Current noise at the oxide hard breakdown

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Current noise at the oxide hard-breakdown

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Abstract

In this work we analyze the noise properties of the current at the hard-breakdown of a 6 nm thick oxide in an MOS structure. It is shown that in the quantum point contact case single fluctuators, probably consisting of electron traps inside the oxide, can be resolved, whereas the current noise at the thermal breakdown presents a $1/f$ spectrum, due to the averaging process between many of these fluctuators. © 2001 Published by Elsevier Science B.V.

Keywords: Oxide breakdown; Quantum point contact; RTS noise; $1/f$ noise

1. Introduction

Although the oxide breakdown represents one of the main reliability issues in MOS integrated circuits for more than 3 decades, the understanding of the breakdown conduction is a quite recent matter. In 1998, Suné et al. first suggested that the oxide hard-breakdown (HBD) behaves as a quantum point contact (QPC) [1]. Their thesis was mainly supported by the observation that the conductance of a broken down oxide exhibits a plateau of the order of the quantum conductance, $2e^2/h$, where h is the Planck constant and e is the elementary charge. It is worth noticing that lower conductance values observed in broken down oxides have been ascribed to a different conduction mechanism, the so-called soft-breakdown [2], whereas higher conductance values have been attributed to the formation of several breakdown spots [1] and/or to the lateral propagation of the breakdown region [3]. Most of the characterization regarding the oxide breakdown conduction is based on the measurements of the d.c. component of the current. On the other hand, it is well known that the a.c. component of the current, the so-called current noise, is a sensitive probe of the interaction of the charge carriers with defects or other charge carriers [4,5]. In this paper we study the noise behavior of the current at the oxide HBD.

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2. Experiments

The samples used in this study are MOS capacitors with an n^+ polycrystalline $Si/SiO_2/n^-$ Si stack. The oxide thickness is 6 nm and the active area ranges from 10^{-4} to 10^{-3} cm^2. The devices were stressed at room temperature by injecting electrons from the substrate using a current limited constant voltage stress [6] with 7.8 V gate voltage and with two different current compliance levels, 100 μA and 10 mA. The stress was interrupted a few seconds after the occurrence of the oxide HBD and we evaluated the *I–V* curve and the noise properties of the breakdown spot. The stress and *I–V* measurements have been performed with a Semiconductor Parameter Analyzer HP4155B, whereas the noise measurements have been realized by means of a purposely designed measurement system, essentially consisting of a differential transimpedance amplifier including a biasing stage and a personal computer (PC) based spectrum analyzer.

3. Results and discussion

Several samples have been stressed following the procedure described in the previous section. In all cases, the post-HBD conductance as a function of the voltage presents an initial increase, up to ~1 V, and a successive plateau. In Fig. 1 we report the value of the post-HBD conductance plateau normalized with respect to the quantum conductance, $2e^2/h$, as a function of the current compliance. Two different HBD modes can be clearly distinguished: for the lower current compliance, the post-HBD conductance results close to the quantum conductance, that is a feature of a Fermi-length size constriction (QPC-HBD) [7], whereas for the higher current compliance, the post-HBD conductance results higher by a factor ≈ 10, thus indicating a larger breakdown region, due to stronger thermal effects (thermal HBD). In both cases, we have observed a high increase of the low frequency noise compared with the case of an unbroken oxide, as a consequence of the localized

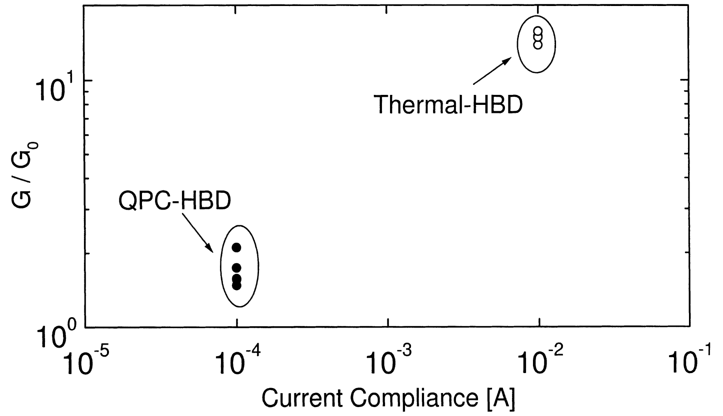

Fig. 1. Normalized conductance evaluated after the HBD of a 6 nm oxide as a function of the current compliance used during a constant voltage stress. Two different hard-breakdown modes can be clearly distinguished.

