Measurement of Thermal Noise for 100nm-MOSFET And Its Modeling

Mitiko Miura-Mattausch (Prof., Graduate School of Advanced Sciences of Matter),
Satoshi Hosokawa (Graduate School of Advanced Sciences of Matter, M2)

1. Research Target

The thermal noise (TN) is becoming important as RF application of MOSFETs is becoming realistic. However, to achieve accurate measurement is still a serious task, and thus to realize its accurate modeling is also an urgent task for accurate simulation of RF-circuits. Our aim is to investigate the origin of observed TN enhancement, and to develop its model based on the origin, which can be even used for testing and supplementing measurements.

The thermal noise is independent of applied frequency. Thus the Nyquist theorem describes the spectral intensity of the TN current ($S_{\rm id}$) of a MOSFET at temperature T [1, 2]

$$S_{\rm id} = \frac{4kT}{{L_{\rm eff}}^2 I_{\rm ds}} \int_{\phi_{\rm S0}}^{\phi_{\rm SL}} {g_{\rm ds}}^2(\phi_{\rm S}) d\phi_{\rm S} = 4kTg_{\rm ds0}\gamma \qquad (2)$$

where k, R, $g_{\rm ds}$, $g_{\rm ds}$, $g_{\rm ds0}$, γ are Boltzmann's constant, channel resistance, transconductance, that at $V_{\rm ds}$ =0, and noise cofficient, respectively. Origin of TN is attributed to the carrier fluctuation in a time interval. The Nyquist theorem predicts that γ varies from 1 to 2/3 as a function of $V_{\rm ds}$ for long-channel transistors as shown in Fig. 1 schematically, and has been prove experimentally. For short-channel transistors, Knoblinger et al. measured much larger γ than 2/3, even more than 3 in the saturation region [3]. The reason was explained by hot electrons [4]. Jamal et al. have measured smaller values, and they modeled $S_{\rm id}$ only with the effective channel length $L_{\rm eff}$ considering the channel length modulation as shown in Fig. 2 [5]. Their result shows a monotonically increasing γ characteristics as a function of $V_{\rm ds}$ for the gate length $L_{\rm g}$ of 0.18μm,similar to the Knoblinger result. Recently, Scholten et al. measured that γ for $L_{\rm g}$=0.18μm is about 1 in the saturation region [6]. They explained the enhanced γ by the velocity saturation. However, detailed description of the model is not given.

2. Research Results

We followed the Nyquist theory given in Eq. (1). For the $g_{\rm ds}$ description we applied HiSIM, a circuit simulation model based on the drift-diffusion approximation [7]. The approximation allows the description to be valid for any bias conditions. The final TN description is verified with γ , which gives universal relationship without varying from technology to technology. Fig. 3 shows the calculation result including both the velocity saturation and the channel-length modulation by symbols. Calculated γ characteristics are nearly the same for all gate lengths, and expected γ increase is not obtained. From this fact a conclusion is derived that an important feature of the enhanced TN origin is missing in the modeling.

We have derived the TN description including position dependence of all physical quantities along the channel such as the mobility and the carrier concentration. The final equation is a function of surface potentials at source & drain sides and derivalives. Calculated γ with the model is also depicted in Fig. 3. Thus the reason of the γ increase for short-channel MOSFETs is attributed to the position dependence of physical device quantities. Here origin of the dependence is reduced to the surface potential distribution along the channel. The basis of the Nyquist theorem is the carrier fluctuation by scattering, and this is enhanced by the potential increase along the channel. HiSIM distinguishes potential values at source & drain sides, which allows us to include the potential gradient in a consistent way.

Calculated TN characteristics are compared with the Scholten measurements in Fig.4. Required model parameters for the calculation were extracted from measured current-voltage characteristics with a normal parameter extraction. Without any fitting parameter good agreement can be achieved for any channel length and any bias conditions. This concludes that the TN characteristics are determined only by the carrier transport in the channel, and the origin of the carrier transport is the potential difference along the channel. The difference of TN with other device characteristics such as the drain current is that the gradient itself, namely $g_{\rm ds}$, determines the characteristics. Fig. 5 shows the γ characteristics as a function of $V_{\rm ds}$. By reducing $L_{\rm g}$, γ increases, but not so drastic as reported previously. It is also seen that γ for short $L_{\rm g}$ length reduces in the liner region, and starts to increase as $V_{\rm ds}$ entering the saturation condition, causing steep potential increase in the channel. The minimum of γ becomes larger than 2/3 as reduction of $L_{\rm g}$ is further continued.

3. Summary

We found that the enhancement of TN for short-channel MOSFETs is caused by potential gradient in the channel. A model developed on the basis of the concept reproduces measured noise characteristics without fitting parameter.

4. Future Plan

The noise induced by drain current has been investigated. For RF-circuit applications the gate induced noise becomes serious as well. This will be focused.

5. Papers and Presentation

Presentation

S. Hosokawa, Y. Shiraga, H. Ueno, M. Miura-Mattausch, H. J. Mattausch, T. Ohguro, S. Kumashiro, M. Taguchi, H. Masuda, and S. Miyamoto, *Ext. Abs. Int. Conf. SSDM*, 20 (2003).

Patent

2003-420845: Drain-current-thermal-noise analysis and simulation method, 18th December, 2003.

References

[1] H. Nyquist, Phys. Rev., 32, p.110 (1928).

[2] A. van der Ziel, ”Noise in Solid State Devices and Circuits”, New York Wiley (1986).

