SCALING DOWN AND LOW FREQUENCY NOISE TESTING OF SUBMICRON MOSFET‘S

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ABSTRACT

A large amount of experimental results show that for MOSFET's with channel area exceeding 10 µm^2, 1/f noise is clearly present. On the other hand, for transistors of area less than 1 µm^2, Random Telegraph Signals (RTS) are appearing, giving rise to lorentzian spectra. A relation is established between the level of 1/f noise and the defectiveness of the device. An important result concerns the reliability of integrated circuits: beyond a certain limit of scaling down, one can show that it is impossible to predict, with a given accuracy, the low frequency noise of an individual transistor. A critical question also arises: are the RTS's the ultimate components of the 1/f noise? In this paper, we emphasize the interest of observing extensively intermediate cases MOSFET's (i.e., with a surface of a few µm^2). In these cases, several traps are involved, leading to single or multi level temporal signals.[1][2].

1. INTRODUCTION

There are three main and well-understood types of noise that are frequently seen in noise studies. These are thermal noise, shot noise and generation-recombination noise (RTS noise respectively). The third one is also of theoretical interest for 1/f noise models.

(a) Thermal noise originates from the thermal motion of the charge carriers. In equilibrium situations this motion has an average energy of $3/2kT$. The relaxation time is extremely fast, $\tau \approx 10^{-12}$ s, so that at all available frequencies we measure white noise spectrum given by:

the voltage noise spectral density

$$S_U = 4kTR, \tag{1}$$

the current noise spectral density

$$S_I = 4kTG, \tag{2}$$

or the power noise spectral density

$$S_P = S_U / R = S_I \cdot R = 4kT, \tag{3}$$

where k, T and R are Boltzmann constant, the absolute temperature, and the appropriate resistance. It is important that the thermal power noise spectral density does not depend on resistance and geometry of sample [3] [4].

(b) Shot noise is also a white noise in the usual frequency range. It is found when a current of discrete particles leaves a cathode or passes a potential barrier. With the assumption of individual, rectangular current impulses of the width τ for every charge component, we can calculate a power density spectrum

$$S_i\,(f) = \cdot\ \cdot\ \cdot\ \frac{\sin^2(\ \ \cdot}{\pi\cdot\ \ \cdot}\,, \tag{4}$$

where *e* is electric charge in coulombs, *I* is a sample current in amperes and *f* is frequency in hertz. For low frequencies, i.e. small values of $f\cdot\tau$, sin(x)/x ~ 1 and we obtain the commonly used equation for the shot noise

$$S_i^{LF}(f) = \cdot\ \cdot\ . \tag{5}$$

Shot noise also is ideally white because of the very short transit time τ of the electrons and also has amplitude that possesses a gaussian distribution [3] [4].

(c) Generation – recombination noise is of particular interest of us, since some 1/f noise theories are variations on this theme. Consider a semiconductor with number of identical trap levels. A fraction of them will be occupied by electrons. Since there is a continuing trapping and detrapping between the traps and the conducting band (or valence band) the number of trapped electrons, and therefore also the number of free electrons will fluctuate. Transition between traps and band are described by a decays of deviation ΔX on the average, according to

$$-\ \Delta \qquad = \Delta \qquad , \tag{6}$$

Referring to the energy band model, transitions between conduction and valence band as well as various trap levels are possible, a noise spectrum following to

$$S_n(f) = \Delta \qquad \cdot \frac{}{1+} \,. \tag{7}$$

2. NOISE MEASUREMENT TECHNIQUE

The block diagram of the basic apparatus is shown in Fig.1. Measuring set-up consists of noise voltage source, low impedance low noise preamplifier, optional passive LP or HP filter and also with computer which is served for processing of measured data and in our case also for controlling preamplifier through RS 232C interface.

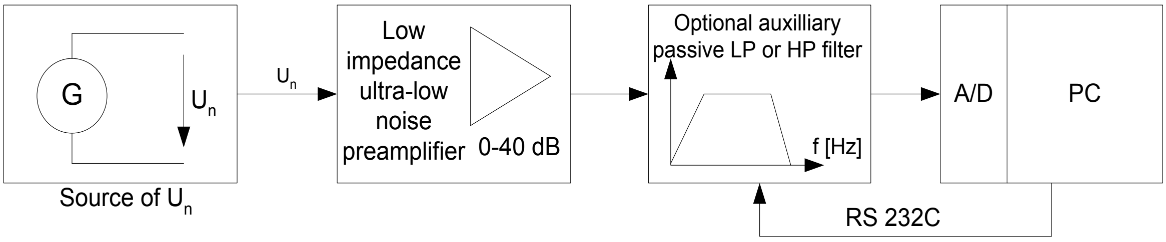

Fig. 1: Block diagram of the experimental set – up.

