Trap Density Evolution in FRAM: from Wake-up to Fatigue

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Ferroelectricity in high-κ HfO_2 and $Hf_{0.5}Zr_{0.5}O_2$ is associated with the ability to stabilize noncentrosymmetric orthorhombic phase $Pbc2_1$ [1]. Hafnia-based materials have a number of advantages over conventional ferroelectric regarding compatibility with the technological processes used in microelectronics. They have already demonstrated their ability to provide a very high density of elements. Considering the advantages of ferroelectric random access memory (FRAM) as non-volatile, high-speed performance, high number of switching cycles, the discovery of ferroelectric effect in these materials gave an impetus for the development of the universal memory concept which may lead to a significant breakthrough in the development of memory devices [2]. The unsolved problems in the way of development of FRAM-based universal memory are the Wake-up and Fatigue modes of FRAM elements. One of the possible reasons for these effects is the presence of defects in $Hf_{0.5}Zr_{0.5}O_2$ thin films. The purpose of the present work is to study the evolution of charge trap density in ferroelectric $Hf_{0.5}Zr_{0.5}O_2$ after set/reset cycling.

Transport measurements were performed for $TiN/Hf_{0.5}Zr_{0.5}O_2/TiN$ structures. Test structures were fabricated with the ALD technique. The presence of ferroelectric properties of $Hf_{0.5}Zr_{0.5}O_2$ films is confirmed by observing the characteristic hysteresis on the polarization-voltage (P-V) plate for $TiN/Hf_{0.5}Zr_{0.5}O_2/TiN$ structures.

The P-V measurements show that after 10 set/reset cycles, residual polarization P_r rises from 19 μC/cm^2 to 20.6 μC/cm^2 (wake-up). After 10^3 set/reset cycles, P_r began to decrease (Fatigue) and, after 10^6 cycles, it reached the value of 13 μC/cm^2. At ~10^4 cycle, the residual polarization exhibits a local maximum.

The leakage currents were extracted from the current responses by removing displacement currents. The leakage current depends on the voltage exponentially and can be described by the phonon-assisted tunneling between traps [3]. The slope of the initial I-V curves on the semi-log plot corresponds to the trap density of $N = 8.9\times10^{19}$ cm^{-3}. After 10^4 set/reset cycles, the current increases spasmodically and the slope of the log I-V curves corresponds to $N = 8.5\times10^{19}$ cm^{-3}. During further set/reset cycles the current rises at a particular voltage on the test structure. After 10^6 cycles, the trap density is $N = 1.2\times10^{20}$ cm^{-3}. Possible reasons of these phenomena are the subject of discussion in this work.

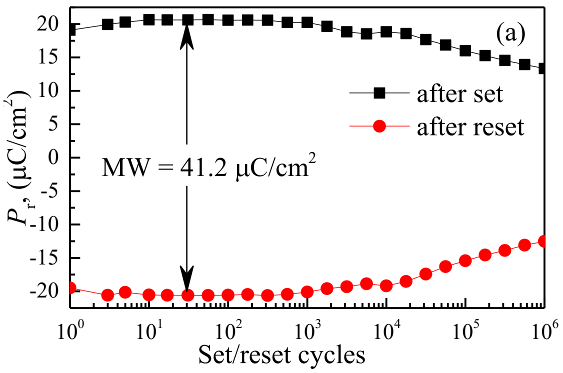

Fig. 1 Endurance of $TiN/Hf_{0.5}Zr_{0.5}O_2/TiN$ FRAM element.

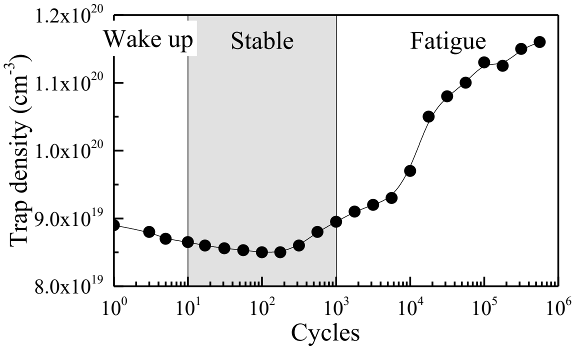

Fig. 2 Evolution of tap density in $Hf_{0.5}Zr_{0.5}O_2$ film after set/reset cycles.

[1] J. Müller et al., Nano Lett. 12, p. 4318, 2012
[2] M. H. Park et al., Adv. Mater. 27, p. 1811, 2015
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