nature of the HBD. After the QPC-HBD occurrence, we always observed two-level or multilevel random telegraph signal (RTS) in the current through the breakdown contact. The individual fluctuators responsible for this phenomenon can be explained as the capture-emission process of a single electron in a defect site close to the HBD spot. In Fig. 2 we plot the average time in which the current is in the high state, capture time τ_c, and the average time in which the current is in the low state, emission time, τ_e, as a function of the applied voltage for a two-level RTS. As in this case the relative amplitude of the RTS was very high compared with other samples (about 20% independently on the voltage), the corresponding defect should be completely bathed by the electron flux through the HBD contact. The decrease of τ_c with the voltage can be explained by the corresponding increase of the electron flux, whereas the increase of τ_e with the voltage can be a consequence of the lower number of states available for the conduction at higher current densities. In Fig. 3 we plot the power spectral density (PSD) of the current noise through the QPC-HBD spot measured in another sample. As shown in the inset, in this case two RTSs with different corner frequencies, $f_{c1} \approx 1$ Hz and $f_{c2} \approx 10$ Hz, are active in the measurement bandwidth. It can be observed that in the bandwidth between f_{c1} and f_{c2} the PSD shows a $1/f$ behavior as a result of the overlapping of the two Lorentzian spectra.

After the occurrence of the thermal HBD, the low frequency current noise presents a $1/f$ spectrum, that results proportional to the square of the d.c. current component, I_{DC}, as shown in Fig. 4. In this case, we never observed RTS noise and the level of the low frequency current noise at the same I_{DC} was a few orders of magnitude lower than the QPC-HBD case. Both differences can be ascribed to the larger area of the thermal HBD and, therefore, to the higher number of active fluctuators. In fact, it is well known that the superposition of a sufficiently high number of RTSs generates a $1/f$ spectrum proportional to $1/A$ and I_{DC}^2.

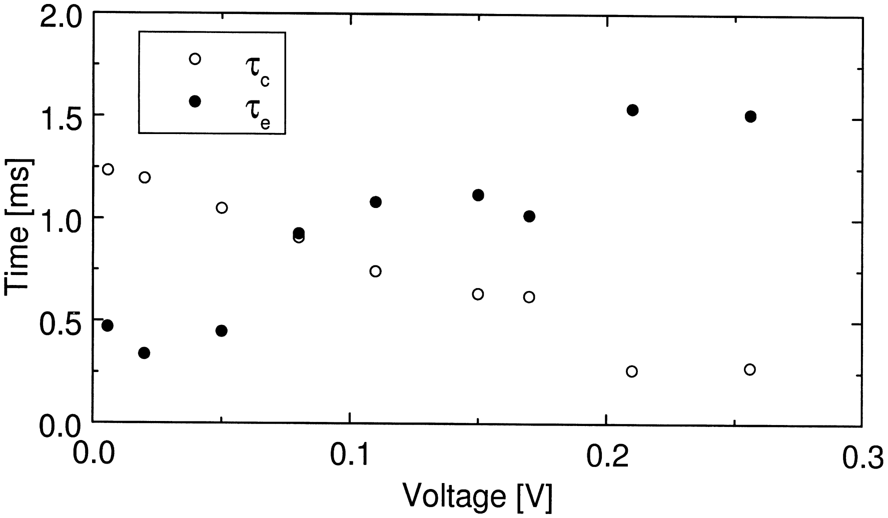

Fig. 2. Capture and emission time of a two-level RTS as a function of the applied voltage measured in a quantum point contact. Each point has been obtained by averaging over more than 200 transitions. An opposite trend is observed for the two time constants.

