Rtot in the frequency range up to 10GHz on multi finger n-MOSFETs of 16 x 2.5μm gate width at VDS=0V with increasing temperatures of 27 to 250°C. The values of Rtot are determined using the low-frequency data of Figs. 1 and 2 obtained from (2). In Fig. 3, extracted values for CG 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 Rtot vs. Lmsk are plotted with varying VGS and T, respectively. The qin data obtained using (3) are plotted as a function of Lmsk at several VGS in Fig. 6. Fig. 7 shows VGS-dependent curves of extracted μeff data at various high temperatures. Fig. 8 shows the temperature dependent curves of extracted μeff data with gradually decreasing behavior. In order to model the temperature-dependence of μeff, the following equation is conventionally used in SPICE model [4].

\[ \mu_{eff} = u_0 (T/T_{nom})^{1/T} \]  

where u0 is a mobility value at T=Tnom and 1/T is a mobility temperature exponent. However, this conventional equation produces inaccuracy in modeling μeff data in the broad range of T up to 250°C in Fig. 8. Thus, in order to model the μeff data accurately, the new equation with a constant value u0 is proposed as follows:

\[ \mu_{eff} = u_0 (T/T_{nom})^{Y_T} + u_b \]  

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 VGS 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 μeff equation has been proposed and its accuracy has been verified in the wide temperature range up to 250°C.
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References

