Journal of Electron Devices, Vol. 8, 2010, pp. 320-324

© JED [ISSN: 1682 -3427 ]

Journal of Electron Devices
www.jeldev.org

# MODELING OF THERMAL AND FLICKER NOISE FOR DOUBLE GATE MOSFET

**Swapnadip De[1,*], Angsuman Sarkar[2], C.K. Sarkar[3]**

[1,*]Dept. of ECE, Meghnad Saha Institute of Technology, Nazirabad, Kolkata -107,India
[2]ECE Dept. , Kalyani Govt. Engg. College, Kalyani-741235, India
[3]ETCE Dept., Jadavpur University, Kolkata-700032, India.
1,*swapnadipde26@yahoo.co.in 2. angsumansarkar@hotmail.com 3. phyhod@yahoo.co.in

Received 21 October 2010, Accepted 8 November 2010

## ABSTRACT

The use of low power, low noise devices for future electronic applications is becoming more and more important. The most promising device in the nanoscale range are based on multiple gate structures such as double- gate (DG) MOSFETs. These devices could be used for high frequency applications due to the significant increase in the transition frequency $f_T$ for these devices. For low noise radiofrequency applications, high frequency noise models are required. An useful compact modeling for circuit simulation applications require accurate, computationally efficient and physics-based formulations of a symmetrical DG MOSFET. In this paper, compact channel noise model for Double Gate (DG) MOSFET has been developed and experimentally verified. The compact channel noise model of a DG MOSFET includes the physics based expressions for thermal noise, flicker noise and the corner frequency. Using this model the DG MOSFET noise performances are studied.

## KEYWORDS

**Compact noise modeling; Double-gate MOSFETs; High-frequency operation; Thermal Noise; Flicker Noise.**

## I INTRODUCTION

The Silicon device technology is facing several difficulties, especially increase of power consumption due to short-channel effects (SCEs) become the biggest issue in further device scaling down.

The low frequency noise (Flicker Noise) being attributed to the fluctuations of the current in MOS transistors would thereby be influenced by the back gate quality and bias. Indeed, excessive low frequency noise and fluctuations could lead to serious limitation of the functionality of the analog and digital circuits. It is well known that the Flicker noise is a serious concern for the RF IC design. A careful analysis is therefore necessary to identify the main noise sources and related parameters on which, the LF noise depends. In this paper, the thermal noise and the low frequency noise (Flicker Noise) models are presented and discussed through experimental data obtained on advanced DG MOSFET.

Compact analytical expressions to model the thermal noise, flicker noise and the corner frequency are presented. These expressions depend on the mobile charge density and the drain current. We use here the compact model for symmetric doped DG MOSFET.

## II COMPACT ANALYTICAL NOISE MODELING

### A: Thermal noise prior to velocity saturation:

The DG transistor structure under analysis is shown in Fig. 1, where $N_a$ is the uniform acceptor concentration in the silicon layer with thickness equal to $t_{si}$; $t_{ox}$ is the equivalent gate dielectric thickness; and L is the channel length.

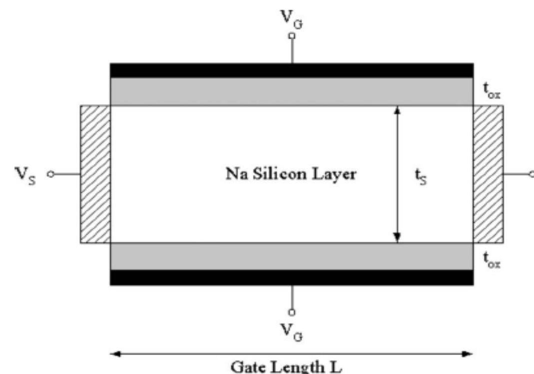


Figure 1. DG structure used to model the thermal and flicker noise..

The drain current noise power spectral density $S_{id}(A^2/Hz)$ in the presence of mobility degradation has been given as[4]

$$S_{id} = \frac{1}{I_D.L^2}\int_0^{V_{deff}} \frac{g^2{}_c(V,E)}{g(V,E)} S_{\partial i_n^2} dV$$

Where L is the channel length and $V_{deff}$ the effective source-referenced drain voltage, respectively and g(V,E) can be expressed as[4]

$g(V,E)=W\mu(x)\,Q(x)$ where Q is the is the mobile charge sheet density per unit area. Again $g_c(V,E)$ can be expressed as[4] $g_c(V,E) = g(V,E)\,(1+E/E_0)$

For the long channel device $E_0 \rightarrow \infty$. So we can write for a long channel device $g_c(V,E) = g(V,E)$

*Corresponding author.

