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On-State Resistance Instability of Programmed Antifuse Cells during Read Operation

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Abstract—**The on-state resistance (R_{ON}) instability of standard complementary metal-oxide-semiconductor (CMOS) antifuse cells has been observed for the first time by using acceleration factors: stress current and ambient temperature. If the program current is limited, the R_{ON} increases as time passes during read operation.**

Index Terms—**Antifuse, reliability, on-state resistance instability**

I. INTRODUCTION

Among various kinds of one-time programmable (OTP) memory technologies, the standard complementary metal-oxide-semiconductor (CMOS) antifuse cell based on conventional polysilicon-gate with silicon dioxide gate insulator has been regarded as one of the most promising technologies. It is usually used for the redundancy memory of dynamic random access memory (DRAM) or static RAM (SRAM) [1-4]. This antifuse cell is cost-effective because its fabrication process is compatible with CMOS baseline process.

In terms of the reliability of an antifuse cell, the on-state resistance (R_{ON}) instability of the programmed cell during read operation is an important issue. The R_{ON} instability means the time-dependent resistance increase of the conductive filament (CF) in the programmed antifuse cell during read operation. It can induce the read disturb: the R_{ON} increase of programmed antifuse cells to an off-state resistance (R_{OFF}) level during read operation. In the case of metal-insulator-metal (MIM) antifuse cells, read disturb problems have already been reported [5, 6]. On the other hand, in the case of standard CMOS antifuse cells, few research results on read disturb problems have been reported yet. It is because the thermal hard breakdown (HBD) of a silicon dioxide film with Joule heating effects does not recover.

If the stress current is limited during the breakdown process of an ultra-thin silicon dioxide film, the post-HBD leakage conductance is similar to that of a quantum point contact. It means that a CF is regarded as an atom-sized constriction, which is explained by the quantum point contact HBD (QPC-HBD) model [7]. The anti-breakdown has been reported which means that the reversibility of the QPC-HBD path in an ultra-thin silicon dioxide film [8, 9]. The anti-breakdown is induced by the rearrangement of defects which form CFs. The rearrangement process is driven by electron wind force [8, 9]. Because the program current of an on-chip antifuse cell is limited, the CFs of programmed antifuse cells can be formed by the QPC-HBD. Thus, the R_{ON} of programmed antifuse cells may vary during read operation: R_{ON} instability.

In this paper, It has been observed that the R_{ON} instability of programmed standard CMOS antifuse cells by using stress current and ambient temperature as acceleration factors for the first time. Also, the data retention of programmed standard CMOS antifuse cells has been discussed.

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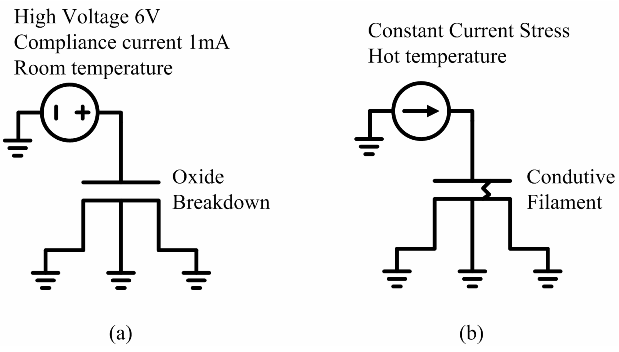
II. MEASUREMENT CONDITION

The R_{ON} instability during read operation is generally negligible as long as stress current is low. Thus, in order to observe the R_{ON} instability within short measurement time, acceleration factors should be introduced. In order to accelerate the R_{ON} instability, the electron wind force needs to be strengthened. It is well-known that the intensity of the electron wind force is related to the current and temperature [10]. Thus, it is predicted that the R_{ON} instability will be accelerated when the antifuse cells are exposed to high stress current and temperature.

For experiments, we have used typical single antifuse test patterns based on n-channel MOSFET in sub 30 nm technology node for DRAM. As shown in Fig. 1(a) antifuse cells are programmed at room temperature by 6-V gate voltage with program current fixed at 1 mA. This program condition has been selected in order to form QPC-HBD paths. Subsequently, in order to observe the R_{ON} instability, the programmed cells are exposed to constant current stress as shown in Fig. 1(b). The stress current should be lower than the program compliance current in order to prevent the phase change of CFs by Joule heating at high temperature. The accelerated stress conditions are summarized in Table 1.



(a) (b)

Fig. 1. (a) Program condition, (b) read disturb measurement.

Table 1. Acceleration conditions for read disturb measurement

	Stress current	Ambient temperature
Acceleration condition 1	500 μA	300°C
Acceleration condition 2	800 μA	300°C
Acceleration condition 3	800 μA	250°C

III. MEASUREMENT AND DISCUSSION

The R_{ON} instability consists of three regions as shown in Fig. 2. The first region is defined as "soft R_{ON} instability region" where R_{ON} increases slightly. The second region is defined as "hard R_{ON} instability region" where R_{ON} increases abruptly. The last region is defined as "R_{ON} recovery region" where the R_{ON} increased in the hard R_{ON} instability region is recovered to its initial value.

