Scaling of oxide-based resistive switching devices

D. Ielmini*, S. Balatti, S. Ambrogio

Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano
Piazza L. da Vinci 32, 20133 – Milano, Italy. *Email: daniele.ielmini@polimi.it

Resistive switching memory (RRAM) is one of the main contender for future memory technologies, thanks to its fast switching, low power and non-volatile operation. The RRAM switching current can be controlled through the size of a conductive filament (CF): compliance techniques using one-transistor/one-resistor (1T1R) structures allow to reduce the filament size to only few defects, thus resulting in operation currents approaching few µA [1,2]. By reducing the filament size, it is possible to minimize cell area, which is speculated to reach below 3 nm [3]. Also, low-current operation allows to prevent voltage disturbs in multiGb arrays [4] and reduce energy consumption, which is a concern for low-power applications such as the internet of things and portable computing. However, as the filament size decreases, statistical fluctuations of the number of filament defects cause a broadening of the program distributions. Also, filament defect migration and trapping lead to read noise. Since program/read noise affects the resistance distribution, predicting and controlling statistical variability is a key objective to develop reliable RRAM technology.

This work addresses the program and read variability in HfOₓ RRAM. Program variability is highlighted in Fig. 1, showing measured I-V characteristics of RRAM devices with 1T1R architecture for a compliance current Iᶜ = 80 µA (a) and 8 µA (d). Characteristics over repeated cycles show variability of low and high resistance. As Iᶜ is decreased to minimize current consumption, switching variability increases, due to the decreased number of defects in the filament (Fig. 1c and f) and the correspondingly larger statistical variation [4]. A Monte Carlo model is developed to capture the statistical fluctuations as a function of Iᶜ by describing the migration of discrete defects in the filament. The calculated I-V curves reported in Figs. 1b and e show that the model correctly captures the increased variability at decreased Iᶜ due to the larger number fluctuation. The results are also in agreement with previous models for Poisson statistics of filament defects during set transition [5]. The same model was also extended to the reset transition, allowing to describe the impact of reset voltage on the variability of the high resistance state.

Read noise due to the fluctuation of localized defects close to the filament is finally discussed. A numerical model for random telegraph noise (RTN) is introduced to account for the voltage and temperature dependence of read noise. The voltage-dependence of RTN frequency is explained by Joule heating within the filament during read. Complex RTN effects due to multiple bistable defects is reproduced by the numerical model (Fig. 2) [6]. The improved understanding of program/read noise in RRAM and the capability to predict program/read distributions through modeling allow to derive program/read methods to minimize variability at reduced RRAM area and current consumption.
Fig. 1 Measured (a,d) and calculated (b,e) I-V curves for 1T1R devices at $I_C = 80 \mu A$ (top) and $8 \mu A$ (bottom). Large (c) or small CFs (f) are affected by small and large variability, respectively.

Fig. 2 Measured (a) and calculated (b) current showing 4-levels RTN, the corresponding carrier density for 0/0 (c), 0/-(d), -/0 (e) and -/- (f), and the square plot of $I_{n+1}$ as a function of $I_n$ (g), where $I_n$ and $I_{n+1}$ are the currents at sample n and n+1, respectively. Each square in (g) indicates an independent RTN fluctuator.