Shot noise partial suppression in the SILC regime

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Abstract

The power spectral densities of the current fluctuations through fresh and stressed thin oxide are investigated by means of a purposely designed ultra low noise measurement system. It is reported for the first time that the SILC noise spectrum exhibits partially suppressed shot noise down to about 70% with respect to the full shot noise observed for fresh oxide in Fowler-Nordheim regime. It is shown that a single trap assisted tunneling model with a uniform trap distribution in both energy and space is able to justify the observed noise behavior.

1. Introduction

Stress-induced leakage currents (SILCs) are an important reliability problem for MOS integrated circuits and currently limit the downscaling of non-volatile memories [1-3]. Although several SILC models have been proposed in the past, e.g. localized positive charge trapping [4] and Fowler-Nordheim tunneling through a lowered potential barrier [5], nowadays there is a general consensus that SILC is due to trap assisted tunneling [6].

The purpose of this work is to improve the understanding of the SILC conduction mechanism using an alternative approach based on the evaluation of the power spectral density S_i of the fluctuations of the current tunneling through the oxide. The major result presented in this study is the measurement of the partial suppression of the shot noise in the SILC regime.

2. Experimental

The samples considered are polysilicon-gate MOS capacitors with n-type substrate. The gate oxide thickness is 6 nm and the active area is $1.2 \cdot 10^{-3}$ cm^2. Noise characterization has been performed using a purposely designed ultra low noise measurement system characterized by a background noise of 3 fA/√HZ in the band between 1 Hz and 1 kHz. First, we measured the *I-V* characteristics and the noise power spectral densities of the current through the fresh oxide for different DC current levels. Successively, we stressed the MOS capacitors for a few seconds with a gate voltage of 7.8 V, corresponding to an oxide field of 11.2 MV/cm. Then we measured again the *I-V* characteristics and the current noise spectra at the same DC current levels considered before the stress. Although the measurements were performed with a constant

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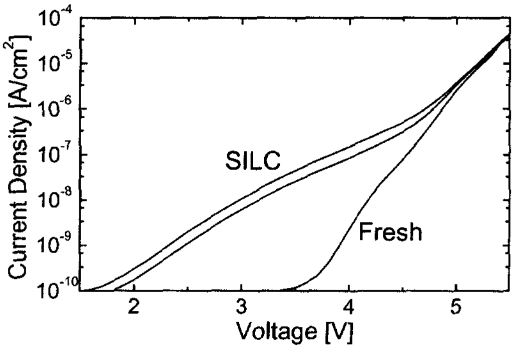


Fig. 1 Typical *J-V* curves of a fresh oxide and after FN stress. The n-MOS was biased in the accumulation region.

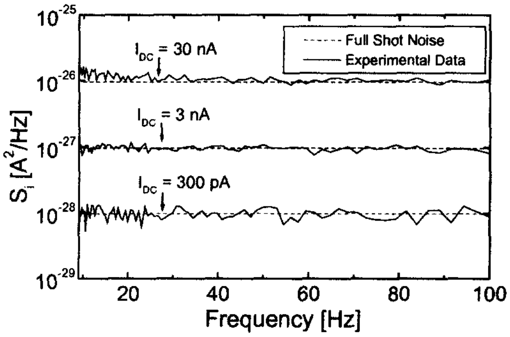
voltage source, we checked that the variation of the level of the DC current during a single measurement was smaller than 1% of the corresponding mean value. In order to obtain an almost steady-state current in the SILC regime, the measurements have been realized after the initial period characterized by a current decay due to the trap-filling process [6].

3. Results and discussion

Fig. 1 shows the typical *J-V* curves measured before and after stress in the Fowler-Nordheim (FN) regime. For a fresh oxide *1/f* noise is observable below a few Hertz, whereas at higher frequencies S_i exhibits a plateau.