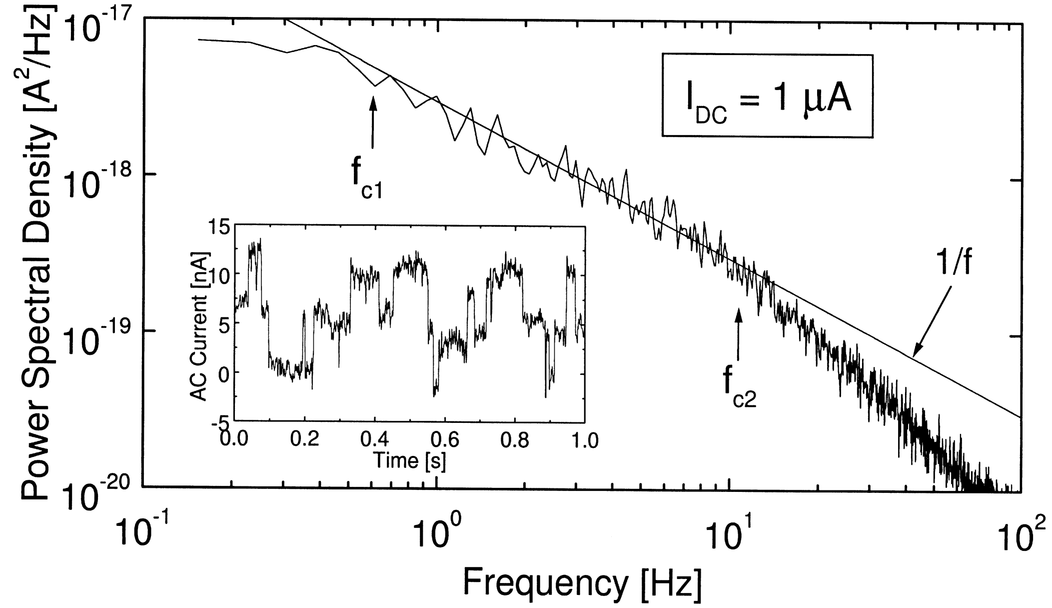

Fig. 3. Current noise PSD measured in a quantum point contact. The corresponding time evolution is reported in the inset. A $1/f$ behavior is observed in the bandwidth between the frequency corners of the two RTSs.

It is worth noticing that most of the results presented in this work on the current noise through the oxide HBD are in agreement with those reported by Kirton and Uren in small-area MOSFETs [4] and by Rogers and Buhrman in metal–insulator–metal microstructures [8].

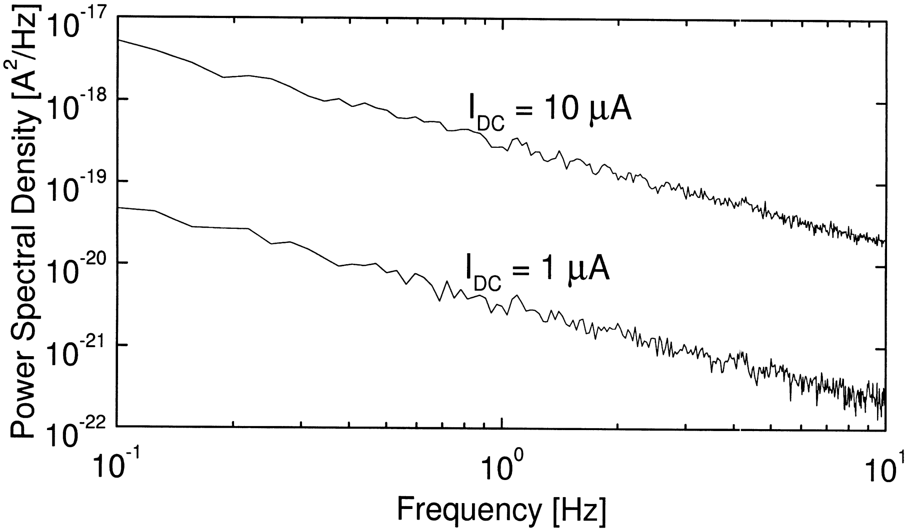

Fig. 4. Current noise PSD evaluated after the thermal oxide HBD for two different d.c. current values. The spectrum shows a $1/f$ behavior with an amplitude proportional to the square of the d.c. current level.

4. Conclusions

In this work, we have studied the noise properties of the current after the occurrence of the oxide hard-breakdown in an MOS structure. Depending on the current compliance used during a constant voltage stress, two different hard-breakdown modes have been observed, characterized by conductance values close to the quantum conductance (quantum point contact) or significantly higher (thermal breakdown). It is shown that in the quantum point contact case, the low frequency noise is characterized by a few Lorentzian components, due to individual fluctuators, probably consisting of electron traps inside the oxide. After the thermal hard-breakdown, the low frequency current noise shows a $1/f$ behavior and lower magnitude, as a consequence of the higher number of fluctuators, that are present in the larger area breakdown region.

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