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Investigation of the Resistive Switching Behavior in Ni/HfO₂-based RRAM Devices

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1. Abstract

In this work, a systematic study of the electrical properties and the cycle-to-cycle variability in Ni/HfO₂-based RRAM devices is presented. Besides the resistive switching behavior, attention is also given to the thermal stability of the conductive filaments.

2. Introduction

Filamentary resistive random access memories (RRAM) based on metal-insulator-metal (MIM) configurations are widely being explored as emerging non-volatile memory devices because of their high scalability, improved switching speed, low power consumption, and potential for 3-D integration. However, switching variability is one of the important problems to be overcome before their industrial application [1-3]. This problem is associated to the instabilities of the switching parameters (currents and voltages) due to the random nature of the reversible conductive filament (CF) formation. Hence, understanding the key mechanisms involved in switching variability is crucial to optimize the device performance and to foster the development of this emerging technology.

3. Experimental

The studied Ni/HfO₂/Si devices were fabricated on (100) n-type CZ silicon wafers with resistivity (0.007-0.013) Ωcm following a field isolated MIS process. The 20nm-thick HfO₂ layer was deposited by atomic layer deposition at 225°C using TDMAH and H₂O as precursors. The top metal electrode, consisting of a 200nm-thick Ni layer, was deposited by magnetron sputtering. The resulting structures are square cells of 5x5μm². A schematic cross-section of the final device structure is shown in the inset of Fig. 1(b). The current-voltage (I-V) measurements were performed using a HP-4155B semiconductor parameter analyzer. The voltage was applied to the top Ni electrode, while the Si substrate was grounded. In order to evaluate the cycle-to-cycle variability, numerous cycles and measurements are necessary to be assessed. For this purpose, a software tool has been developed (implemented by Matlab) to control the instrumentation and to smartly detect the SET and RESET currents.

3. Results and Discussion

Fig.1 shows the nonpolar switching behavior of the studied devices. The unipolar switching phenomenon in Ni/HfO₂/Si devices has been recently analyzed by real time TEM micrographs [4], where it was found that

during the SET process, Ni diffusion from the top electrode through the dielectric was detected, leading to the formation of Ni-based CFs. During the RESET process, a partial dissolution of the CFs has been observed due to thermally enhanced diffusion induced by joule heating [4,5]. To analyze the cycle-to-cycle variability [2] associated to Ni diffusion and migration processes in Ni/HfO₂-based RRAM devices, the stability of the switching parameters during successive measurements is evaluated. Fig.2 shows the evolution of the on (I_{on}) and off (I_{off}) state currents at fixed bias (V = -0.2V), corresponding to more than 3000 cycles. In the case of the I_{off} a larger spread of the current values is observed. This fact can be explained by the cyclical variations of the gap distances in the dissolved CF. The evolution of I_{on} versus applied voltage and cycle number is shown in Fig.3, where slight current variations during cycling are evidenced for all the voltages assessed. Additional parameters affecting the device variability are the SET/RESET voltages, V_{set} and V_{reset}, respectively. Fig.4 shows the cumulative distribution functions (CDF) of the V_{set} and V_{reset}. The nearly parallel CDF slopes indicate similar widths of the switching voltages distributions. Besides the cyclical variability, the impact of temperature on the switching stability is also analyzed. It can be observed in Fig.5 that the current obtained for the low resistive state significantly increases with the temperature, suggesting the contribution of tunneling-based transport mechanisms associated to a filament with a narrow constriction [5]. A detailed analysis of the thermal dependence of the switching parameters will be given at the conference.

4. Conclusions

The switching phenomenon of Ni/HfO₂-based devices is investigated. The results show a non-polar resistive switching behavior of the studied 5x5μm² devices. Moreover, the cyclical variability is analyzed, where a larger dispersion of the off state current is evidenced. This larger dispersion could be attributed to the cyclical variations of the gap distances. Finally, the electrical and thermal stability of the conductive path is also discussed.

References

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Fig.1. (a)-(d) Nonpolar resistive-switching behavior of Ni/HfO₂-based devices during SET and RESET operations for the different voltage polarity combinations. The inset of Fig. 1(b) shows a schematic cross-section of the studied devices. The area of the devices is 5x5 μm².

Fig.2. Evolution of I_{on} and I_{off} at fixed bias under negative voltage ramps (left). Schematic representation of a conductive filament (right) with high (top) and lower (bottom) conduction.

Fig.3. 3-Dimensional plots of I_{on} versus applied voltage and cycle number corresponding to Fig.2.

Fig.4. CDF of V_{reset} and V_{set} corresponding to more than 3000 cycles under negative voltage ramps. The inset shows the associated histogram.

Fig.5. Current-voltage characteristics of the on-state-current for temperatures ranging from -40°C to 200°C.