[3] G. Knoblinger, P. Klein, M. Tiebout, IEEE J.Solid-State Circuits, 36, No. 5, p.831 (2001).

[4] R. P. Jindal, IEEE Trans. Elec. Dev. ED-33, No. 9, p.1395 (1986).

[5] M. Jamal Deen et al., Proc. of MSM, p.694 (2002).

[6] A. J. Scholten et al., Tech. Dig. of IEDM, p.129 (2002).

[7] http://www.starc.or.jp/kaihatu/pdgr/hisim/index.html

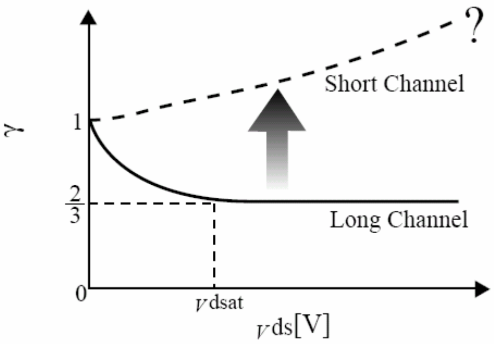

Figure 1: Schematic of γ as a function of V_{ds} for a long channel MOSFET. The dashed line showes that given in [4].

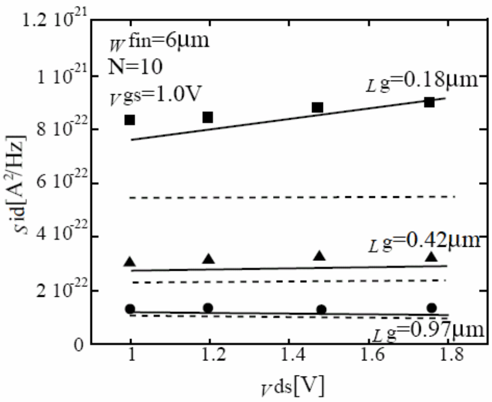

Figure 2: Comparison of measured thermal noise current (symbols) with calculated results as a function of V_{ds} given in [5] : with the channel length modulation (solid lines) and without the channel length modulation (dashed lines).

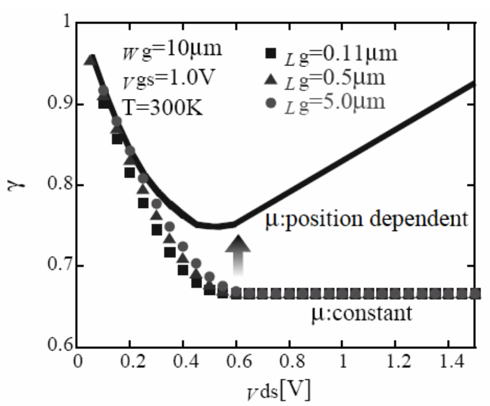

Figure 3: Calculated γ with a constant mobility (symbols) and that considering the position dependence (solid line) for a short channel.

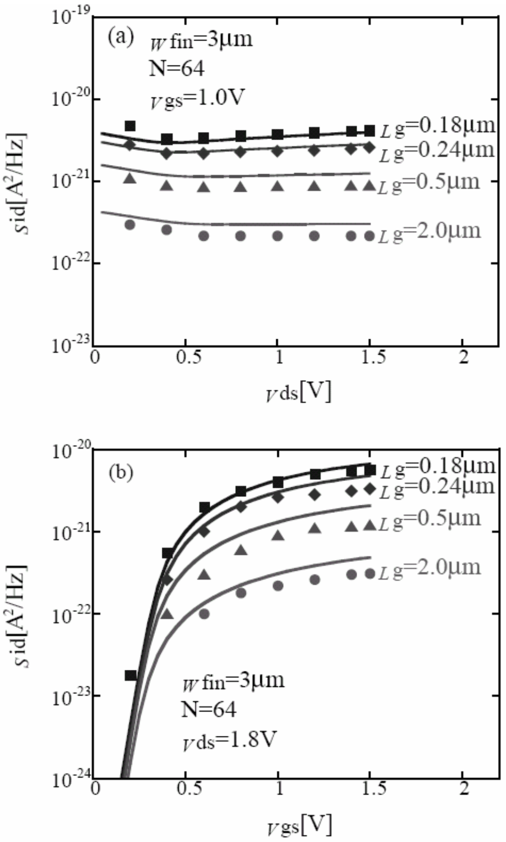

Figure 4: Calculated thermal noise cuurent characteristics with the developed model (solid lines) compared with measurements (symbols) given in [6], (a) as a function of V_{ds} and (b) as a function V_{gs}.

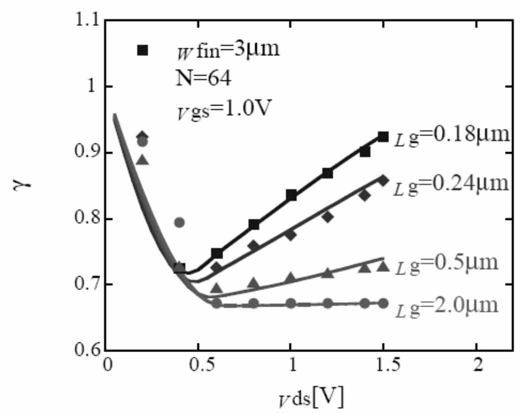

Figure 5: Calculated γ with the developed model as a function of V_{ds} (solid lines) compared with the transformed Scholten measurements into γ, where the g_{ds0} values are selected so that γ unity at V_{ds}=0.