Extended Abstracts of the 1995 International Conference on Solid State Devices and Materials, Osaka, 1995, pp. 377-379

Extremely Low ON-Resistance Metal to Metal Antifuses with Al/p-SiN/Al Structure for Next Generation FPGAs

Yoshitaka Kimura, Yoshimitsu Tamura, Chie Tsutsui and Hiroshi Shinriki

Advanced Technology Research Section LSI division Kawasaki Steel Corp.
1, Kawasaki-cho, Chuoh-ku, Chiba, 260, Japan
TEL:043-262-2831, FAX:043-262-2619

This paper presents a novel metal-to-metal antifuse structure consisting of a plasma nitride (p-SiN) dielectric sandwiched between two aluminum layers. A leakage current in off-state is remarkably reduced by using aluminum film as an upper electrode instead of titanium or titanium nitride film. Al/SiN/Al structure antifuse provides a sufficient off-state reliability exceeding ten years at 3.6V while keeping the low breakdown voltage. Extremely low on-resistance below 10Ω and tight distribution are also realized. Finally we propose a new antifuse structure (Al/SiN/Al/Ti/TiN/Al) highly compatible with a conventional via formation process in a double metal interconnect wiring. This antifuse structure is very promising for next generation FPGAs.

1. Introduction

The field programmable gate array (FPGA) has become an essential device for rapid implementation of digital systems. Among various program devices, metal-to-metal antifuses are most promising for future FPGAs [1-3]. Recently, especially low on-resistance were reported by using plasma SiN (p-SiN) film as an insulating material [4]. In case of p-SiN film, the thickness must be reduced down to 10nm to achieve an reasonable programming voltage for 3.3V operation. However, it is difficult to obtain sufficient off-state reliability with such an extremely thin p-SiN film. We had already reported that surface roughness of a lower electrode material degraded insulative property and an amorphous-like WSix film used as a lower electrode provide high insulative properties because of it's smooth surface [5,6].

In this paper, significant influences of an upper electrode material on off-state characteristics is demonstrated. In addition to this, a novel antifuse structure for extremely low on-resistance and compatible process with conventional via fabrication technologies are proposed.

2. Experimental

Metal-to-metal antifuse structure is represented by the schematic cross-section in Fig.1. As a lower electrode, aluminum include 0.5 atomic % Cu was deposited on a thick oxide layer. After metal patterning, plasma oxide was deposited and antifuse vias were patterned. A 10nm-thick SiN film deposited through plasma enhanced chemical vapor deposition (350°C, 0.35 torr, N_2:SiH_4:NH_3=17:5:3). The standard deviation of SiN film thickness was controlled within 2% on 6-inch wafer. An upper metal was then deposited, followed by another metal patterning. Three type of upper electrode, Al, TiN(50nm)/Al and Ti(50nm)/Al were examined in this study considering compatibility with conventional via fabrication process.

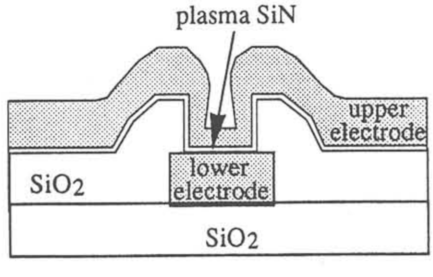

Fig.1 Schematic cross-section of metal-to-metal antifuse.

3. Results and Discussions

3.1. Off-state Characteristics

2μm×2μm antifuses and 500μm×500μm capacitors were used to examine breakdown voltages and off-state leakage currents. Fig.2 and Fig.3 show histograms of breakdown voltage and histograms of off-state leakage currents at 3.3V in three type of antifuses structures, respectively. A positive bias was applied to the upper electrode in each measurement because the dependence of breakdown voltage and off-state leakage current on polarity of applied voltage was not observed with Al/SiN/Al structure.