So, the power spectral density of the local current fluctuations can be expressed as[4]

$$S_{\partial i_n^2} = 4K_B T_L \frac{g_c^{\,2}(V,E)}{g(V,E)} \frac{T_N}{T_L}$$

[Where $K_B$=Boltzman constant, W=channel width, μ=surface mobility, $I_D$=drain current, L=channel length. $T_L$, $T_N$ are the lattice temperature and noise temperature respectively].

For a long channel device $T_C=T_L$. It is difficult for obtaining $T_N$, thus we treat $T_N$ as $T_C$ during calculation and $g_c(V,E) = g(V,E)$ .Due to the above condition, the power spectral density of the local current fluctuations can be expressed as can be obtained from the following equation:

$$S_{\partial i_n^2} = 4KBT_L g(V,E)$$

So, the drain current noise power spectral density $S_{id}(A^2/Hz)$ in the presence of mobility degradation has been given as

$$S_{id} = \frac{4K_B T}{I_D.L^2} \int_0^{V_{deff}} g^2(V,E)dV.$$

Now, $g(V,E) = W\mu Q$ [4]

So, $$S_{id} = \frac{4K_B T_L}{I_D L^2} W^2 \mu^2 \int_0^{Vdeff} Q^2 dV$$

Since for DGMOSFET [2]

$$dV = -\left[\frac{dQ}{2Cox} + \frac{KT}{q}\left(\frac{dQ}{Q} + \frac{dQ}{Q+2Q_0}\right)\right]$$

$Q_0=4(KT/q)\, C_{si}$

Where Q is the mobile charge sheet density per unit area and $Q^/$ is the $1^{st}$ iteration result to solve the Q[2],[3]

$$Q = 2C_{OX}\left(-\frac{2C_{OX}\beta^2}{Q_0} + \sqrt{\left(\frac{2C_{OX}\beta^2}{Q_0}\right)^2 + 4\beta^2 Log^2\left[1+\exp\left[\frac{Vgs - Vth + \Delta Vth - V}{2\beta}\right]\right]}\right)$$

And

$$Q^/ = 2C_{OX}\left(-\frac{2C_{OX}\beta^2}{Q_0} + \sqrt{\left(\frac{2C_{OX}\beta^2}{Q_0}\right)^2 + 4\beta^2 Log^2\left[1+\exp\left[\frac{Vgs - V_0 - V}{2\beta}\right]\right]}\right)$$

Where $V_{th}$ and $V_0$ and $\Delta_{Vth}$ is defined as[2],[3]

$$V_{th} = V_0 + 2\beta\log\left(1+\frac{Q^/}{2Q_0}\right) \text{ and}$$

$$V_0 = \Delta\varphi + \beta\log\left(\frac{qn_i\varepsilon^2{}_{si}}{2Q_0 C^2{}_{ox} t_{si}}\right) \text{ and}$$

$$\Delta V_{th} = \frac{\left(\frac{C_{ox}\beta^2}{Q_0}\right)}{Q_0 + \frac{Q^/}{2}} Q^/$$

Where $V_{th}$ is the threshold voltage, q being the electronic charge, $n_i$ being the intrinsic carrier concentration, $\varepsilon_{si}$ is the permittivity of silicon, Δφ is the work function difference between the gate electrode and the intrinsic silicon, $C_{si}$ is the silicon capacitance and $C_{ox}$ is the oxide capacitance, μ is the effective mobility[3], W is the width of the device and L is the channel length.

The term $\Delta V_{th}$ ensures the correct behavior of Q above threshold. β=KT/q. The drain current can be expressed as[2

$$I_D = (W\mu/L)\int_0^{V_{deff}} Q(V)dV$$

Integrating the above equation of $I_D$ between $Q_S$ and $Q_D$ ($Q=Q_S$ at source end and $Q=Q_D$ at the drain end)[2].

