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# New Practical Model for Endurance Degradation Analysis of Ferroelectric Capacitors

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**Abstract**

We have investigated the endurance degradation of $SrBi_2Ta_2O_9$ (SBT) and $PbZrTiO_3$ (PZT) ferroelectric capacitors. We found that SBT and PZT capacitors have similar degradation behaviors according to log-normal distribution analysis. This behavior can be explained by our proposed simple capacitor model which is comprised of parallel connected imaginary capacitors. Polarization degradation is also found to be strongly dependent on the electric field. Log-normal plots and electric field acceleration can enable very fast prediction of endurance limit.

## 1. Introduction

Nonvolatile ferroelectric random access memory (FeRAM) has can potentially replace other memory devices because of its high speed read/write capability and low voltage operation[1-3]. Endurance limit or fatigue [4-7] is one of the biggest concerns in FeRAM production. However, method of endurance degradation analysis has not been necessarily established yet. The purpose of this paper is to investigate the endurance of SBT and PZT capacitors and to propose a new practical method of capacitor degradation analysis using simple capacitor model.

## 2. Experimental Procedure

SBT and PZT films were deposited on Pt(200 nm)/Ti(30 nm)/$SiO_2$/Si substrates using metal organic decomposition (MOD) and sputtering, respectively. Upper electrode of Pt was made by sputtering through a metal mask. SBT films were dried at 300℃ and annealed at 730℃ in $O_2$ ambient (RTA) and at 800℃ in a furnace. PZT films were annealed at 650℃ in $O_2$ ambient (RTA). The electrode area was $7.85 \times 10^{-3}$ $cm^2$. The thicknesses of the SBT and PZT films were 300 nm and 185 nm, respectively. In the polarization measurement, 3-10 V bi-polar pulses with a 1 μs width were applied to the capacitors.

## 3. Results and Discussion

Figures 1 and 2 show the relation between changes in the switching charge (Qsw) and switching cycles, where Qsw is defined as P*(changes in switching polarization charge)-P^(changes in non-switching polarization charge). In these figures, the Qsw of each applied voltage is normalized as maximum Qsw is unity. Qsw appears to increase in the early switching cycles and then decrease after reaching a maximum value.

Figure 3 shows log-normal plots of the decreasing Qsw. The decreasing Qsw of each pulse voltage is shown to be linearly proportional to the logarithmic switching cycles. Optimal fitting lines as shown in figure 3 appear to have a similar gradient both in SBT and PZT capacitors. The log-normal distribution is generally used for statistical analysis of random failure among a finite number of devices. We propose then a simple capacitor model as shown in figure 4 to explain the decrease of Qsw. Our capacitor model is comprised of imaginary parallel connected capacitors. Decreasing Qsw can be regarded as a failure of imaginary capacitors. There may be no discrepancy between this degradation model and other fatigue models such as domain wall pinning(DWP)[8], since the non-switching region in the ferroelectric films induced by DWP can be regarded as a failed imaginary capacitor in our model.

The electric field dependency of the specific switching lifetimes (N(50%)) is shown in figure 5. N(50%) is the number of switching cycles when Qsw decreased to half of the maximum value. N(50%) for SBT capacitors was predicted by extrapolating the log-normal distribution lines. The N(50%) clearly shows 1/E dependency[2,3]. Capacitor fatiguing lifetimes can be predicted for a very short time using electric field acceleration.

Figure 6 is the log-normal plot of the increasing Qsw of the early switching cycle. Increasing Qsw both in SBT and PZT capacitors also can be approximated with log-normal distribution, which is probably associated with "poling" of the 90° domain. An increase of Qsw corresponds to an increase in the number of imaginary capacitors in our model.

## Summary

We have investigated polarization changes with applying bi-polar pulses on ferroelectric capacitors. Our method of capacitor degradation analysis using simple capacitor model is effective for rapid prediction of the endurance limit on the ferroelectric capacitors.

## Acknowledgements

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## References

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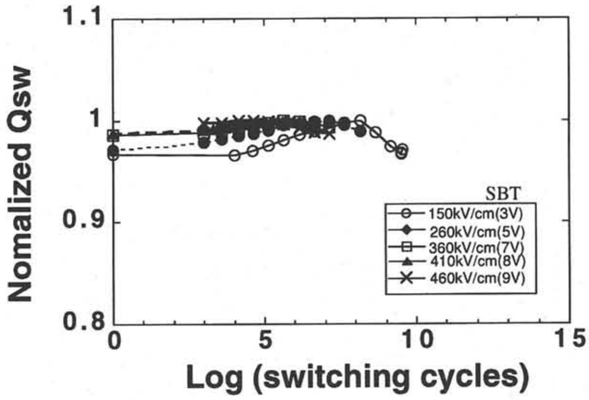


Fig. 1. Changes in normalized switching polarization (Qsw) of an SBT capacitor as a function of applied pulse voltage. Definition of Qsw is described in text.