In Al/SiN/Al structure, a tight distribution with the mean value of 9.7V and the standard deviation of 0.58V were obtained. Furthermore, the leakage current was much lower than our criterion of 0.1pA/μm². On the other hand, in Al/SiN/TiN and Al/SiN/Ti structure, the mean values of breakdown voltage were smaller and the leakage currents were considerably larger than those in Al/SiN/Al structure although the same thickness of p-SiN film was deposited. The breakdown voltages of Al/SiN/TiN and Al/SiN/Ti antifuses are expected to be nearly equal to that of Al/SiN/Al antifuses because of a little difference between work function of Ti or TiN and that of Al. Therefore, the reduction of breakdown voltage and the increment of leakage current seem to be due to degradation of insulative properties of p-SiN film. The degradation is assumed to be caused by following two reasons. One is a chemical reaction between p-SiN and Ti film or chemically reactive Ti atom existing in the TiN film. The other is high tension to the thin p-SiN film by highly aligned TiN crystalline film. These results indicate that aluminum is the most appropriate material for an upper electrode in case of utilizing p-SiN film as an insulator.

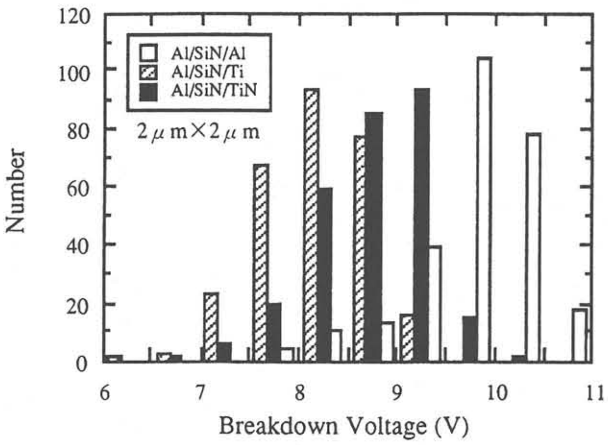

Fig.2 Histograms of breakdown voltage for Al/SiN/Al, Al/SiN/Ti and Al/SiN/TiN antifuses.

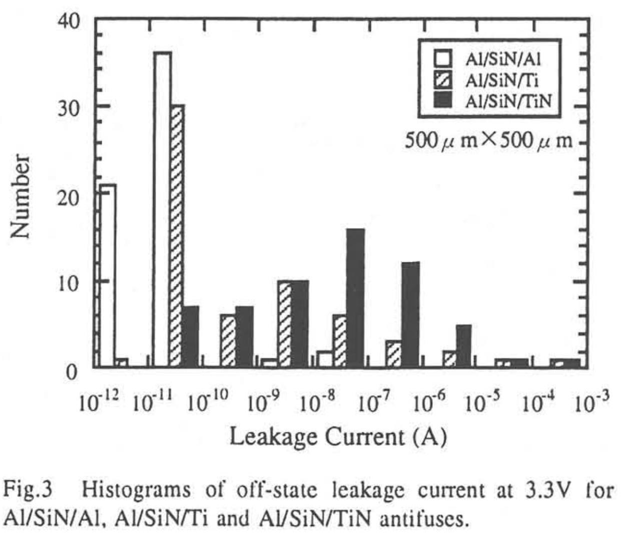

Fig.3 Histograms of off-state leakage current at 3.3V for Al/SiN/Al, Al/SiN/Ti and Al/SiN/TiN antifuses.

Fig.4 shows time to dielectric breakdown (TDDB) characteristic of Al/SiN/Al structure antifuses. A lifetime to breakdown in Al/SiN/Al structure was estimated using antifuses' array which include 1,000,000 vias. A 0.0001% failure time is extrapolated to be above 1E8 years operating at 3.6V.

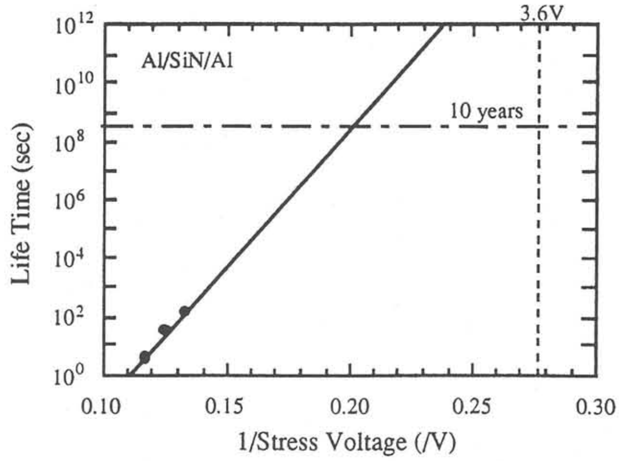

Fig.4 Time to dielectric breakdown (TDDB) of 10nm p-SiN film.