So $$S_{id} = -P\int_{Q_S}^{Q_D} Q^2\left[\frac{dQ}{2Cox} + \frac{KT}{q}\left(\frac{dQ}{Q} + \frac{dQ}{Q+2Q_0}\right)\right]dQ$$

**B: Flicker noise prior to velocity saturation:**

The mobility fluctuation which affects the flicker noise depends on the inversion carrier density.

$$I = g(V,E).E$$

$$or, E = \frac{I}{g} = \frac{I}{\dfrac{2mWQ}{S\left(1+\dfrac{E}{E_0}\right)}} = \frac{Q}{Q - \dfrac{SI}{2mWE_0}}$$

Taking the value of $I_D$, g(V,E), Q and the Effective mobility then we can write the flicker noise spectral density as[4]

$$Sid = \frac{2Ids.Not.m}{f.L^2.S}\int_0^{Vdeff}\left[\frac{q}{\left(Q + nCox\phi_t\right)} + \sigma_{sh} m\right]^2. \frac{Q^2}{Q - B}.dV$$

Where

$$B = \frac{S.I}{2.\mu.W.E_0}$$

Since for DGMOSFET

$$dV = -\left[\frac{dQ}{2Cox} + \frac{KT}{q}\left(\frac{dQ}{Q} + \frac{dQ}{Q+2Q_0}\right)\right]$$

Then substituting the value of dV in the above equation and we get,

$$S_{idflicker} = -K.\int_{Qs}^{QD}\left[\frac{q}{(Q+nCox\phi_t)} + \sigma sh\,.\frac{Q^2}{Q-B}\right].$$

$$\left[\frac{dQ}{2Cox} + \frac{KT}{q}\left(\frac{dQ}{Q} + \frac{dQ}{Q+2Q_0}\right)\right]$$

$$= -K.\{(I1+I2+I3)+(I4+I5+I6+I7+I8+I9)\}$$

$$I1 = \frac{q^2}{2Cox}\int_{Qs}^{QD}\frac{Q^2}{(Q+d)^2.(Q-b)}dQ$$

$$I2 = \frac{KT}{q}\int_{Qs}^{QD}\frac{q^2.Q^2}{(Q+d)^2.(Q-b)}\frac{dQ}{Q}$$

$$I3 = \frac{KT}{q}\int_{Qs}^{QD}\frac{q^2.Q^2}{(Q+d)^2.(Q-b)}\frac{dQ}{(Q+2Q_0)}$$

$$I4 = \int_{Qs}^{QD}\sigma sh^2\mu^2\frac{Q^2}{(Q-b)}\frac{dQ}{2Cox}$$

$$I5 = \int_{Qs}^{QD}\sigma sh^2\mu^2\frac{Q^2}{(Q-b)}.\frac{KT}{q}\frac{dQ}{Q}$$

$$I6 = \int_{Qs}^{QD}\sigma sh^2\mu^2\frac{Q^2}{(Q-b)}.\frac{KT}{q}\frac{dQ}{Q+2Q_0}$$

$$I7 = \frac{q\sigma sh\ \mu}{Cox}\int_{Qs}^{QD}\frac{Q^2}{(Q+d)(Q-b)}.dQ$$

$$I8 = 2\sigma\ sh\ \mu KT\int_{Qs}^{QD}\frac{Q}{(Q+d)(Q-b)}dQ$$

$$I9 = 2\sigma\ sh\ \mu KT$$

$$\int_{Qs}^{QD}\frac{Q^2}{(Q+d)(Q-b)(Q+2Q_0)}dQ$$

Where $B=b=S.I_D/(2\mu WE_0)$, $d= n.C_{ox}.\Phi$ and $Q_0=4(KT/q)\ C_{si}$ and

$$I = I_D = (W\mu/L)[(2kT/q)(Q_S - Q_D) +$$

$$\frac{Q_S^2 - Q_D^2}{4C_{OX}} + 8(kT/q)^2 C_{Si}\log[\frac{Q_D+2Q_0}{Q_S+2Q_0}]]$$

## III. RESULTS

**A.Thermal noise:**

As the channel length gradually decreased , the peak near the drain also becomes a major contributor for gate noise because the high electric field near the drain generates high energy carriers and more thermal noise is produced as shown in fig 2 .