Noise signal, which is a random physical process, is fetched to low noise amplifier where the extremely low signal is amplified to the level, which is acceptable for further processing with A/D card in computer. Due to low level of noise signal mentioned above, we require unique properties of the amplifier, the emphasis is laid especially on amplification (typically 100 dB and more) and also on intrinsic noise of the amplifier (exemplary 10^{-18} V^2/Hz), which must be much lower than level of measured noise. Amplifier is also equipped with selective filters (slope at least 40 dB/ dec) to obtain amplified signal in appropriate narrow band and communication interface (RS232, IEEE 488) for controlling its functions with computer. Schematic of the noise set-up is shown in Fig.2.

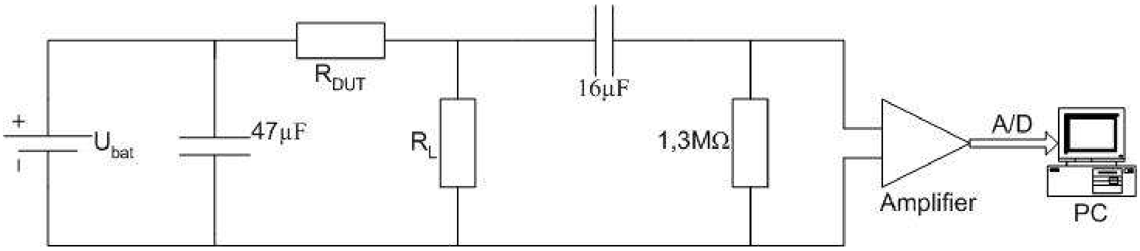

Fig. 2: Schematic chart of the noise experimental set – up.

It is necessary to keep certain conditions during measurement to obtain correct interpretation of measured data. The main effects which may effect measured data are:

- Modification of temperature or intensity of magnetic or electric field during measurement
- Parasitic signal 50 Hz
- Decreases of power supply voltage

3. EXPERIMENTAL

Experiments were carried out for n-channel devices, processed in a 0.3 µm spacerless CMOS technology. The investigated devices have a gate oxide thickness of 6 nm and the effective interface area is estimated to be A = 1.5 µm2. The RTS measurements were performed for drain voltage 1V, where the drain current was changed by varying the gate voltage Ug. The source and substrate contacts are grounded.

3.1. NOISE SPECTRAL DENSITY

According to Tacano, the spectral density of current modulation at frequency ω is:

$$S_U(\omega = \overset{\wedge}{2\pi} + \frac{\quad}{\quad}\frac{\tau}{+} \tag{8}$$

The results of our experiments are shown in following Fig.3, 4, 5 and 6. Low frequency component is 1/f noise.

As mentioned above, 1/f noise is caused by conductivity fluctuation which is caused by variation of carrier concentration as a spectral superposition of single GR noises with relaxation times in wide ranges, near the Si-SiO2 interface. In our case, measured curves from Fig. 3 were fitted with eq. 1.8. to verify proposed theory that 1/f noise is attributed to the random trapping and detrapping of charge carriers in oxide traps with different relaxation times. Results are shown in Fig. 4 and 5. The current noise spectral density vs. drain current for sample N51 is shown in Fig.6. The generation-recombination noise has cut off frequencies from 10 Hz to 1 kHz, which corresponds to relaxation time $\tau = 1/2\pi f$, which sof the order 0.1 to 10 ms.

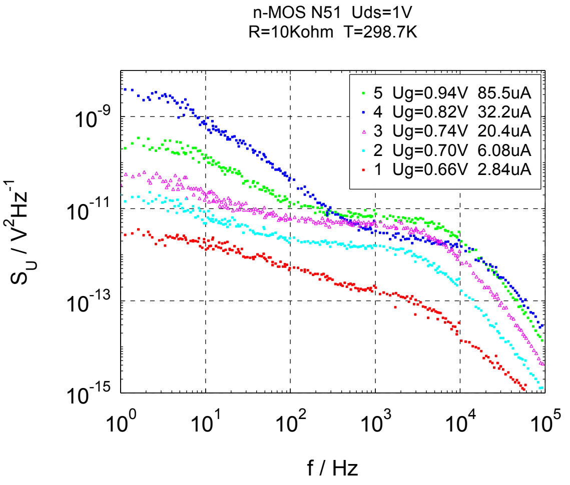

Fig. 3: The current noise spectral density vs. frequency for sample N51.