3.2. On-state Characteristics

The Al/SiN/Al antifuses were programmed using a pulse generator. The programming time is 10ms at 12V programming voltage. Series resistors of 600Ω were inserted in both side of an antifuse's electrode, between the upper electrode and the pulse generator, and between the lower electrode and the ground line to limit programming current and to reduce discharge current. Fig.5 shows the histograms of on-resistance programmed at approximately 10mA. Extremely low on-resistance below 10Ω and tight distribution are obtained in Al/SiN/Al antifuse structure.

Programmed antifuse is known to show a switch-off phenomenon [7]. We also have observed such a phenomenon as shown in Fig.6 where typical I-V curves of programmed antifuse are plotted. The switch-off phase did not appear as long as the read current remains below the programming current, which is 10mA in this case.

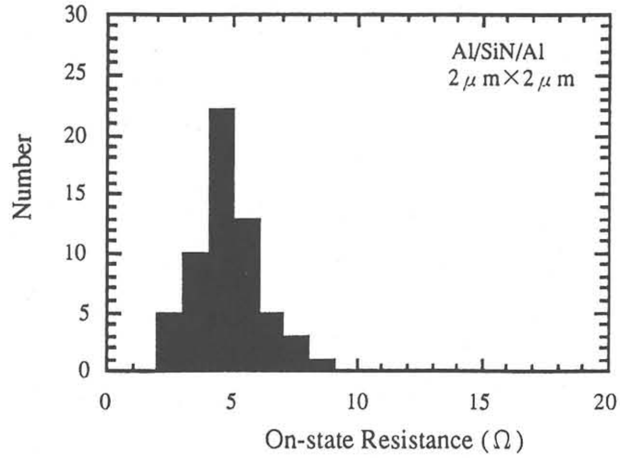

Fig.5 Histogram of on-state resistance after the parasitic resistance was subtracted. The programming current was 10mA and the read current was 1mA.

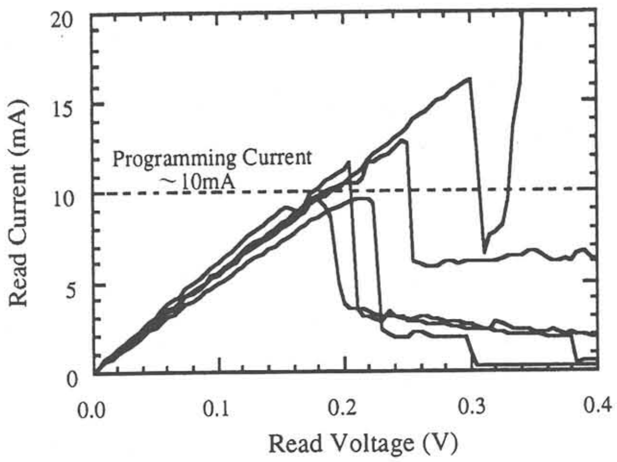

Fig.6 Typical I-V characteristics of the programmed Al/SiN/Al antifuses. Switch-off phenomenon was observed when the read current was larger than programming current of 10mA.

3.3. New antifuse structure

We propose a new antifuses structure to incorporate Al/SiN/Al antifuse into a conventional CMOS fabrication process. The feature of this process is a high compatibility with a normal via formation process as described in Fig.7. In this process, the TiN film used as an anti-reflective film of the first interconect layer is removed during via etching. After p-SiN formation, Al film is deposited as a buffer layer against Ti/TiN film. SiN/Al stacked layer is removed except portion of antifuse and then Ti/TiN film is deposited. The Ti/TiN film is necessary to decrease an normal via resistance and to enhance an electromigration tolerance.

