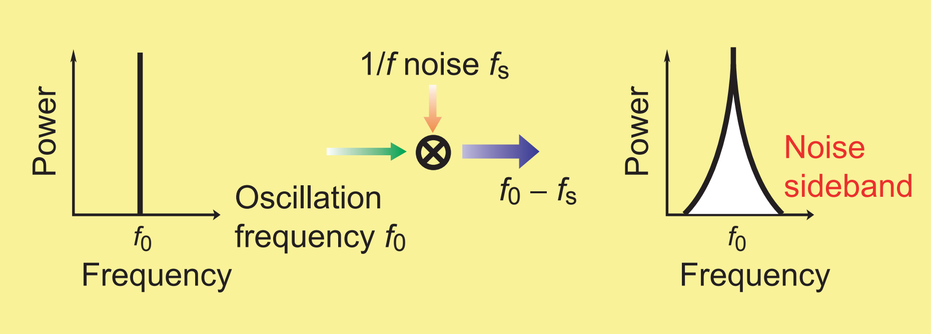
1. Background

RF applications of MOSFETs

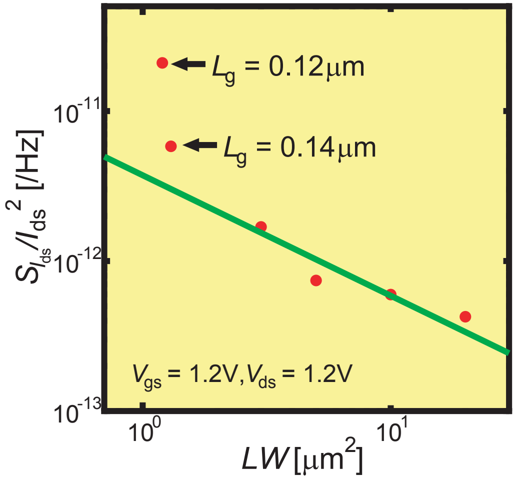
1. Noise characteristics → Noise generated in MOSFETs
2. High frequency operation
   - 1/*f* noise → Phase noise → Instability of frequency
   - Thermal noise

e.g. Oscillator



2. Motivation and Objective

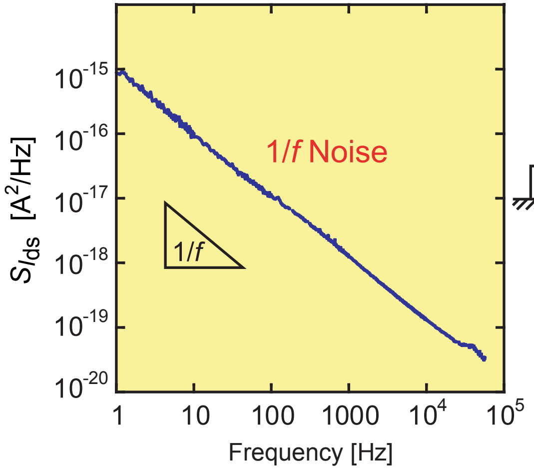
The measured 1/*f* noise was found to exhibit the large increase of noise by reducing the gate length.

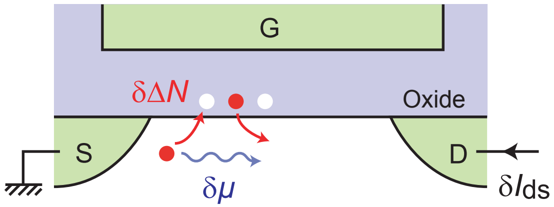


Our objective

Develop the 1/*f* noise model for circuit simulation valid for all gate lengths with a single parameter set.

