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Optimisation of $CoSi_2$ Based Electrical Fuses for Redundancy Implementation in Sub-0.13 μm Embedded DRAM Applications

C. Kothandaraman[1], Sundar K.Iyer[2], J.J. Wu[2] and Subramanian S. Iyer[2]
[1]Infineon Technologies Corp. , Hopewell Junction, NY 12533,USA
Phone:+1-914-892-9851 Fax: +1-914-892-6462 e-mail: Kothandc@us.ibm.com
[2]IBM Microelectronics, Semiconductor R&D centre, Hopewell Junction, NY 12533,USA

1. Introduction

In embedded DRAM applications, where the memory blocks could be distributed over the chip area, it is advantageous to implement redundancy using electrical fuses, as they do not pose strict layout restrictions. Electrical fuses can also provide module level repairability and field programmability in combination with Buit-in Self-Test / Self–Repair (*BIST/BISR*)[1]. The currently available alternative for redundancy implementation, laser programmed fuses, can be implemented only on upper levels of metalization and have to be surrounded by a 'blast-shield'. Moreover, unlike laser fuses, which cannot be shrunk below the wavelength of the laser used, electrical fuses are scalable with future shrinks in the device dimensions. Electrical fuses also provide a wider choice of back-end materials, as there are no restrictions on their transparency. In this paper we discuss the optimisation of $CoSi_2$ based electrical fuses for sub-0.13 μm applications.

2. Experimental Results & Discussion

The fuses consist of gate level, poly-Si lines, silicided with $CoSi_2$ to obtain a typical sheet resistance of 8Ω/□. The layout and the cross-section of the fuses studied are shown in Fig. 1. Care was taken to obtain a structure that does not perturb the normal process flow. The plan view SEM of a fuse that was programmed with a 3.3V, 4ms pulse is shown in Fig. 2. The increase in resistance is due to the rupture in the fuse link. The change in resistance, $10^9\Omega$, is greater than the resistance change obtained by the agglomeration of the silicide[2]. The large change in resistance obtained with this technique is preferable as it eases the burden on the sensing circuitry.

Table 1 shows the effect of fuse length on the constant current programming of the fuses. The initial power density that is available for fuse blow is tabulated in Table 1. Although the small fuses had the highest power density coupled into them, they showed the smallest change in resistance. The fuses with the intermediate length were found to be optimal as they showed the highest change in resistance, in spite of the lower energy density. Longer fuse lengths were not optimal, as they required higher voltages to program them.

The heat generated in the fuse link is lost to the surrounding areas. The volume to which the energy is lost can be characterised by the thermal diffusion length, L, given as $(Dt)^{1/2}$, where D is the thermal diffusivity given as $k/\rho C_p$, k is the thermal conductivity, ρ is the density and C_p is the specific heat of the materials involved. Since the silicon and the metal contacts have significantly higher thermal diffusivity than the surrounding materials[2], the predominant path for heat transfer is through the contacts. In the case of the shortest fuse, the contact behaves as a heat sink, resulting in a reduced temperature rise, in spite of the larger power density coupled into it.

Fig. 4 shows the cross-section of a fuse-bank with a pitch of 0.6 μm after the center fuse was programmed to a resistance value of 10^9 Ω. The neighbouring fuses were unaffected by this programming. It must be emphasized that this fuse pitch is significantly smaller than the pitch attainable with the current laser fuse technology.

The effect of polarity on the fuse structures was studied by reversing the direction of the current during programming, keeping all other variables constant. In the case of intermediate length fuses, the rupture was independent of the direction of the current and occurred within the body of the link. This failure can be attributed to a thermal 'run-away' condition. However, in the long fuses, the location of the breakage was found to be near the ends and changed location when the polarity was reversed, a clear sign of electromigration (Fig. 4). Also, the magnitude of the resistance change was smaller, 10^3 ohms as opposed to 10^9 ohms in the case of the clear rupture.

In the case of electromigration, the failure occurs at the location of the highest thermal gradient, where the migration of the atoms is largest[3], while the thermal 'run-away' rupture occurs at the hottest point. In the fuse structures studied, the highest thermal gradient is expected near the contacts and the hottest point within the body of the fuse. So when the rate of electromigration is greater than the rate at which the fuse link is heating up, as in the case of long fuses, the electromigration increases the resistance to the point where no further power coupling is possible. This stops any further heating of the link resulting in a final resistance of only about $10^3\Omega$. So the optimal configuration is a fuse with an intermediate link length ~1μm.

3. Conclusions

The optimisation of $CoSi_2$ based electrical fuses was described and the intermediate length fuse (~1μm) is identified as the optimal fuse. Two competing mechanisms, electromigration and thermal 'run-away', are shown to be active during the programming. The thermal 'run-away' condition produces a clear rupture in the link and is the desirable process. A fuse pitch of 0.6μm, currently not achievable with laser fuses, is demonstrated with this technology.

