Chapter 8

Conclusions

In this work, we have study the oxygen pressure effect of Pb(Zr,Ti)O3 thin films using one step low pressure annealing. The pressure effect on physical, electric and dielectric properties are characterized and discussed. Then, layer-by-layer crystallized $SrBi_2Ta_2O_9$ film and a low leaky HfO_2 film was introduced to fabricate a high endurance and high retention MFIS stack. The electrical and physical properties of layer-by-layer crystallized and conventionally crystallized Pt/SBT/HfO_2/Si MFIS structures are characterized and compared. Next, the electrical hysteresis of micron-sized ferroelectric capacitors was successfully measured using the constant current (CC) method. The parasitic effect of probing setup was also determined to yield the corrected hysteresis loop. Additionally, a triangular current (TC) method was first proposed to measure the hysteresis loop of ferroelectric capacitors. The polarization-voltage curves of MIS and MFIS capacitors can also be determined by the TC method. Moreover, current-voltage (I-V) measurement method was also presented to determine the hysteresis loop and retention property of ferroelectric capacitor. The dynamic phenomenon of switching current was observed during the remained procedure.

In chapter 3, we have successfully demonstrated low-voltage ferroelectric characteristics suitable for embedded ferroelectric nonvolatile memory applications with the proposed one-step low-pressure oxygen annealing of $PbZr_{0.52}Ti_{0.48}O_3$ thin films. The ferroelectric properties and microstructures of $PbZr_{0.52}Ti_{0.48}O_3$ films annealed in low-pressure oxygen ambient are found to improve significantly compared with those annealed in 1 atm oxygen ambient. The improvements are ascribed to less incorporation of residues and adapted oxygen content in the resultant films, which are beneficial for complete perovskite transformation. Based on the P-E hysteresis characteristic, electrical property and dielectric property, decreasing the crystallization annealing pressure appears to be an effective method for achieving well-saturated polarization behavior at low operation voltages for $PbZr_{0.52}Ti_{0.48}O_3$ thin films.

In chapter 4, we have successfully fabricated a high endurance and high retention MFIS stack using layer-by-layer crystallized $SrBi_2Ta_2O_9$ film. A 320-nm-thick $SrBi_2Ta_2O_9$ film was prepared on Si(100) substrate using a 14-nm-thick HfO_2 buffer layer, which has low-leaky properties and a high dielectric constant. The C-V characteristics of the layer-by-layer-crystallized and the conventionally crystallized Pt/SBT/HfO_2/Si MFIS structures showed ferroelectric hysteresis. The memory windows of the layer-by-layer- crystallized and the conventionally crystallized MFIS structures were about 0.34 V and 0.67 V at an operating voltage of ± 6.0 V. The experimental results of MFM capacitors indicate that layer-by-layer crystallization can suppress the current through the metal-ferroelectric interface and reduce the trap density in the SBT films. Additionally, the MFIS structure with the layer-by-layer-crystallized SBT film exhibits favorable capacitance retention characteristics. When the PDA temperature was as high as 850 ^{o}C, the retention time of the layer-by-layer-crystallized MFIS structure exceeded 10^4 s and the extrapolated retention time was approximately 10^5 s. Moreover, the structure exhibits good switching characteristics with negligible degradations of the memory window and the retention time, when the number of switching cycles was about 10^9.

In chapter 5, a constant current method (CCM) was implemented to yield electrical hysteresis loops of micron-sized ferroelectric capacitors. The results for a small capacitor show that the parasitic capacitance of a probe station may markedly increase the maximum polarization as the area of the capacitor declines. The CCM technique can be exploited to calculate the parasitic capacitance of the probe station and thus construct the corrected hysteresis loops. Additionally, the dielectric constants of small capacitors were measured using an LCR meter. Satisfactory agreement was obtained between the measured dielectric constants and those obtained from the high-field slopes of hysteresis loops that had been corrected for parasitic effects. These results suggest that the CCM technique represents a method for investigating the ferroelectric characteristics of small ferroelectric capacitors.

In chapter 6, a triangular current (TC) method was first employed to measure the hysteresis loops of ferroelectric capacitors. This method yields an almost noiseless voltage profile and a smooth curve in the high-field region. Additionally, the similarity between the obtained hysteresis curves imply that neither the step charging current nor number of steps affects the P-V curve. Moreover, the results for a small capacitor reveal that the parasitic effect of the probe setup may markedly increase the maximum polarization as the area of the capacitor decreases. The triangular current method can be used to determine the parasitic capacitance of the probe setup and thus derive the corrected hysteresis loops. Furthermore, the TC method can also be utilized to determine the P-V curves of MIS and MFIS capacitors at very low frequency (< 1 Hz). The TC method also appears a smaller temperature sensitivity of hysteresis measurement as the charging current increased. The findings imply that the TC method constitutes an approach for investigating the ferroelectric characteristics of small ferroelectric capacitors and MFIS stacks.

Expect CC and TC methods, the current-voltage (I-V) measurement method was also presented in chapter 7 to determine the hysteresis switching current characteristics of ferroelectric capacitors to obtain the polarization-voltage (P-V) loops. The similarity between the P-V curves obtained by the virtual ground and I-V measurement methods implies that the I-V measurement method can also be utilized in the hysteresis measurements. The full-switching and nonswitching current characteristics were investigated using two kinds of poling measurement. The nonvolatile polarization (ΔP) calculated from the poling measurements is consistent with that obtained from P-V loops. Additionally, the dynamic switching current characteristic and the retention property of PZT(30/70) capacitor were also investigated by the modified poling measurements. An increased coercive voltage of half P-V curves was observed as remaining time increased. Moreover, the depolarized characteristics of ferroelectric capacitors and the phenomenon of space charge switching were also investigated using another modified poling profile. Furthermore, the temperature effect of switching current characteristics of ferroelectric capacitor was also discussed and the corrected P-V loops were constructed using the I-V measurement method. The findings indicate that the I-V measurement method constitutes an approach for investigating ferroelectric properties.