The origin of the conventional 1/*f* noise in MOSFETs

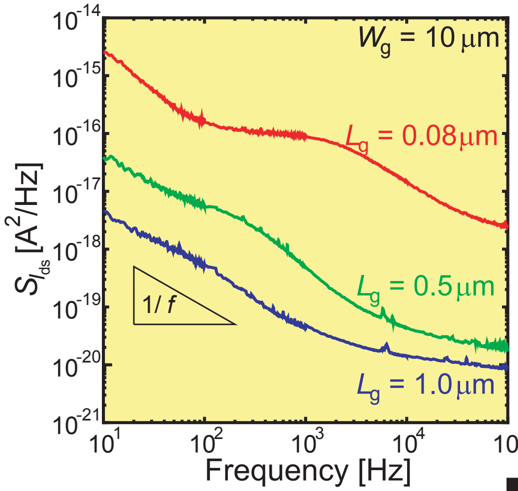


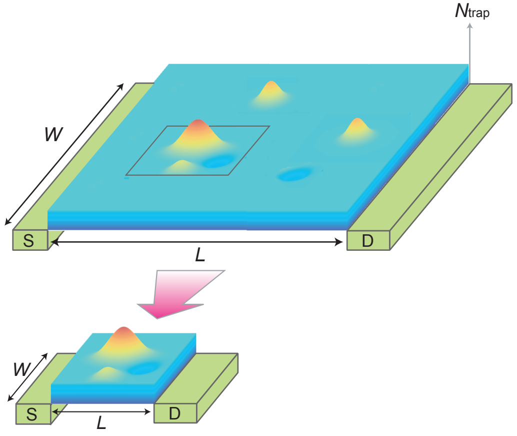


carrier number fluctuation δΔ*N*

mobility fluctuation δ*μ*

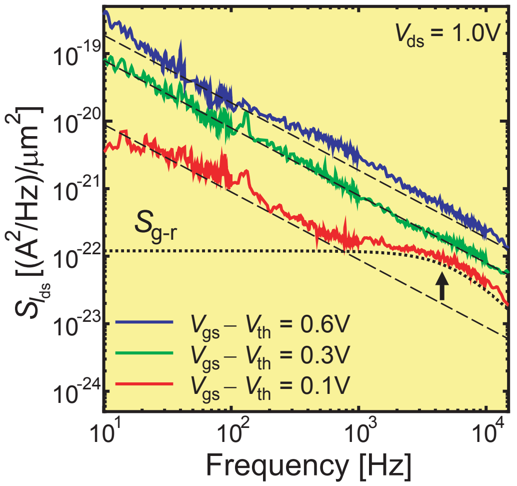
3. Analysis of Measured 1/*f* and Non-1/*f* Noise

