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A study of measurement system noise for sensitive soft breakdown triggering

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Abstract - This work discusses a simple and effective method to determine the short-term repeatability of current measurements in a large range of currents. With this method, we obtain a quantitative estimate of the background fluctuations that obscure the soft breakdown signal of a large area capacitor under constant voltage stress. Details of the fluctuations are discussed, as well as the consequences for soft breakdown detection.

INTRODUCTION

MOS capacitors with an oxide thickness less than 10 nm under electrical stress exhibit soft (or quasi-) breakdown [1]. In the soft breakdown regime, the conductance of the device under test shows a relatively weak change after breakdown, and therefore detection of a dielectric breakdown (or 'breakdown triggering') during a constant voltage stress (CVS) or constant current stress (CCS) becomes difficult. The traditional trigger approach, identifying a *strong* current increase (in case of CVS) or voltage drop (in case of CCS) is no longer effective, especially for large area capacitors [1-3]. As an alternative approach, recent papers have proposed to trigger on the increase of the noise on the observable (current or voltage) in these tests [4,5]. Pioneering work in this field has without exception been carried out on high-precision, well-shielded equipment with e.g. HP4155 and HP4140 instruments. The weaker breakdown signal may pose significantly larger problems when it must be identified with an automatic parametric test system in an IC fabrication line. Suitability of these test systems for soft breakdown identification is not evident.

We have studied the feasibility of noise triggers as well as current increase triggers during CVS on large capacitors (10^{-4} - 0.1 cm^2) with gate oxides down to 1.8 nm, using an automatic parametric tester (reported in [3]). In this capacitor area and oxide thickness range, the soft breakdown signal becomes so small that the instrument noise plays a significant role. In this paper we propose a simple and effective method to quantify the short-term signal variation to be attributed to instrument noise, and show results obtained with a Keithley S400 automatic tester.

An example of soft breakdown, observed on a MOS capacitor during a constant voltage stress, is shown in Figure 1. A soft breakdown trigger in CVS is generally designed to identify breakdowns either from a sudden *small* change of current, or from a sudden increase in the noise of the current, quantified as the root-mean-square (RMS) variation of the current over a number of consecutive measurements (see e.g. [4]). In both cases, we rely on a small system induced variation on the observed current or voltage, to be able to select a trigger level to well above the system noise floor. To be precise, the short-term repeatability of a current measurement is the key parameter that determines the best achievable sensitivity of the equipment to sudden changes in the device under test.

SHORT-TERM REPEATABILITY

The short-term repeatability is not easily measured on capacitors under stress, because these devices change with time; besides, they are a source of white noise and 1/f noise [6]. To circumvent the limitations of a capacitor

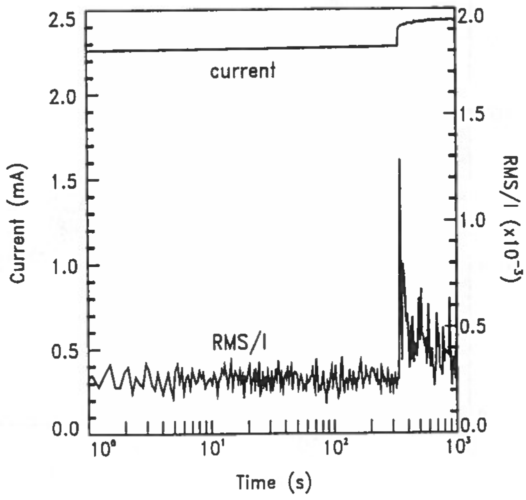

Figure 1: example of a soft breakdown event (at t=341 s) on a capacitor during a constant voltage stress. The current through the device increases, and so does the RMS variation of the current (used as a noise indicator).