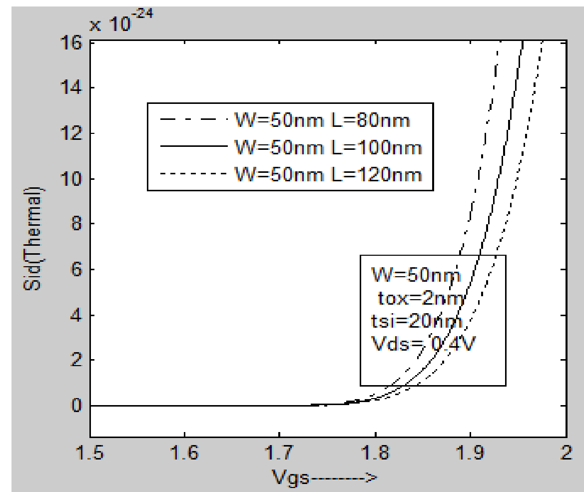


Figure 2. Modeled channel thermal noise prior to velocity saturation for different channel length

If we increase the oxide thickness then the oxide capacitance decreases and drain current decreases. The thermal noise is linearly proportional to the drain current. So, if we increase the oxide thickness then the thermal noise is decreased as shown in fig 3.

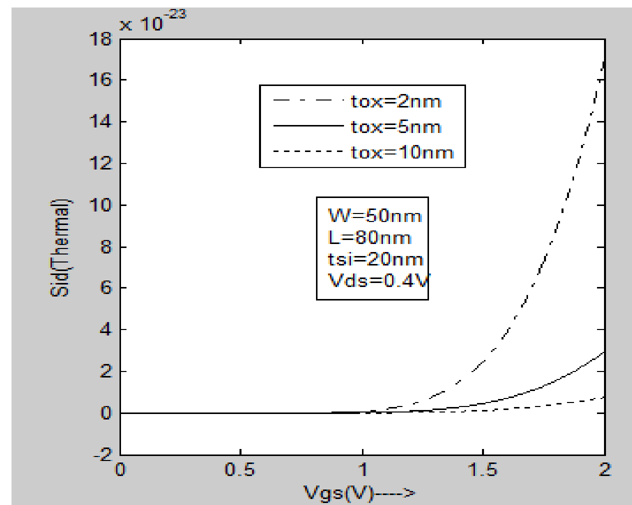


Figure 3. Modeled channel thermal noise prior to velocity saturation for different oxide thickness

**B.Flicker Noise:**

Mainly, the flicker noise (1/f noise) depends on the number of fluctuations due to trapping and detrapping of carriers in the gate oxide and the mobility fluctuation due to drift velocity of the carrier.

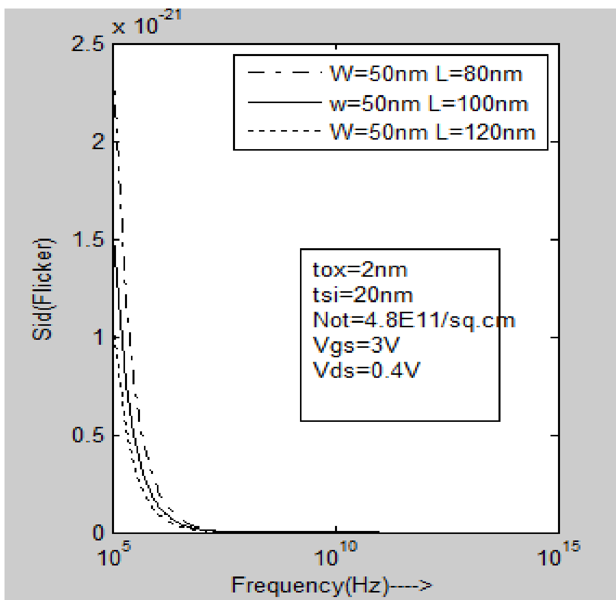

Figure 4 Modeled channel flicker noise prior to velocity saturation for different channel length.

If we increase the carrier concentration, then the trap will be increased and the tunneling current also increased, then the number of fluctuation also increased. Due to this the flicker noise also increased as shown in fig 5.