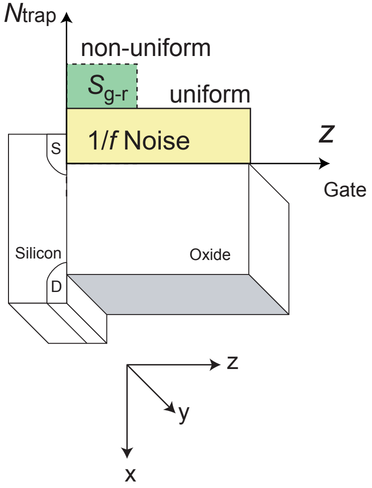


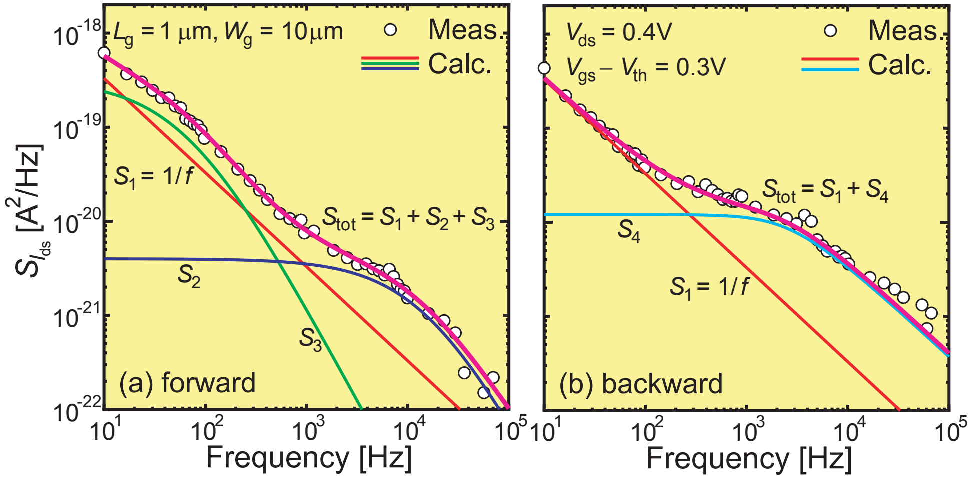


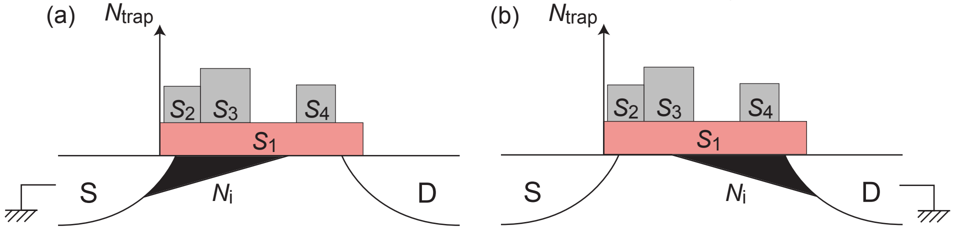
As device size reduces, measured low-frequency noise strongly departs from the 1/*f* dependence.

Lorentzian noise spectrum : $S_{g\text{-}r}(f) = \dfrac{A\tau}{1+(2\pi f\tau)^2}$





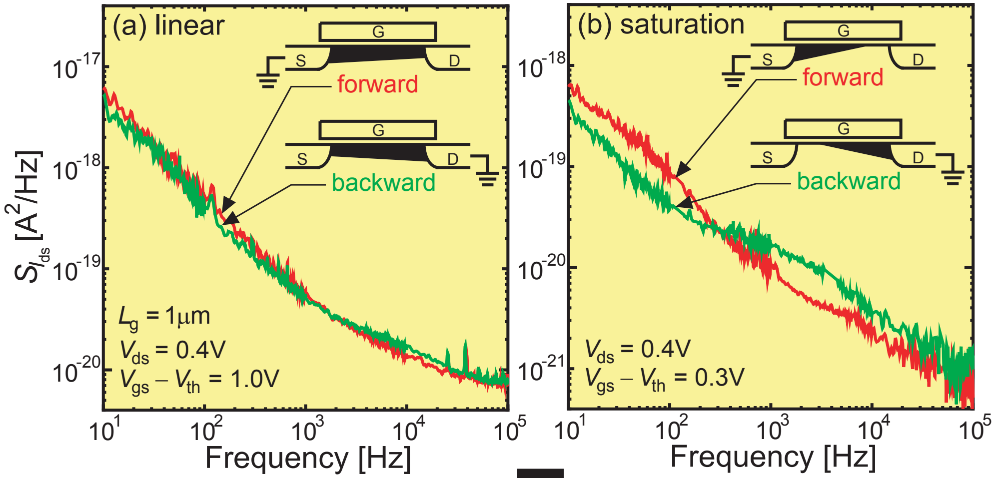




The pinch-off condition occurs under the saturation condition.

The carrier distribution along the channel becomes inhomogeneous

Forward and backward measurements of noise characteristics



(a) linear condition
The difference in the noise spectra is hardly observed.
(b) saturation condition
The difference becomes clear.

Problem

Measured noise is not 1/*f* noise!

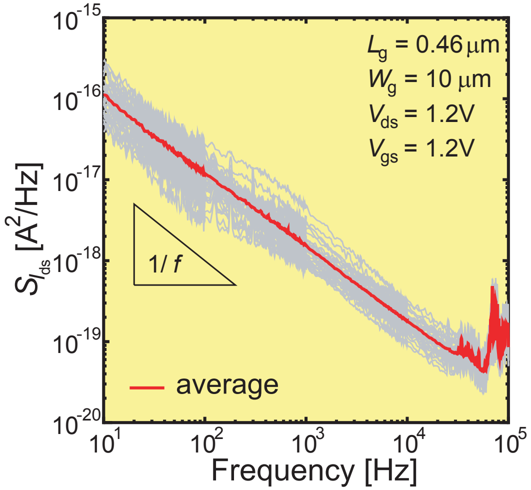
The non-1/*f* noise is due to the non-uniform trap density.

Solution

By averaging the noise spectra of many devices with the same size over chips on a wafer.

