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Pb Content Control in Sputtered PZT Films for FRAM Mass Production

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1. Introduction

Ferroelectric Random Access Memory (FeRAM or FRAM™) device has several excellent properties, such as high-speed operation, high write endurance, and non-volatility. Among the ferroelectric materials proposed, $Pb(Zr,Ti)O_3$ (PZT) has widespread acceptance and we are successfully mass-producing FRAM™ devices with PZT-family ferroelectric capacitor. It is well known, however, that Pb in PZT films is unstable and a change of Pb content causes not only structural and electrical properties but also whole device reliability. Thus, it is important to control the Pb content in PZT films. Among the deposition method of PZT films, sputtering has the advantages of high productivity and low cost. Nevertheless, it has been considered that sputtered PZT films had the problem of poor control in Pb content across the wafer and wafer-to-wafer. In this paper, we describe the methods of improving the controllability of Pb contents in sputtered PZT films.

2. Effect of Pb content for ferroelectric capacitors

Figure 1 shows the effect of Pb content in the as-deposited sputtered PZT films on switching charge (Qsw) with IrO_2 top electrode and Pt/Ti bottom electrode[1)]. Qsw has strong dependence on Pb content. Other ferroelectric properties are also affected by Pb contents. Table 1 shows the required ferroelectric properties in 0.5μm embedded FRAM™ with triple layer metal[2)]. Table 1 also shows the required range of Pb content for each ferroelectric property. Thus, we need to control the Pb/(Zr+Ti) ratio from 1.10 to 1.12.

3. Monitoring Pb contents in PZT films

In order to guarantee the electrical properties and reliability of FRAM™ devices, production-worthy Pb content monitoring methods are needed. Inductively coupled plasma (ICP) analysis was compared to X-ray fluorescence (XRF) measurement to monitor the composition of PZT films. Figure 2 shows the relationship between ICP and XRF on Pb content measurement of PZT films. It is clear that there is high correlation in these two techniques and that XRF measurement has smaller error bar than ICP analysis. In addition, ICP measurement needs complicated sample preparation and the sample wafers need to be broken. In XRF method, we can measure production wafers automatically without breaking wafers, and measuring time is 60 seconds for each point.

4. Control of Pb content in PZT films

Sputtering parameters, such as power or pressure, affect Pb content in the PZT films. However, even with the same sputtering condition, Pb content is not necessarily reproducible. Figure 3 shows the changes of Pb content in continuously deposited PZT films on 50 wafers in the same condition with conventional sputtering equipment. The reasons of unstableness are existence of other parameters affecting Pb content. The authors pay attention to plasma stability and wafer temperature. As reported by Suu, Pb content depends on substrate potential, since the charged particle bombardment re-evaporates Pb from PZT films[3)]. So, the wafer potential was set to floating to minimize the bombardment. Furthermore, the grounded area in plasma chamber was expanded to keep the plasma stable. Figure 4 shows the schematic view of improved PZT sputtering machine, in which the wafer is mounted on a electrically floating hot plate with an electrostatic chuck. Figure 5 shows the change of Pb content in PZT deposited by the improved sputtering machine. Seven points on a wafer from every 50 wafers are measured for 80 days. Compare with Fig. 3, Pb content reproducibility was significantly improved.

The uniformity of the Pb distribution across wafer is another important factor to guarantee the quality of FRAM™ products. Figure 6 shows the result of preliminary experiments to check the influence of magnetic field. Small change of magnet field by adding extra magnets changed the Pb distribution. Figure 7 shows the Pb distribution in the wafer before and after the improvement of magnetic field. Pb contents are controllable from 1.10 to 1.15 with excellent uniformity using improved magnetic field.

Figure 8 shows the distributions of Qsw and leakage current with the improved magnetic field. Scattering of Qsw in the wafer are controlled within ± 2 $\mu C/cm^2$ and the leakage current are in the range of 1E-4 to 2E-4 A/cm^2 except for the area of filled square. Figure 9 shows the cross sectional view of mass-produced FRAM™.

5. Summary

The techniques to control the Pb content in the sputtered PZT films are studied. The Pb content is perfectly controlled by improving the plasma stability, wafer temperature and magnetic field. XRF analysis monitors the Pb content quickly and correctly. These two techniques realize the superior quality PZT films, which enable high performance, good productivity and high yield in mass production of FRAM™.

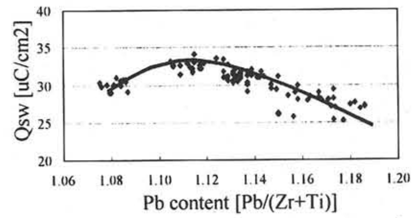


Figure 1. Dependence of Qsw on Pb content in sputtered PZT films.