Fig. 3 shows the average R_{ON} variation ($\Delta R_{ON}(t) \equiv R_{ON}(t) - R_{ON}(0)$) in the soft R_{ON} instability region of several samples measured under the three acceleration conditions as shown in Table 1. Fig. 3 clearly shows the two acceleration factors of R_{ON} instability: stress current and ambient temperature. In the first place, comparing the acceleration condition 1 with 2, R_{on} instability is accelerated as stress current increases. The R_{ON} in the

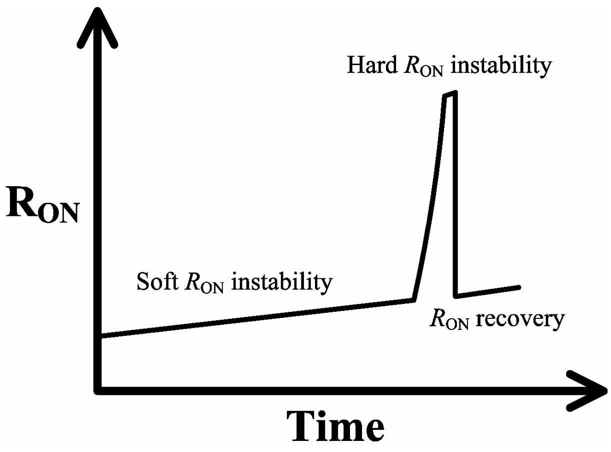


Fig. 2. Three regions of the R_{ON} instability: soft R_{ON} instability, hard R_{ON} instability and R_{ON} recovery region.

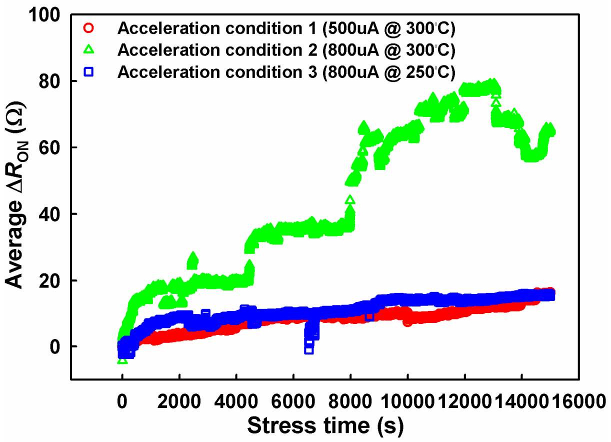


Fig. 3. $\Delta R_{ON}(t)$ in soft R_{ON} instability region under each acceleration condition.

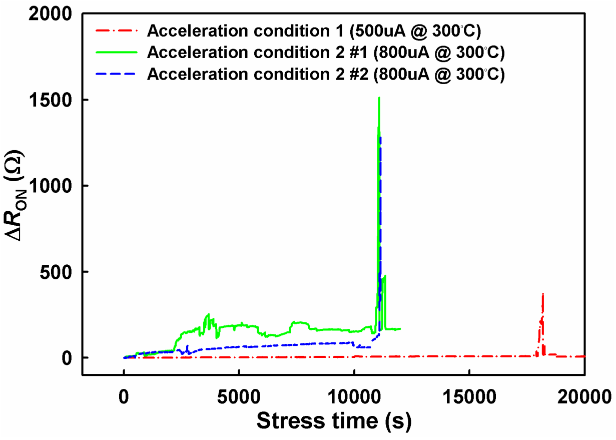


Fig. 4. ΔR_{ON}(t) of programmed antifuse cells showing a hard R_{ON} instability event.

acceleration condition 2 increases more rapidly than that in the acceleration condition 1. R_{ON} increases ~4.4 mΩ/s under the acceleration condition 2, whereas R_{ON} increases ~1.1 mΩ/s under the acceleration condition 1. In the same manner, the comparison between the acceleration condition 2 with 3 shows that high temperature accelerates R_{ON} instability. The R_{ON} in the acceleration condition 2 increases more rapidly than that in the acceleration condition 3. R_{ON} increases ~4.4 mΩ/s under the acceleration condition 2, whereas R_{ON} increases ~1.0 mΩ/s under the acceleration condition 3.

Some of the measured antifuse cells exhibit hard R_{ON} instability which is similar to anti-breakdown as shown in Fig. 4. It is because the rearrangement of defects by electro-migration effects eventually makes CFs narrower or disconnected. These unusual cells also exhibit the same trend as in Fig. 3 ahead of the hard R_{ON} instability region. It means that the occurrence of the hard R_{ON} instability is determined randomly depending on the atomic topology of CFs. Hard R_{ON} instability events occur earlier, more frequently and more rapidly in the acceleration condition 2 than in acceleration condition 1. Also, no hard R_{ON} instability event has been observed in the acceleration condition 3. Thus, it is expected that hard R_{ON} instability will show the same trend as soft R_{ON} instability.

However, in our experiment, R_{ON} does not increase to the R_{OFF} level which is larger than several MΩ, as shown in Fig. 4, even in the case of hard R_{ON} instability. If multiple hard R_{ON} instability events occur repeatedly, read disturb may occur. However, R_{ON} is recovered to its initial value before another hard R_{ON} instability event occurs because the high electric field applied across the unoccupied CF spots generates new defects. This R_{ON} recovery occurs hundreds of seconds after hard R_{ON} instability event. However, it takes more than 10,000 s to induce the hard R_{ON} instability. Thus, it is not probable that R_{ON} instability occurs repeatedly without R_{ON} recovery. Therefore, in spite of the hard R_{ON} instability, it is predicted that read disturb will not occur, even at 300 °C. Obviously, CFs in the programmed antifuse cell have been guaranteed for ten years at room temperature.

III. SUMMARY

The R_{ON} instability of the programmed CMOS antifuse cells has been investigated by using the two acceleration factors: stress current and ambient temperature. Based on experimental results, it has been found that the R_{ON} instability depends on the stress current and ambient temperature for the first time. Then, it has been confirmed that read disturb will not occur in the case of CMOS antifuse cells.

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