The trap density reduces to uniform

The noise reduces to the 1/*f* characteristics.



4. Noise Model Description

General Expression for the 1/*f* Noise

$$S_{I_{ds}}(f) = \frac{I_{ds}{}^2 N_{trap} kT}{L^2 W q f} \boxed{\int_0^L \left(\frac{1}{N(x) + N^*} \pm \alpha\mu\right)^2 dx}$$

Position-integral part of
the inversion-charge density $N(x)$

$$N^* = \frac{kT}{q^2}\left(C_{ox} + C_{dep} + C_{it}\right)$$

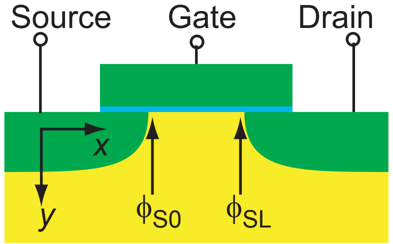
Model parameters

N_{trap} : the ratio of trap density to attenuation coefficient into the oxide
α : the coefficient of the mobility fluctuation
C_{it} : the capacitance caused by the interface trapped carriers

Develop an precise 1/*f* noise model

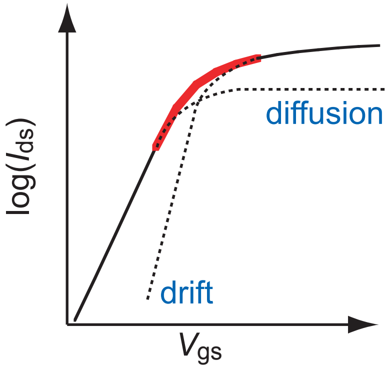
Not only I_{ds} itself, but also the position dependent carrier concentration along the channel is necessary.

HiSIM



HiSIM is based on

- Poisson equation
- Drift-diffusion approximation



Contribution of drift and diffusion

HiSIM provides the carrier concentrations at the source N_0 and drain side N_L determined by surface potential consistently.

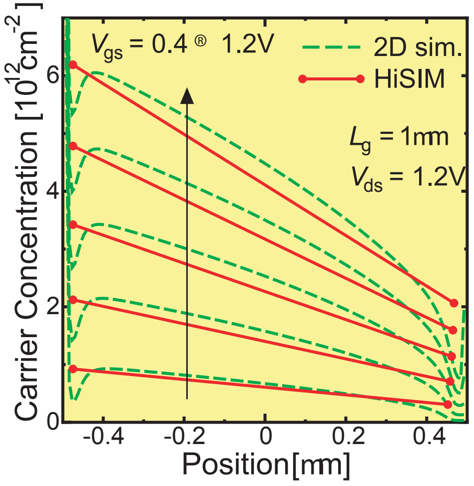
$$S_{I_{ds}}(f) = \frac{I_{ds}{}^2 N_{trap} kT}{L^2 W q f} \int_{\phi_{S0}}^{\phi_{SL}} \left(\frac{1}{N(\mathrm{f}) + N^*} \pm \alpha v\right)^2 \mathrm{df}$$

1. The integration in the equation is done from ϕ_{S0} to ϕ_{SL}.
   ← Beyond the pinch-off point under the saturation condition the carrier concentration becomes negligibly small.
2. The mobility m is replaced by the velocity *v* of the second term in the brackets in the equation.
   ← The field increase along the channel has to be considered together with the mobility distribution.

Assumption for Analytical Integration

The carrier concentration *N* is linearly decreasing from N_0 to N_L.

The linear approximation of *N* is applicable for any bias conditions.



Final Analytical Equation of the 1/*f* noise

$$S_{I\mathrm{ds}}(f) = \frac{I_{\mathrm{ds}}^2 N_{\mathrm{trap}} kT}{(L\text{-}\mathrm{D}L)^2 Wqf}\left\{\frac{1}{(N_0+N^*)(N_L+N^*)}+\frac{2\alpha v}{2N_L-N_0}\log\left(\frac{N_L+N^*}{N_0+N^*}\right)+(\alpha v)^2\right\}$$