Fig.2 reports the measured plateaus for different values of the DC current, along with the line corresponding to the full shot noise $2qI$. The perfect fitting clearly indicates that S_i for the tunnel current through a fresh oxide shows the full shot noise value. This result was expected as the FN conduction mechanism presents the two necessary and sufficient conditions to have full shot noise, i.e. the motion of the carriers is unidirectional and uncorrelated.

Fig.3 compares S_i measured before and after FN stress for the same DC current of 500 pA. As can be seen, shot noise in the SILC regime is partially suppressed with respect to the full shot noise value. An useful parameter for characterizing the degree of suppression is the shot noise suppression factor, or Fano factor, defined as $\gamma = S_i / 2qI$ [7]. We have measured S_i in a range of DC current densities for



which the level of S_i is significantly larger than the background noise coming from the instrumentation and the SILC

Fig. 2 Current noise spectra measured in a fresh oxide (solid lines) corresponding to the full shot noise (dashed lines) as a function of the DC current level. A perfect fitting is observed.

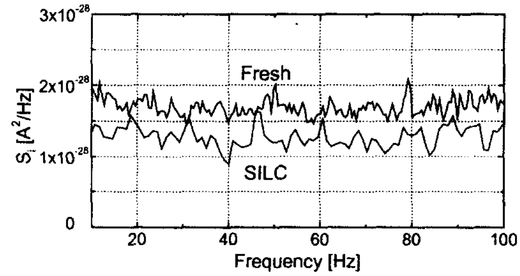


Fig. 3 Power spectral densities of the current noise of a fresh and stressed oxide corresponding to the same DC current level (500 pA). A partial suppression of the shot noise is observed in the stressed oxide.

component is a relevant fraction of the total current. As the total DC current can be written as $I = I_{FN} + I_{SILC}$, where I_{FN} and I_{SILC} are the FN and SILC components, respectively, and assuming that the two components are independent, the corresponding spectrum can be written as:

$$S_i = 2qI_{FN} + \gamma_{SILC} 2qI_{SILC} \qquad (1)$$

where the FN component exhibits full shot noise, i.e. $\gamma = 1$, as shown in Fig. 2, and the SILC component exhibits suppressed shot noise with Fano factor γ_{SILC}. Since I, I_{FN}, and S_i are measured, γ_{SILC} can be readily obtained. Fig.4 shows the mean values of γ (a), of the fraction of SILC $\alpha = I_{SILC} / I$ (b) and of γ_{SILC} (c) as a function of the total current density J obtained in

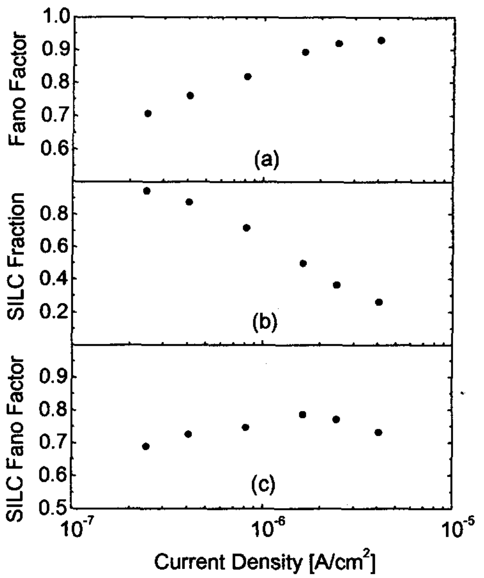


Fig. 4 Fano factor of the total current (a), fraction of SILC (b) and Fano factor of the SILC component (c) in a stressed oxide as a function of the total DC current density. The points are the average values obtained by measuring four samples. A quite constant suppression factor is observed in the current density measured range

four samples. It is found that increasing J, γ increases and α decreases, whereas γ_{SILC} is quite constant around 0.75 in all the considered DC current density range.

