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Implementation of electrically programmable fuse (eFUSE) in CMOS technologies using electromigration

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1. Introduction

Fuses find extensive application in activation of redundancy, voltage trimming, circuit retiming, memory storage and other critical applications in VLSI manufacturing and circuits. These have been traditionally programmed with lasers. The electrically programmable fuse (eFUSE) has several advantages over laser programmable fuse. While laser fuses can only be programmed at the wafer level, eFUSEs offer the advantage of hierarchical invocation at wafer, module and in the field. Besides, eFUSE improves overall wirability, is more scalable, is more area efficient and is transparent to the choice of interlevel dielectric and metal interconnects. All these factors make it attractive for implementation in state-of-the-art logic and embedded DRAM technology.

This paper discusses polysilicon-silicide eFUSE technology that is programmed by a novel electromigration method which we have implemented in our Logic and embedded DRAM offerings.

2. The eFUSE Sturcture and Programming Mechanism

The eFUSEs are implemented at the gate stack level of *p*-doped polysilicon and $CoSi_2$ [Fig. 1]. The sheet resistance of the fuse link is 8Ω/□. The eFUSE programming circuit is shown in Fig. 2a. With a programming voltage, V_{DD}, applied to the free fuse terminal, the transistor-gate is turned on for the duration of the programming. The magnitude of the gate voltage may be used to control the programming current flowing through the eFUSE.

The eFUSE may be programmed by either thermal rupture or by electromigration of $CoSi_2$ and dopants in the polysilicon[1]. The eFUSE shape and size is optimised to favour the electromigration blow mechanism – which is the preferred mechanism. The fuse link has typically the minimum dimension width allowed for that technology and is thermally insulated by the nitride and oxides surrounding it. The cathode is wider than the fuse link and is designed to be an effective heat sink. This sets up a thermal gradient between the fuse link and the cathode during fuse programming. Due to the differential electromigration in the cathode and the fuse link a discontinuity is created in the $CoSi_2$ and high resistance is obtained.

3. Results and Discussion

The pre-programmed and programmed resistance percentile distributions for a sample of 80,000 fuses are shown in Fig. 2b. While the initial resistance measured is tightly distributed around 125 Ω, the final resistance is typically above 1 MΩ.

The top view SEM micrograph of a programmed eFUSE structure is shown in Fig. 3. The $CoSi_2$ is found to have moved along the fuse link towards the anode along the direction of flow of the electrons. As the silicide moves away from the cathode and is not replaced, a region of high resistance polysilicon region is left behind and the fuse is programmed. The absence of *Co* in the cathode is confirmed by energy dispersion analysis of x-rays along the fuse link (Fig. 4).

Fig. 5 shows the real-time eFUSE current characteristics during programming. During the first 50 μs a discontinuity in the $CoSi_2$ is formed. The current, however, continues to flow for the entire duration of the gate pulse. This is due to the polysilicon heating up with a high intrinsic carrier concentration lowering the polysilicon resistance. The availability of an alternative current path through the now intrinsically conductive polysilicon underlayer, allows further electromigration of the $CoSi_2$ layer to occur, thus ensuring a clean and reliable break. Simultaneously the dopant in the polysilicon also electromigrates rendering the polysilicon undoped. When the current is turned off, the intrinsic polysilicon is no longer conductive and the fuse link is rendered programmed.

The stability of eFUSEs was confirmed by a study on programmed and unprogrammed fuses (sample size 0.5 million) which were subjected to temperature, bias and humidity stress tests. Statistical studies have shown that there is no significant effect on the metal lines running above the fuse due to fuse programming. Fig. 6 shows an SEM cross-section of programmed fuses with no damage to the environment around programmed fuse.

The eFUSEs has been incorporated successfully in our 16 MB embedded DRAM products circuits. They have resulted in significant area saving, while allowing redundancy implementation at both wafer and module level.

4. Conclusions

The electromigration method of programming $CoSi_2$ eFUSE is a reliable and efficient method of implementing eFUSE technology. We have successfully studied and implemented eFUSEs for redundancy application, using this method.

Acknowledgement

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Reference

[1] C. Kothandaraman, *et al.* Proceedings of SSDM'00 p.166

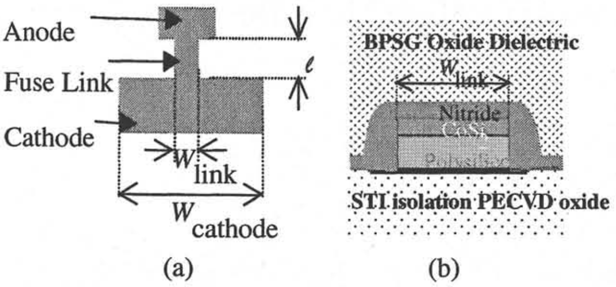

Fig. 1 The eFUSE is implemented at the gate stack level. (a) The cathode is made wider than the anode connected by a narrow fuse link. (b) The cross-section of the fuse link is shown. The poly is *p*-doped and the silicide is $CoSi_2$ obtained by the salicidation process.