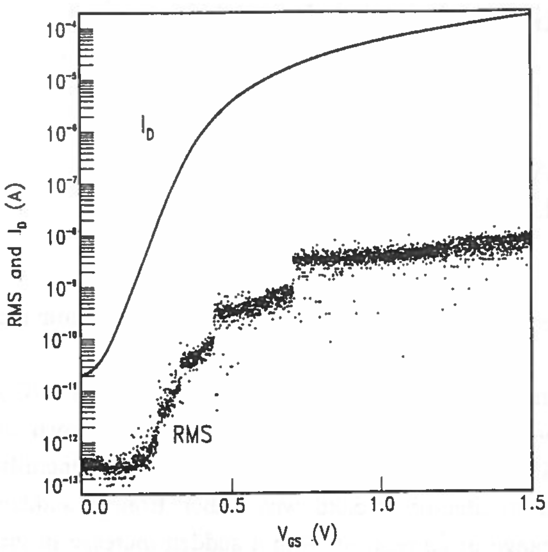

Figure 2: gate voltage sweep on an NMOS transistor. At each gate voltage, 25 consecutive measurements of I_D are performed. From these we compute average I_D (top curve) and its RMS variation (lower).

under real test conditions, we performed a drain current sweep over 7 decades on a MOSFET to measure the short-term repeatability. We carried out a very slow gate voltage sweep on a W/L=10µm/10µm NMOS transistor fabricated in 0.18 µm technology. The gate voltage was incremented with 0.2 mV steps. After each step (and a short delay time) the drain current of the MOSFET was measured 25 consecutive times under the same bias conditions, with $V_{BS} = 0$ V and $V_{DS} = 1.8$ V. The measurement integration time was 1 power line cycle (20 ms), and autoranging was used. The gate voltage sweep was performed from 0 to +1.5 V. Under these bias conditions, no observable device degradation occurs.

A normal I_D-V_G curve was obtained, as shown in Figure 2. We performed the sweep with increasing and decreasing gate bias as a sanity check: the results must be independent of the sweep direction, as indeed they were (not shown).

Ideally, the 25 subsequent measurements under the same bias conditions give an identical result. Non-ideal devices and non-ideal measurement instruments however cause the values to vary. This is demonstrated in Figure 2. The shown RMS value is computed after removal of the two lowest and two highest of each group of 25 measurements. We use a similar approach for CVS and CCS tests [3]. We realize that for Gaussian data variation, discarding data points results in a systematic underestimate of the standard deviation and a correction factor should be applied when the RMS value is used for variance estimation.

The relative RMS variation (RMS divided by average current) is shown in Figure 3 as a function of drain current. A graph like this contains a large amount of information about the system. Above 2 nA, in each current decade the

