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ON THE ORIGIN OF 1/F NOISE IN MOS TRANSISTORS

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Abstract - It is proposed that 1/f noise is due to 'fast surface states' which give rise to a redistribution of carriers by diffusion. This leads to the modulation of the carrier density. The square of the modulus of the Fourier transform of the carrier density time function is shown to be inversely proportional to the frequency.

1 - INTRODUCTION

The origin of 1/f noise has puzzled workers for several decades. It is now generally recognised that 1/f noise is due to fluctuations in conductance described empirically by the expression /1/

< \frac{\Delta \sigma}{\sigma}^2 > = \frac{C \Delta f}{f} ............(1)

where C is a constant with a wide range of values.

The noise is strongly associated with fast surface states /2/ and yet there is evidence that it occurs in the bulk /3/. It has been observed in a wide range of materials and devices; any theory purporting to explain the mechanism of 1/f noise must therefore have its basis in universal phenomena.

In this model two phenomena are invoked: the 'fast surface states' and the resulting diffusion of carriers in the bulk. The 'fast surface states' give rise to charge impulses which diffuse into the bulk and produce a time varying carrier density. In the mathematical analysis which follows, it will be shown that the square of the modulus of the Fourier transform of the time varying component of the carrier density is inversely proportional to the frequency.

2 - ANALYSIS

The analysis is based on the continuity equation:

\frac{\partial p}{\partial t} = J .............(2)
where \( J \) is the diffusion current density and \( p \) the charge density. If one considers an MOS transistor as a thin strip of n-type silicon having one main face (outside) with an even distribution of 'fast surface states' and if \( J \) is the diffusion current density in the \( x \)-direction perpendicular to the main faces, the carrier density, \( n \), is given by:

\[
\frac{\partial n}{\partial t} = D_n \frac{\partial^2 n}{\partial x^2} \quad \text{...........}(3)
\]

The solution \( n = n(t,x) \) for a unit impulse is

\[
n = \frac{1}{\sqrt{\pi D_n t}} e^{-\frac{x^2}{4D_n t}} \quad \text{...........}(4)
\]

The square of the modulus of the Fourier transform of \( n(t,x) \) is given by:

\[
|N(\omega,x)|^2 = \frac{1}{D_n} \frac{1}{\omega} e^{-\left(\frac{2}{D_n} \omega x\right)} \quad \text{...........}(5)
\]

For \( x < \sqrt{\frac{D_n}{2\omega}} \)

\[
|N(\omega,x)|^2 \approx \frac{1}{D_n \omega} \quad \text{...........}(6)
\]

If there are \( S \) impulses per unit time of mean square value \( m \) per unit surface area

then

\[
|N(\omega,x)|^2 = \frac{Sm}{D_n \omega} \quad \text{...........}(7)
\]

If \( N_0 \) is the total number of carriers

\[
\langle \frac{\Delta n}{n} \rangle^2 = \frac{Sm}{D_n N_0^2 \omega} \Delta \omega
\]

\[
= \frac{Sm}{D_n N_0^2 \omega f} \Delta f \quad \text{...........}(8)
\]

For \( Sm = K N_0 \)

\[
\langle \frac{\Delta n}{n} \rangle^2 = \frac{K}{D_n N_0 f} \Delta f
\]

\[
= \frac{C \Delta f}{N_0 f} \quad \text{...........}(9)
\]
3 - COMMENTS
It should be noted that the condition imposed on equation (5) to obtain the
approximate relation (6) limits the thickness of the MOS transistor channel
to 10μm in order to maintain the 1/f noise law to high frequencies.

Although this 'surface state diffusion' theory has only been applied to MOS
transistors, a more general approach has been accepted for publication
elsewhere /3/.

Direct experimental support for the 'surface state diffusion' theory is
described in work on the 'generation of augmented 1/f and 1/Δf noise' /4/.
It is proposed that the augmented 1/f noise is produced by stimulating the
'surface states' using an external stimulus.

The main conclusion is that this model is in accord with the McWhorter-van
der Ziel model /5/ insofar as it acknowledges the surface states as the
origin of 1/f noise. It does not, however, require an oxide layer to
produce convenient time constants; the carrier diffusion mechanism produces
the 1/f fluctuations in conductance.

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