References

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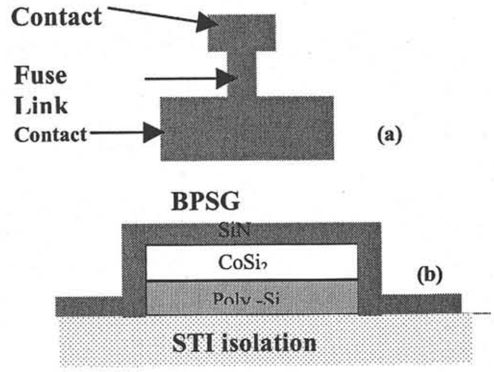

Fig. 1 (a) Layout and (b) cross-section of the fuses

Table 1. Programming parameters for constant current Programming

Type of Fuse	Nominal Length L(µm)	Current I (mA)	R before (Ω)	R after (Ω)	Power Density I^2R / L
Long	2.4	10	141	8.46E+06	5.88E-03
Long	2.4	5	150	5.60E+04	1.56E-03
Intermediate	1.2	10	83	6.49E+09	6.92E-03
Intermediate	1.2	5	85.6	3.32E+09	1.78E-03
Short	0.24	10	36	3.56E+01	1.50E-02
Short	0.24	5	35.4	3.52E+01	3.69E-03

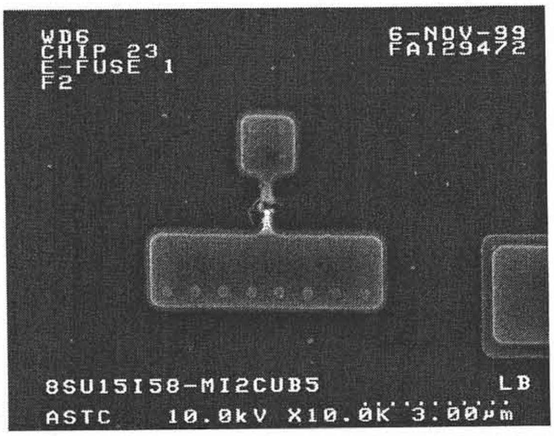

Fig. 2 Plan view SEM of a programmed fuse. The rupture of the fuse link causes the fuse to be programmed

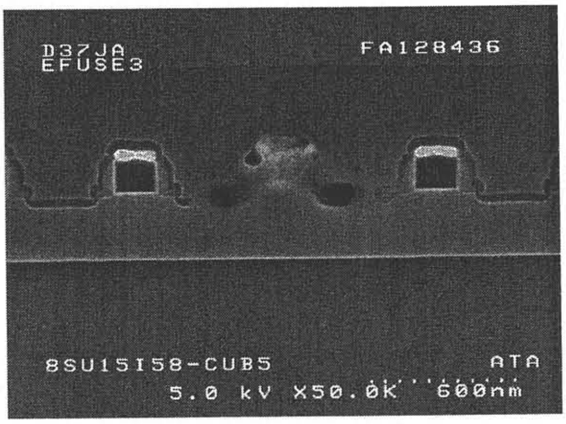

Fig. 3 Cross-section of a fuse bank with a pitch of 0.6 µm, The center fuse was programmed to a resistance value of $10^9\Omega$. The neighboring fuses were unaffected

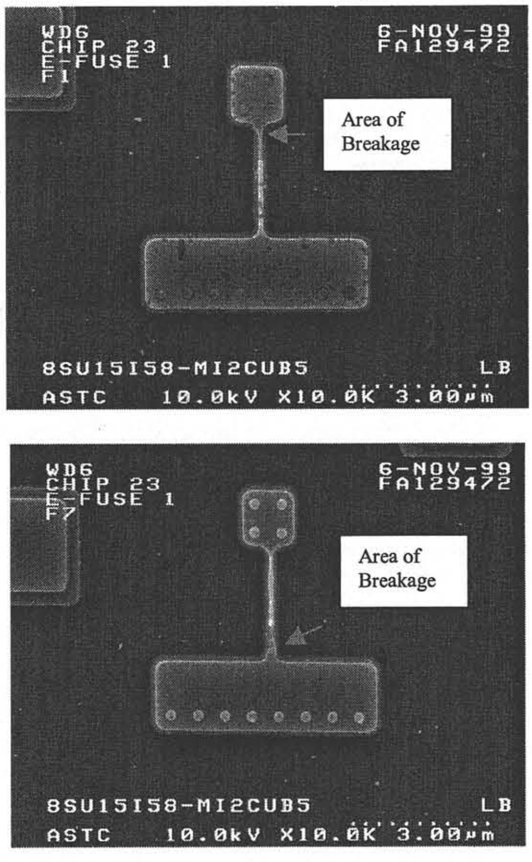

Fig. 4 Dependence of polarity on the long fuses. When the polarity was reversed (the smaller electrode in the upper picture and the larger electrode in the lower case were biased negative) the area of breakage switched location.