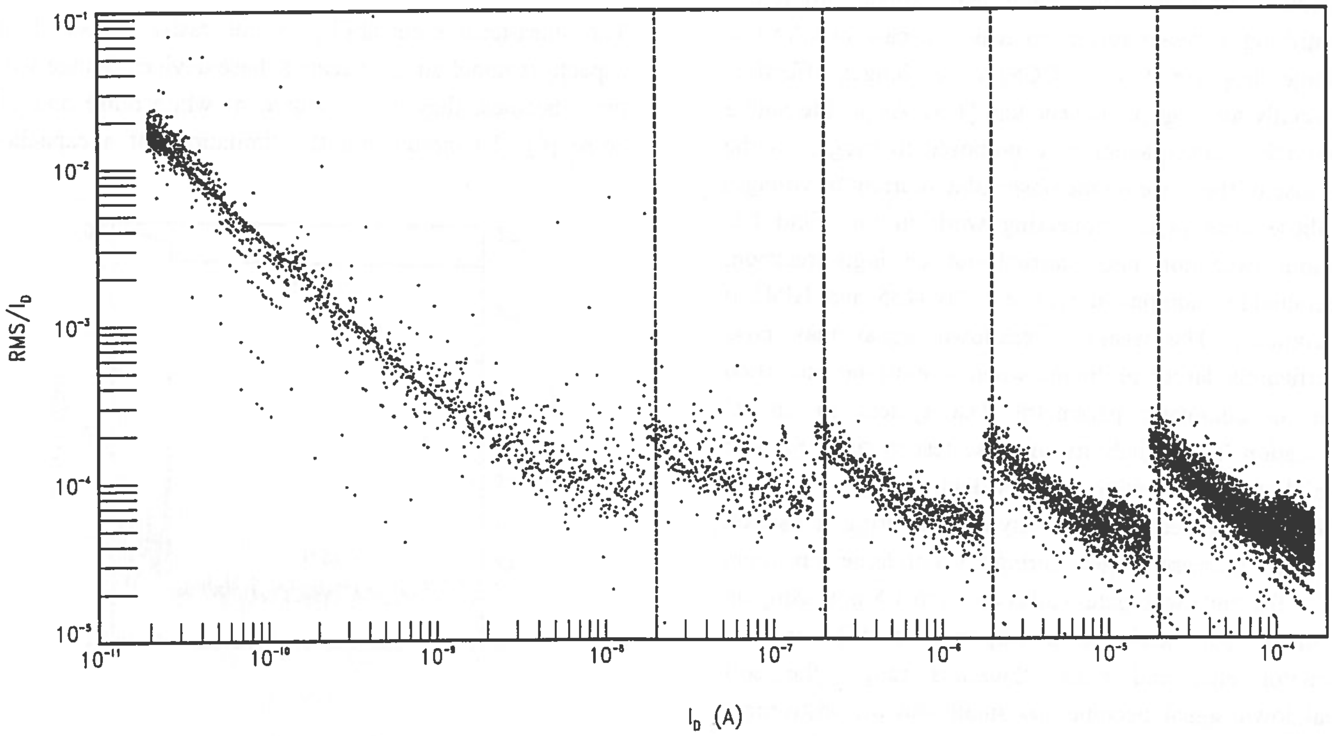

Figure 3: Relative short term repeatability as a function of the measured current. The figure shows the RMS variation of 25 consecutive data points measured under frozen bias conditions, after exclusion of the 4 outermost points, divided by their average value. The dashed vertical lines indicate current range limits of the measurement system. The total measurement time to collect these data was 9 hours.

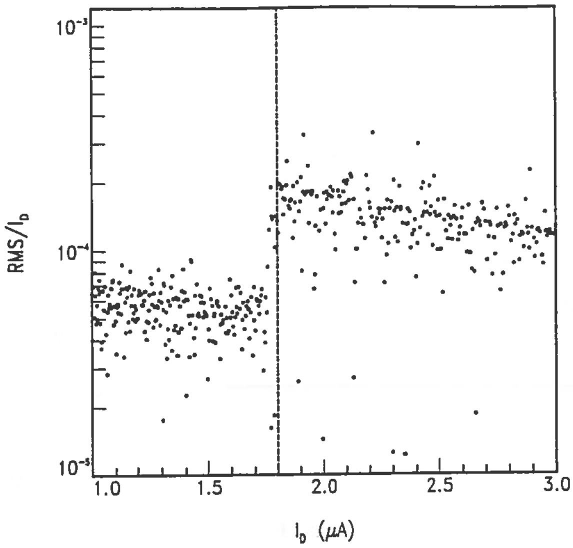

Figure 4: A selection of the data from Figure 3, showing the range crossover around 1.8 μA (indicated with the dashed line). No abnormally high RMS value is present at the range crossover, in spite of a possible range mismatch.