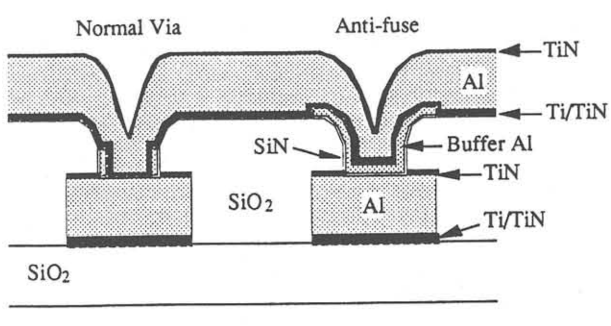

Fig.7 New antifuse structure compatible with conventional via formation process.

In order to optimize the buffer Al film thickness, off-state leakage currents of Al/SiN/Al/TiN/Al structure antifuses at 3.3 V bias were investigated as a function of buffer Al film thickness. This test structure is more severe to the insulative properties than Al/SiN/Al/Ti/Al structure as shown in Fig.3. Fig.8 clearly shows that the leakage current strongly depends on the thickness of the buffer Al film. The leakage current caused by a chemical reaction or high tension between TiN and p-SiN film is completely suppressed by 100nm-thick buffer Al film, which thickness is well acceptable.

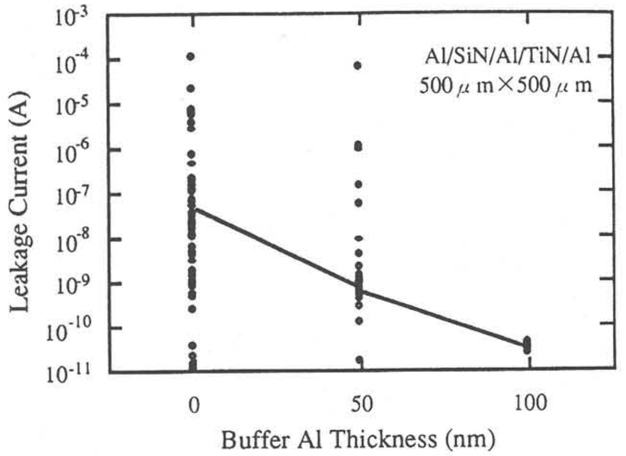

Fig.8 Off-state leakage current versus buffer Al thickness of Al/SiN/Al/TiN/Al antifuse.

4. Conclusion

A novel metal-to-metal antifuse consisting of a plasma nitride dielectric sandwiched between two aluminum layers has been developed. A leakage current in off-state is remarkably reduced by using aluminum film as an upper electrode instead of titanium or titanium nitride film. Al/SiN/Al structure antifuse provides a sufficient off-state reliability exceeding ten years at 3.6V while keeping the low breakdown voltage. Extremely low on-resistance below 10Ω and tight distribution are realized. We have also proposed a new antifuse with Al/SiN/Al/Ti/TiN/Al structure. The leakage current is completely suppressed by using buffer Al film with 100nm thickness. This antifuse structure allows easier integration of antifuse technology into a conventional CMOS fabrication technology.

5. References

1) C. Hu: IEEE IEDM Tech. Dig. (1992) 591.
2) S. Chiang, R. Forouhi, W. Chen, F. Hawley, J. McCollum, E. Hamdy and C. Hu: IEEE IEDM Tech. Dig. (1992) 611.
3) K. E. Gordon and R. J. Wong: IEEE IEDM Tech. Dig. (1993) 285.
4) M. T. Takagi, I. Yoshii, N. Ikeda, H. Yasuda and K. Hama: IEEE IEDM Tech. Dig. (1993) 31.
5) Y. Tamura and H. Shinriki: IEEE IEDM Tech. Dig. (1994) 285.
6) Y. Tamura and H. Shinriki: Proc. IEEE IRPS (1995) 36.
7) G. Zhang, C. Hu, P. Yu, S. Chiang, S. Eltoukhy and E. Hamdy: IEEE IEDM Tech. Dig. (1994) 281.