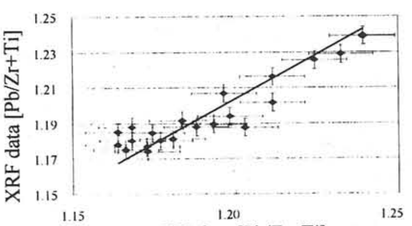


Figure 2. Relationship between ICP and XRF.

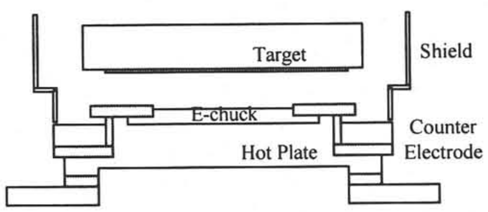


Figure 4. Schematic view of improved PZT sputtering machine.

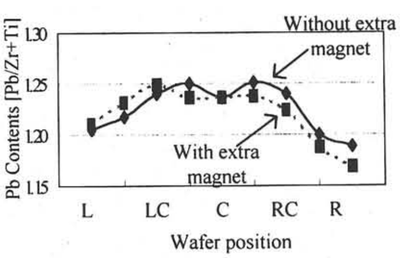
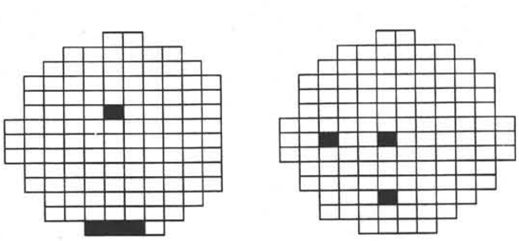


Figure 6. Effects of magnetic field on Pb distribution.



(a) Distribution of Qsw (b) Distribution of leakage current

Figure 8. Distribution of ferroelectric properties in the wafer. (Filled squares show out of range.)

References

[1] T. Takamatsu et al, ISIF 2000 abstracts, p.28 (2000)
[2] A. Ito et al, to be reported at VLSI Tech. Sump. 2000.
[3] K. Suu et al, JJAP 35, Part 1, No. 9B p.4567 (1996)
[4] T. Yamazaki et al, IEDM Tech Dig. p.613 (1997)

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Table 1. Required ferroelectric properties for 0.5um embedded FRAM.™

	Criteria	Pb/(Zr + Ti)
Qsw (uC/cm2)	> 30	1.09 ~ 1.15
Leak Current (A/cm2)	< 1E-5	< 1.15
V90 (V)	< 4	> 1.12
Fatigue loss (%)	< 5	> 1.10
Qos rate (imprint) (%)	< -3	1.09 ~ 1.13

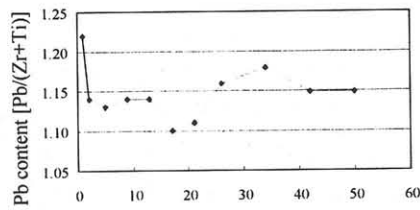

Figure 3. Pb content change in PZT before improvement.

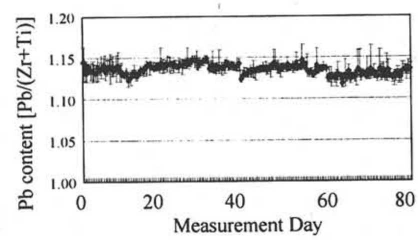

Figure 5. Stability of Pb content after improvement.

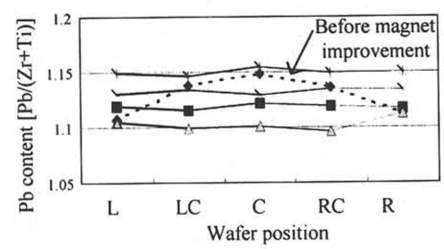

Figure 7. Pb distribution across the wafer after sputtering machine improvement.

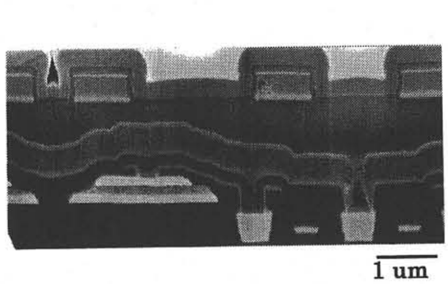

Figure 9. Cross-sectional SEM image of FRAM.™