The partial suppression of the shot noise clearly indicates some kind of correlation. This observation allows one to exclude that SILC are due to single tunneling events, as suggested by the models of localized positive charge trapping and FN through a lowered potential barrier, whereas it is compatible with trap assisted tunneling (TAT). Indeed, there are two factors that induce correlation in the electron motion during TAT: first, a trap cannot contain more than one electron at a time (the Pauli exclusion principle would allow the presence of an other electron with different spin, but Coulomb repulsion would highly raise its energy); second, the occupancy probability of a trap decreases if there are nearby traps occupied, due to Coulomb repulsion. As a consequence, the current pulses associated to the

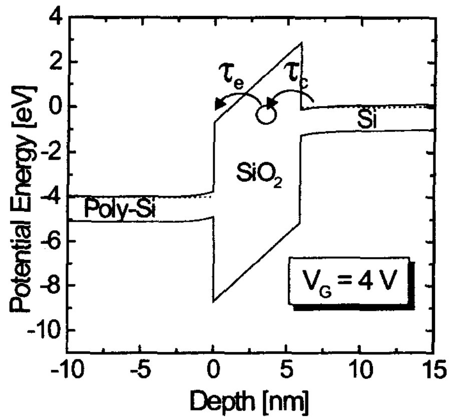


Fig. 5 Band profiles for a MOS structure with the schematic of a single trap assisted tunnel.

same trap are negatively correlated. The effect is quite similar to that observed in the case of resonant tunneling diodes [8]. If the applied oxide field is sufficiently high so that the transition rates in the direction opposite to that of the field are negligible, the suppression factor is related to the capture and emission time of a trap, τ_c and τ_e, (see Fig. 5) by the following equation [8]:

$$\gamma = \frac{1 + (\tau_c / \tau_e)^2}{(1 + \tau_c / \tau_e)^2} \qquad (2)$$

It is worth noticing that Eq. 2 implies that the Fano factor can vary between 0.5, for $\tau_c = \tau_e$ corresponding to a trap positioned in a fixed position in the central region of the oxide, and 1, for a large difference between τ_c and τ_e corresponding to a trap positioned in one of the interfaces. Thus the 0.75 measured value of γ_{SILC} excludes the possibility that all the traps responsible for SILC are in a fixed position in the central region of the oxide or at one of the interfaces, whereas it is compatible with the assumption of a uniform spatial trap distribution inside the oxide. We have developed a numerical model for the calculation of the current noise in the SILC regime based on Eq.2. This model does not take into account the reduction of the occupancy probability of a trap due to the Coulomb repulsion of the nearby occupied traps, thus slightly underestimating the shot noise suppression.

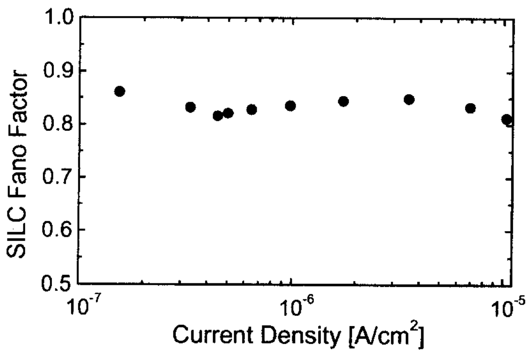


Fig. 6 Theoretical Fano factor of the SILC component as a function of the total DC current density.

Fig. 6 shows the computed γ_{SILC} as a function of the total current density obtained assuming a trap distribution uniform in both energy and space. As can be seen, the noise properties of the SILC are well predicted, thus providing evidence for the validity of the assumptions of our model.

4. Conclusion

It has been found that SILC power spectral density is characterized by a partial suppression of the shot noise around 75%. This experimental evidence allows one to exclude that SILC are due to single tunnel mechanism, whereas is compatible with trap assisted tunneling. The good agreement between the experimental data and the results obtained by means of a numerical calculations indicates that the noise properties of the SILC are well predicted by a single trap tunneling model with a uniform trap distribution in both energy and space. A wider experimental characterization of the phenomenon of the partial suppression of the shot noise is strongly recommended in order to acquire a deeper knowledge of the conduction mechanism in the SILC regime.

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