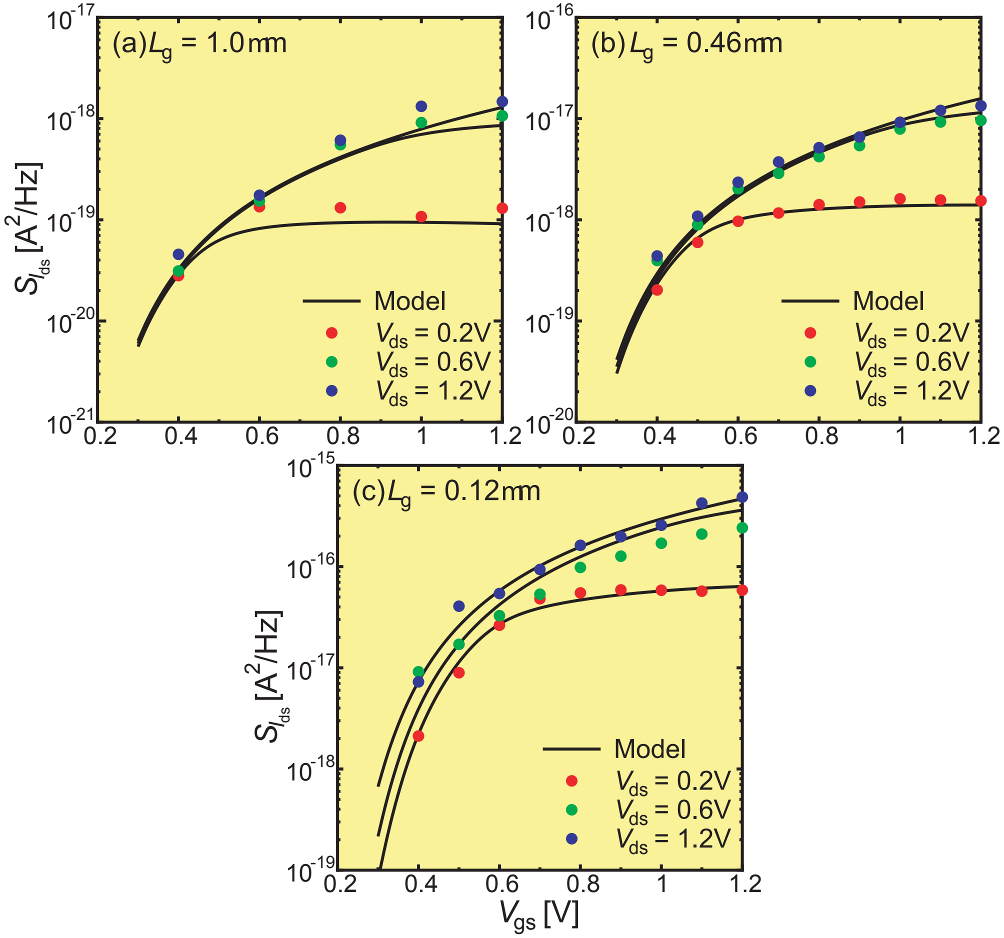
$$N^* = \frac{kT}{q^2}\left(C_{\mathrm{ox}}+C_{\mathrm{dep}}+C_{\mathrm{it}}\right)$$

N_0 and N_L are calculated by HiSIM.