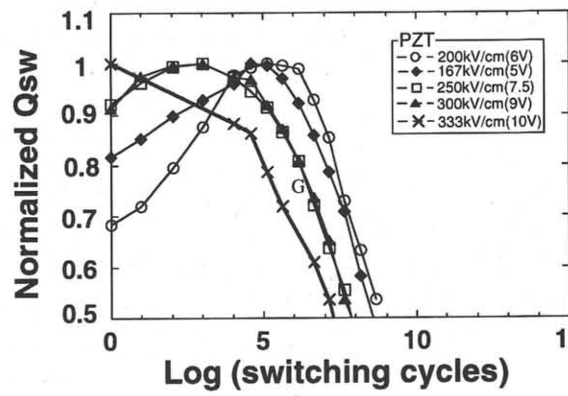


Fig. 2. Changes in normalized switching polarization (Qsw) of a PZT capacitor as a function of applied pulse voltage. Definition of Qsw is described in text.

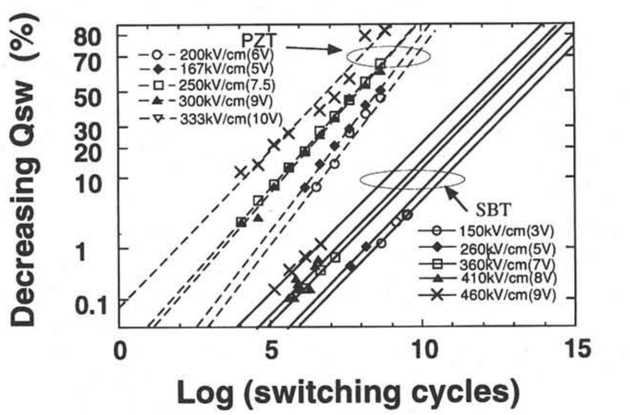


Fig. 3. Log-normal plot of decreasing Qsw. Solid lines and broken lines are obtained by optimal fitting of data on an SBT capacitor and on a PZT capacitor.

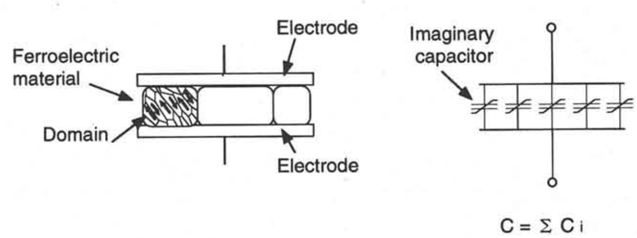


Fig. 4. Actual ferroelectric capacitor (left hand side) and a model capacitor (right hand side). The model capacitor is comprised of imaginary parallel connected capacitors.

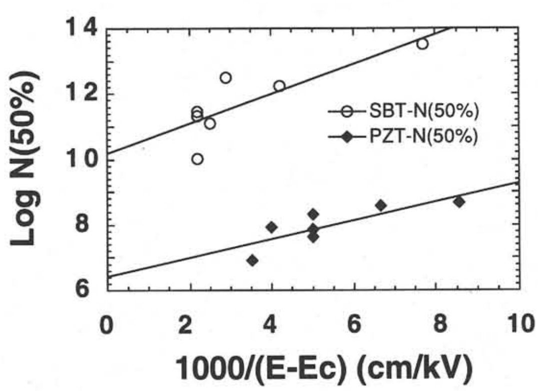


Fig. 5. Electric field strength dependency of the specific switching lifetime (N(50%)). N(50%) is the number of switching times when Qsw decreased to half of the maximum value. Ec is coercive electric field.

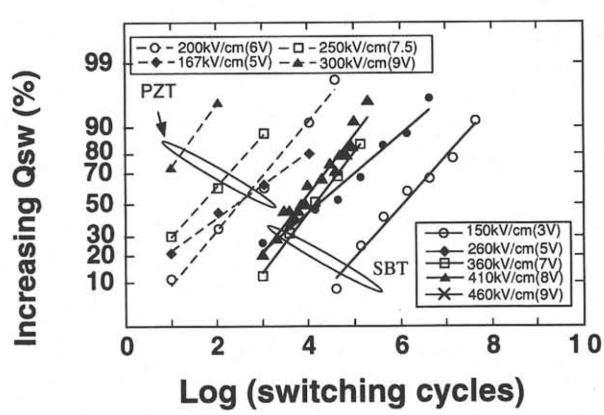


Fig. 6. Log-normal plot of increasing Qsw. Solid lines and broken lines are obtained by optimal fitting of data on an SBT capacitor and on a PZT capacitor.