Highly-oriented crystallinity of ferroelectric layers for reliable FRAM capacitors

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Reliability of ferrolectric random access memories (FRAM) is influenced by crystal orientation, depended on nano-scale structure of ferroelectric domains. Orientation characteristics of ferroelectric thin films are evaluated in $Pb(Zr,Ti)O_3$ (PZT) ferroelectric capacitors for FRAM. Remanent polarizations are estimated in (001) orientation for epitaxial PZT thin layers on lattice matched (001) buffer layers and in (111) orientation for non-epitaxial PZT thin layers on (111)-oriented noble metal electrode layers (1, 2).

In (001) orientaion crystals, PZT layer on (001) MgO substrate shows good controllability. However, PZT layers on (001) Si substrate with magnesia spinel ($MgAl_2O_4$) buffer layers shows poor (001) orientation (3). The influence of stress in PZT layers from the substrates is assumed in the different thermal expansion coefficients between MgO and Si (4).

Current FRAM devices are fabricated on Si substrates, which are suitable for integrated circuits. To avoid the influence of substrates, (111) orientation is selected to obtain good performance of FRAM devices. We clarify highly (111)-oriented PZT layers show large switching charge (Qsw) with a low operating voltage and high reliability.

A cross-sectional SEM image of stacked 0.18mm ferroelectric capacitors is shown in Fig. 1. Figure 2 shows the switching charge dependence on operating voltages. A 30 μC/cm^2 is obtained at 1.8 V on highly (111)-oriented PZT, while 22 μC/cm^2 on randomly oriented PZT. Figure 3 shows TEM cross-sectional images and electron diffraction patterns of the PZT/Ir/SiO2/Si structure. The electron diffraction pattern in highly (111)-oriented PZT ferroelectric layer has identical direction to that in the Ir electrode. The large switching charge at low operating voltages implies epitaxial growth of PZT layers to an extent on the Ir metal. (111)-oriented PZT is advantageous on Si-based substrates, compared with dissimilar (100) and (001) orientations. Reliability of FRAM is investigated for several measurements under accelerated. We evaluate retention characteristics in Fig. 4. The retention data were obtained at 150°C aging temperature. 1000 hours hold without data loss was achieved. This means that data retention capability can be guaranteed at least for 10 years in ordinary uses.

The switching charge of highly (111)-oriented PZT capacitors is sufficient to achieve 0.18μm FRAM and shows the possibility for further scalability.

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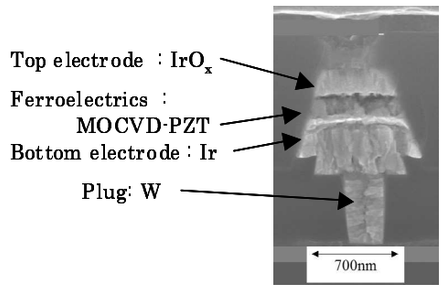

Fig. 1. Cross-sectional SEM image of a ferroelectric capacitor with IrO_2/PZT/Ir/SiO_2/Si structure.

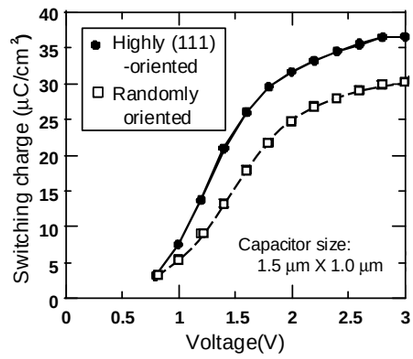

Fig. 2. Switching charges dependence on voltage.

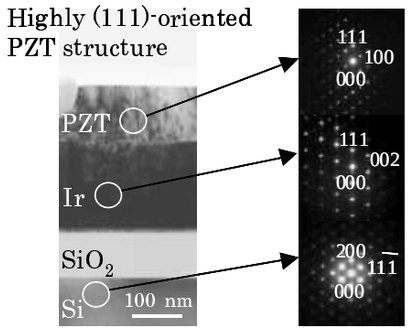

Fig. 3. TEM cross-sectional images and their electron diffraction patterns in PZT/Ir/SiO_2/Si structure.

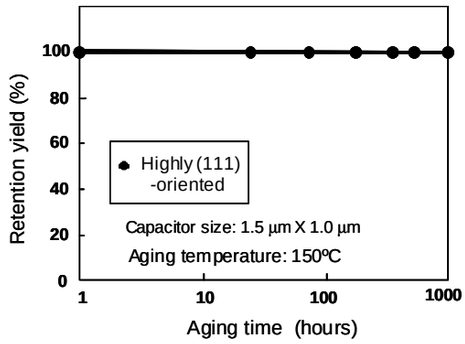

Fig. 4. Retention data of 1000 hours hold without data loss.