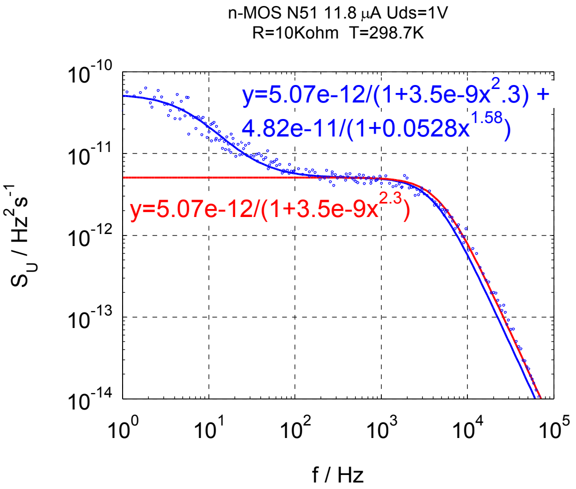

Fig. 4: The current noise spectral density vs. frequency for drain current $I_D = 11.8$ mA for sample N51.

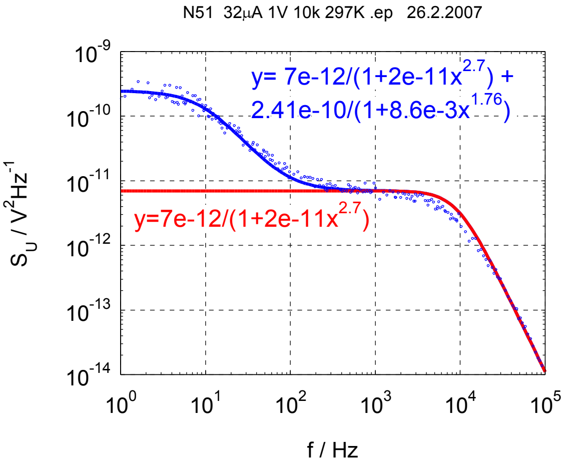

Fig. 5: The current noise spectral density vs. frequency for drain current $I_D = 32$ µA for sample N51.

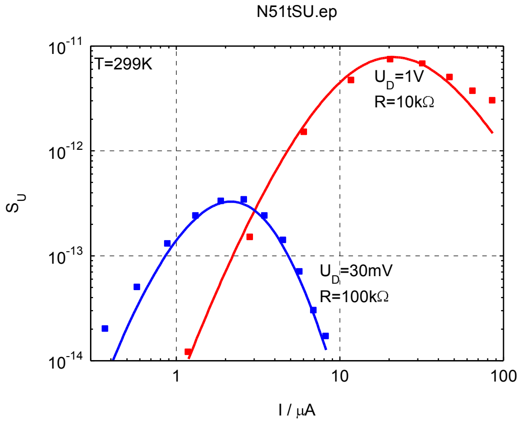

Fig. 6: The current noise spectral density vs. drain current for sample N51.

3.2. HIGH FIELD EFFECTS

The scaling down of electronic devices makes high field transport effects more important. In submicron technology the thin gate oxide and high channel doping results in high transversal electric field. Application of drain voltage 1V (for channel length less than 0.3

μm) results in high lateral electric field, which exceeds about 5 times the silicon critical field. Electron energy was then higher than lattice one and field dependent electron mobility must be considered. Due to small gate area we were able to activate several trap only and then in time domain two levels signal was observed.

4. CONCLUSION

A brief review of recent result about the MOSFET downscaling with impact on the low frequency noise and RTS fluctuations has been carried out. In experimental part, n-channel submicron MOSFET devices, processed in a 0.3 μm spacerless CMOS technology were investigated. Appropriate characteristics of gate voltage, drain current and temperature for high lateral electric field has been shown, resulting conclusions are follows. At low gate voltage the drain current fluctuation amplitude is proportional to the drain current, while for high drain current saturation or decrease is observed. This is attributed to the impact of a high drain electric field. With increasing gate voltage the drain voltage influence is more pronounced. . Proposed theory that 1/f noise is attributed to the random trapping and de-trapping of charge carriers in oxide traps with different relaxation times was verified.

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