ACCELERATION 1/F NOISE IN SILICON MOSFETs
A. Birbas, Q. Peng, A. Van Der Ziel, A. Van Rheenen

To cite this version:
A. Birbas, Q. Peng, A. Van Der Ziel, A. Van Rheenen. ACCELERATION 1/F NOISE IN SILICON MOSFETs. Journal de Physique Colloques, 1988, 49 (C4), pp.C4-153-C4-156.
<10.1051/jphyscol:1988430>. <jpa-00227928>

HAL Id: jpa-00227928
https://hal.archives-ouvertes.fr/jpa-00227928
Submitted on 1 Jan 1988

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
ACCELERATION 1/f NOISE IN SILICON MOSFETs

A.N. BIRBAS, Q. PENG, A. VAN DER ZIEL and A.D. VAN RHEENEN

Electrical Engineering Department, University of Minnesota, Minneapolis, MN 55455, U.S.A.

ABSTRACT - It is usually assumed that the 1/f noise in Si-MOSFETs is limited by collision 1/f noise. We found this to be the case for devices with relatively short channel lengths (L<10µm) but for channels of intermediate length (10µm<L<194µm) we found that the Hooge parameter varies as L^2. We attributed this to acceleration of the electrons by the applied field, accompanied by Bremsstrahlung emission and current 1/f noise generation. This is a new noise source.

INTRODUCTION

In short low noise Si-MOSFETs the magnitude of the 1/f noise is set by collisions processes /1/. Each collision process (normal, Umklapp, intervalley, etc.) has its own characteristic value of the Hooge parameter α_H and can be identified by it. The contributions of the various collisions must be added quadratically.

In long devices (L>10 µm) a new 1/f noise source has been identified in which the Hooge parameter varies as the square of the device length /2/, /3/. It is attributed to acceleration of the electrons by the applied electric field, accompanied by Bremsstrahlung emission and current 1/f noise generation. Since the process is in operation as long as the electron is travelling from source to drain, the contribution must be added linearly. This leads to an L^2- dependence; it represents a new noise source.

ACCELERATION 1/f NOISE

The general expression for the Bremsstrahlung power emitted by a single electron (c.g.s. units) is

$$P(t) = \frac{2e^2}{3c^3} a(t)^2$$ for $0 < t < \tau$  \hspace{1cm} (1)

where $\tau$ is the duration of a single radiation pulse and $a(t)$ is the acceleration of the electron. We can obtain a linear pulse by writing:

$$\sqrt{P(t)} = \left(\frac{2e^2}{3c^3}\right)^{1/2} a(t)$$  \hspace{1cm} (2)
and now we make a Fourier transform
\[
\int_0^\tau F(\omega) \exp(-j\omega t) \, dt = \frac{2e^2}{3c} \, F(j\omega)
\]
(3)

where
\[
F(j\omega) = \int_0^\tau a(t) \, dt = F(0) \frac{\sin(\omega\tau/2)}{\omega\tau/2} \exp(-j\omega\tau/2)
\]
(4)

For frequencies \( \omega \) much smaller than the reciprocal of \( \tau \), \( F(j\omega) = F(0) \). Applying Carson's theorem we find for the energy spectrum of the Bremsstrahlung
\[
S_{\mathcal{F}}(f) = 2 \left( \frac{2e^2}{3c^3} \right) F^2(0) \lambda \quad \text{in erg}
\]
(5)

where \( \lambda \) is the number of power pulses per second. Dividing by the quantum energy \( hf \) we can obtain the number spectrum of the photons and furthermore dividing by the duration of the pulse \( \tau \) we have the spectrum \( S_q(f) \) of the rate of the photon emission.

Hence
\[
S_q(f) = \frac{4e^2}{3c^3} \frac{F^2(0) \lambda}{hf \tau}
\]
(6)

with an 1/f type spectrum.

We now define the Hooge parameter from the Hooge equation by writing:
\[
S_I(f) = \frac{\alpha_H I^2}{f N} = \frac{\alpha_H I}{f N} \frac{N e}{\tau} = \frac{\alpha_H I}{f \tau}
\]
(7)

where \( N = I\tau/e \) and \( \tau \) the transit time. Since \( \lambda = N/\tau \) we can write equation (6) as:
\[
S_q(f) = \frac{4e^2}{3c^3} \frac{F^2(0) N}{hf \tau^2} = \frac{\alpha_H N}{2f \tau^2}
\]
(8)

so that:
\[
\alpha_H = \frac{8e^2}{3\pi} \frac{2\pi}{hc} \frac{F^2(0)}{c^2} = \frac{4a_0}{3\pi} \frac{F^2(0)}{c^2}
\]

using
\[
a_0 = \frac{2\pi e^2}{hc} = \frac{1}{137} \quad \text{(the fine structure constant)}
\]