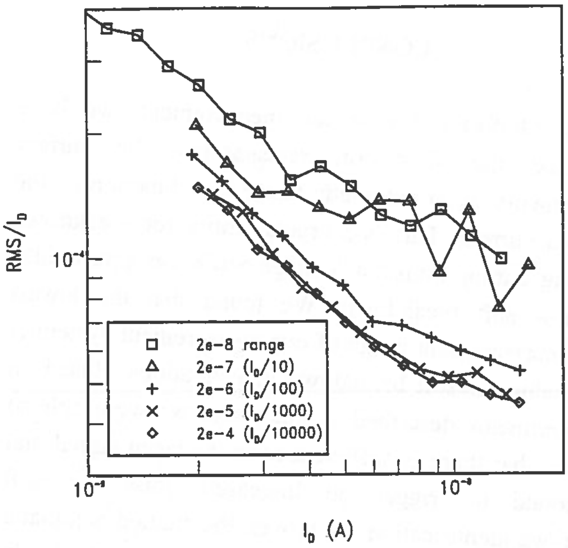

Figure 5: Relative short term repeatability (as in Figure 3) of the various current ranges, after normalization of the data to the I_D of the lowest range. The repeatability improves slightly with increasing current range.

relative RMS decreases steadily, followed by a sudden increase. The sudden increases correspond to range transitions of the current meter, initiated by the system because we use autoranging. One of the range transitions is shown in detail in Figure 4. It is indeed abrupt and it occurs at the point where the measured current is 90% of the limit of the lower range (in this case being 2 μA). We expected to find abnormally high RMS values at the range crossing, where some of the 25 measurement values might be obtained with measurements in the lower range and others in the higher range, the range mismatch causing a large RMS value. However, such a pattern is not found. This may indicate a very good system calibration, or a range transition smoothing protocol in the measurement system.

Below 2 nA, the relative error increases linearly with decreasing drain current, corresponding to an absolute RMS value around 0.3 pA (see also Figure 2). In the lowest measurement range we observe randomly occurring high values of the RMS, for which no explanations have been found. We assume that they can be attributed to EMC disturbances from other, nearby placed clean room equipment. This implies that the lowest range is unsuitable for CVS testing, because the higher background results in lower sensitivity to soft breakdown signals.

In the higher ranges, the short-term repeatability has a periodic trend as a function of current (Figure 3). There is a slight improvement with higher currents that is hardly distinguishable in this figure. Figure 5 summarizes the data from Figure 3 after averaging (with the data from higher ranges shifted to lower currents to enable a direct comparison). In the legend, the current ranges are identified by their respective current limits. The figure demonstrates that the best short-term repeatability can be obtained in the highest current range. Yet, the within-range trend more predominantly affects the short-term repeatability, implying that one should arrange a test to be executed at a fixed current level just below a range crossover to obtain the best possible short-term repeatability.

The relative RMS is typically between 20 and 400 ppm. This is well within the system specification of 600 ppm for measurement repeatability (for currents above 0.2 μA). Therefore in this case the system specification can be used as a trigger level during CVS tests, to distinguish signal from background. When appropriate bias conditions are chosen, one can obtain up to an order of magnitude better short-term repeatability than the system specification, leading to strongly improved soft breakdown sensitivity.

The observations show that a noise trigger on RMS can be used during constant voltage stress on this equipment, with a trigger threshold of 600 ppm (or even lower). This trigger level has been applied on a large amount of raw test data of capacitors with various areas and oxide thickness. No fake triggers were observed, while soft breakdown is successfully identified in most of the studied range of area and oxide thickness. The good short-term repeatability also implies that a very small current increase can be detected as an identifier of soft breakdown. This trigger approach works even better than the noise trigger [3].

CONCLUSIONS

Using a MOSFET I-V sweep measurement, we have determined the short-term repeatability for current measurements of an automatic tester as a function of the measured current. This is a crucial entity for breakdown triggering during Constant Voltage Stress on gate oxides that show soft breakdown. We found that the lowest current measurement range of our measurement system is less suitable for soft breakdown investigations. Based on the experiments described in this paper we were able to conclude that there is sufficient room between signal and background to trigger on increased noise for soft breakdown identification. Moreover, the studied automatic tester allows for very sensitive current increase triggers in a constant voltage stress test.

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