5. Calculation Results

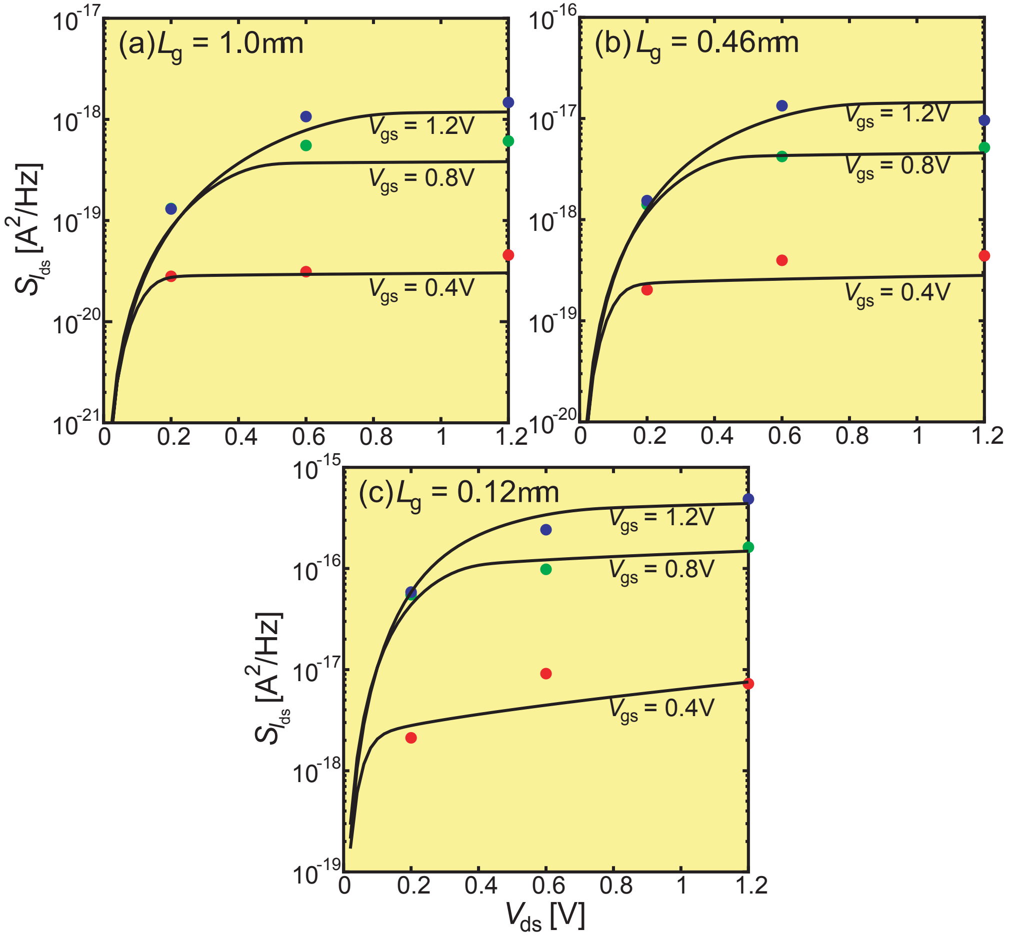
All measured points are averaged values over 30 samples on a wafer.

V_{gs} dependence of 1/*f* noise

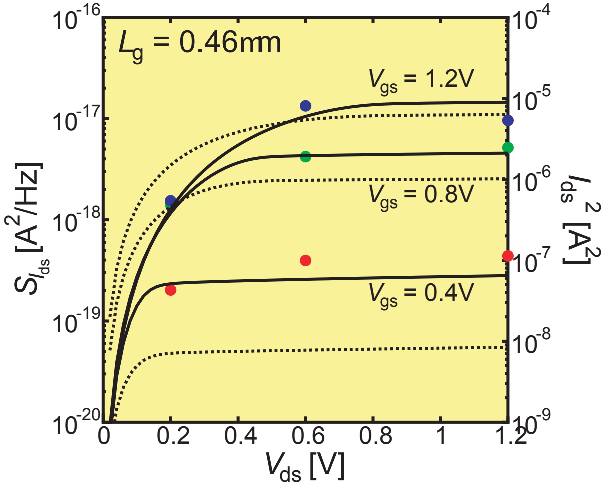


The bias dependences of the noise characteristics for all channel lengths are well reproduced with a sinlge model-parameter set.

V_{ds} dependence of 1/*f* noise



Comparison between the V_{ds} dependence of the 1/*f* noise (solid curves) and square of drain current (dotted curves).



1/*f* noise characteristics in linear condition are different from the square of drain current characteristics.

The bias dependence of the 1/*f* noise is due to not only the current characteristics but also the bias dependence of the *N* distribution.

6. Summary

Measurement

- We have demonstrated that the non-1/*f* noise characteristics is caused by the inhomogeneous trap density distribution along the channel.
- Averaged noise spectra on a wafer reduces to the 1/*f* characteristics, which is suitable for the modeling.

Modeling

- A new 1/*f* noise model for circuit simulation based on the drift-diffusion approximation, HiSIM, reproduces the bias and L_g dependence of the averaged noise spectrum with only three model parameters.