We now discriminate between two processes:

a) noise produced by different scattering events. Here \( m^* a(t) = \hbar \, dk/dt \) for a single collision process and:
\[
F^2(0) = \left( \int_0^\tau a(t) \, dt \right)^2 \left( \frac{\Delta(hk)}{m^*} \right)^2
\]
(9)

where \( \Delta(hk) \) is the change in momentum during an individual collision process and so:
\[
\alpha_H = \frac{4}{3\pi} \left( \frac{\Delta(hk)}{m^*} \right)^2
\]
b) acceleration type of noise. We consider a FET operating in the linear regime \( (V_d << V_{ds}) \). Then the electric field is constant and the acceleration \( a(t) = eE/m^* \) is constant too. Hence:
\[
F(0) = \int_0^t \frac{eE}{m^*} \, dt = \frac{eE \tau}{m^*} \frac{m^* \mu}{e \tau_0}
\]

where \( \tau_0 \) is the intercollision time.

Since \( \mu = e\tau_0/m^* \), \( m^* \mu /e\tau_0 = 1 \)
\[
F(0) = \frac{\tau \mu E}{\tau_0} = \frac{\tau}{\tau_0} \frac{\mu E}{\tau_0} = \frac{\tau}{\tau_0} \frac{L}{\tau_0} = \frac{L}{\tau_0}
\]

where \( L \) is the effective channel length of the device.

Furthermore for semiconductors with a single effective mass \( \tau_0 = m^* \mu /e \) where \( \tau_0 \) is the time
constant of the collision process (intercollision time). For p-channel Si MOSFETs there are three different effective masses \( m_1^*, m_2^*, m_3^* \), a more complicated expression for the time constant might be:

\[
\frac{1}{\tau_0} = \sum_i \frac{g(\tau_i)}{\tau_i}
\]

where \( g(\tau_i) \) is the probability that the hole has the mass \( m_i^* \).

We thus have for the Hooge parameter:

\[
\alpha_H = \frac{4 a_0}{3 \pi} \left( \frac{L}{c\tau_0} \right)^2
\]  

(10)

The dimension of \( L/\tau_0 \) is velocity and increases indefinitely with increasing \( L \). At first it was thought that \( \Delta v \) could not become larger than \( c \) so that \( \alpha_H \) might reach Handel's limit \( 2a_0/\pi \) by relativistic saturation. But as it is pointed out \( L/\tau_0 \) is not a true velocity. The above effect remains correct even for non linear operation. To show that we split the length \( L \) into sections \( \Delta x \), having a length comparable to the free path length of the carriers and then:

\[
\alpha_H = \frac{4 a_0}{3 \pi} \left( \frac{L}{c} \langle \frac{1}{\tau_0(E)} \rangle \right)^2
\]  

(11)

where \( \langle \rangle \) denotes averaging.

**EXPERIMENTAL EVIDENCE FOR THE ACCELERATION NOISE**

In Figure 1 the variation of the Hooge parameter with the effective channel length of p-type MOSFETs made on the same chip is shown. The \( \alpha_H \) varies as \( L^2 \) for intermediate channel lengths. The saturation of the curve is observed as we approach the smaller channel lengths (~ 2 \( \mu \)m). There the collision generated 1/f noise dominates and no channel length dependence is expected for the Hooge parameter. Furthermore for long channel lengths no saturation (relativistic) effects are detected and so no indication exists for the approach of Handel's limit \( 2a_0/\pi \) even though the measured \( \alpha_H \) for \( L = 194 \ \mu \)m is approaching this value. Another question which may be raised is the exact extraction of the experimental Hooge parameter /4/ from the measured current spectrum if the shape of the spectrum is not exact 1/f. Even though the experimental data presented here are coming from current noise spectrums with 1/fY shape with \( 1 < Y < 1.1 \) it can be shown that \( \alpha_H \) has always meaning even if the noise spectrum is not exact 1/f (A. van der Ziel and A.D. van Rheenen, to be published).

In Figure 2 the experimentally obtained time constant is plotted as a function of the channel length and it is found to be constant and of the order of \( 10^{-12} \) sec. This value is reasonable for the intercollision time of p-type silicon which is an evidence of the validity of the above approach.
Fig. 1- The Hooge parameter as a function of the channel length for p-type MOSFETs

Fig. 2- The experimentally obtained effective time constant for the p-type MOSFETs

REFERENCES