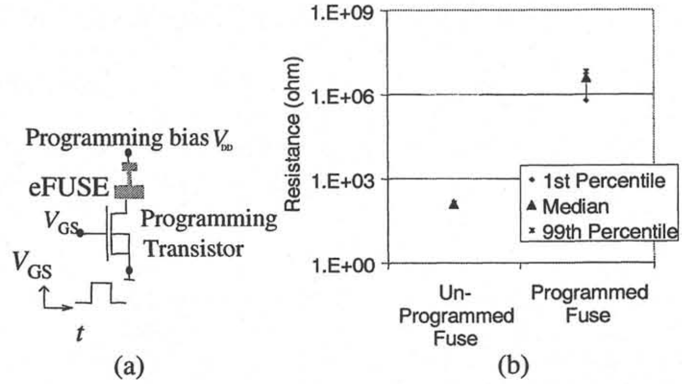

Fig. 2 **(a)** The fuse is programmed with the fuse as the load of the transistor and the programming bias applied to the free terminal of the fuse. The programming duration and current can be controlled by the bias applied to V_{GS}. (b) The pre and post programmed eFUSE resistance distribution for a sample of 80,000 fuses is separated by more than three orders of magnitude.

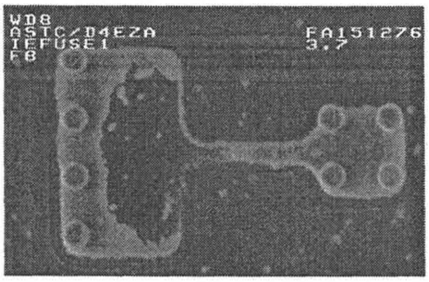

Fig. 3 SEM top view of a programmed fuse. The silicide has been moved from the cathode towards the anode in the direction of the flow of electrons. The *Co* depleted region is highly resistive resulting in the programmed resistance to be > 1 MΩ.

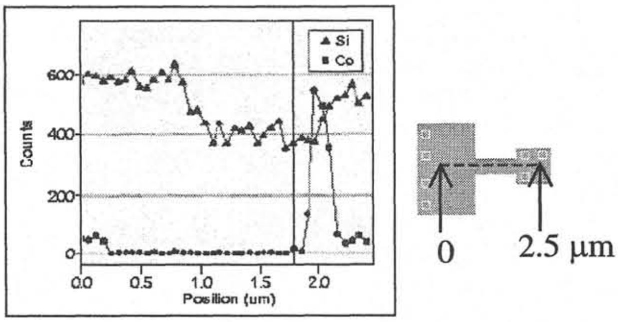

Fig. 4 Energy Dispersion Analysis of X-rays along the length of the fuse-link from the cathode towards the anode in a programmed fuse. *Co* has been removed from the cathode and the fuse link and is piled up in the anode. Lower *Si* concentration is observed along the fuse link because the generation volume is wider than the narrow fuse link.

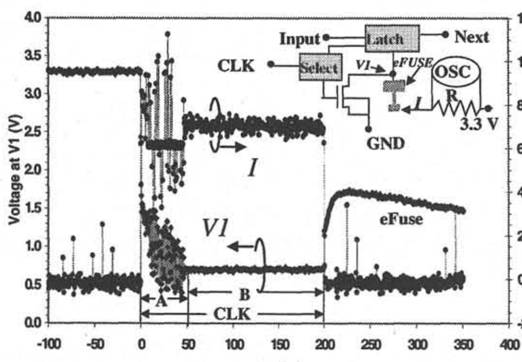

Fig. 5 Current and Voltage across the fuse during programming. The fuse shows a change in resistance during the first 50 μs when discontinuity in the $CoSi_2$ appears. The current continues to flow for the duration of the programming (200 μs). The poly-*Si* at high temperature continues to conduct current even when the $CoSi_2$ is discontinuous. Following the programming, the fuse resistance is > 1 MΩ.

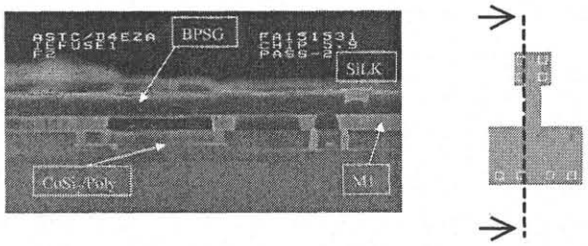

Fig. 6 No damage to the fuse neighbourhood is observed following the programming of the fuse by the electromigration method. This allows more flexible metal interconnect rules in the neighbourhood of the eFUSE compared to laser fuses.