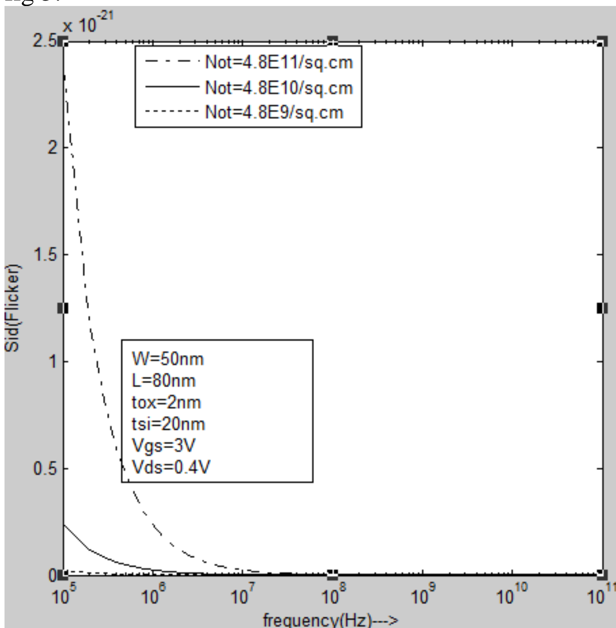

Figure 5 Modeled channel flicker noise prior to velocity saturation for different Not.

If we increase the gate oxide thickness ($t_{ox}$) then the traps will be decreased. The tunneling current also decreases due to decrease of traps. The number of fluctuation decreases and the noise will decrease. We can say that, the flicker noise is inversely proportional to the gate oxide thickness as shown in fig 6.

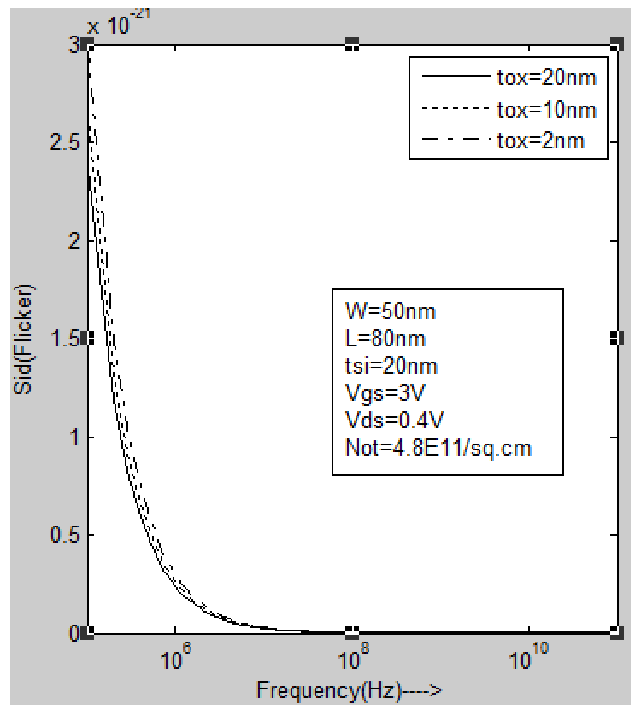

Figure 6 Modeled channel flicker noise prior to velocity saturation for different oxide thickness

## IV CONCLUSION

In this paper we present a compact analytical noise model using the new compact analytical model for long channel DG MOSFET which considers doped silicon layer in a wide range of doping concentrations. We have developed a compact model for the thermal and flicker noise prior to velocity saturation and as well as after velocity saturation. We observe that our model shows better noise performance for the DG MOSFET than other modeling approach described in other literature. The compact model constituted by the expressions for the thermal noise, flicker noise and noise corner frequency can not only be used in hand calculations but also be incorporated in circuit simulation platform to predict the noise performance of DG MOSFET. Thus this paper will show the way for compact modeling the noise including various noise resources, which will be very helpful for the low noise analog IC optimized design at low power supply voltage.

## REFERENCES

[1] Man Wong, Senior Member, IEEE, and Xuejie Shi, "Analytical I–V Relationship Incorporating Field-Dependent
Mobility for a Symmetrical DG MOSFET With an Undoped
Body" IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 53, NO. 6, JUNE 2006

[2]Oana Moldovan, David Jimenez, Jaume Roig Guitart, Ferney, A.Chaves and Benjamin Iniguez,"Explicit Analytical Charge and Capacitance Models of Undoped Double –Gate MOSFETs" IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 54, NO. 7, JULY 2007

[3]Francois Lime, Benjamin Iniguez, Oana Moldovan, "A Quasi-Two-Dimensional

Compact Drain-Current Model for Undoped Symmetric Double-Gate MOSFETs Including Short Channel Effects"IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 55, NO. 6, JUNE 2008.

[4]Zhiyuan Li,Jianguo Ma,Yizheng Ye,Mingyan Yu, "Compact Channel Noise models for Deep-Submicron MOSFETs", IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 56, NO.6, JUNE 2009.