A NOVEL SPICE MACROMODEL OF PHASE CHANGE MEMORY CELLS

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Introduction: CRAM (Chalcogenide Random Access Memory) is a promising candidate for next generation of Non-volatile memory. High scaling potential, high impervious ability to ionizing radiation effects and a large programming margin make this technology attract much concentration. CRAM technology uses chalcogenide materials, which has two stable phases: amorphous state with high resistivity and crystalline state with low resistivity. The resistance ratio can reach 10^3, which provides a large read margin and great potential in multilevel storage. This technology use different current pulses producing different amount of Joule heat to melt or crystallize memory cell.

A big challenging for any new Non-volatile semiconductor memory is to integrate memory cell with standard CMOS technology and to analysis memory performance in a full-function circuit environment. Such circuit analysis is usually achieved by simulation tools, such as HSpice, which need a model represent the CRAM memory cells. But because of complicated and unclear physical mechanisms during CRAM programming, no complete physics model is available now. Therefore we need a macromodel to help circuit analysis and develop CRAM technology on full-function chip level. Unfortunately, few works were done in this area. Some literatures have outlined a steady state PSpice model of CRAM [1], but those models are simply based on internal mapping function got from experiment, which highly depends on the device structure. It is not flexible during the application.

Here, we would introduce a two terminal Spice model including simplified physical models of CRAM programming mechanisms, such as Joule heating, heat dispersion, threshold switch and crystallization kinetics. It's a more accurate general HSpice model. Because all parameters used here are decided by the material and device structure, it's easy for modification and very flexible. Further more, we can monitor the heating and crystallizing condition inside CRAM cells. We also present the simulation result of macromodel with standard write/read circuit.

Simulation: The entire macromodel can be divided into 4 parts: (I) bi-stable circuit, (II) temperature calculation circuit, (III) crystallization calculation circuit, (IV) decision circuit.

In bi-stable circuit, two resistors with different resistances represent two states of CRAM cell. Any time, there would be only one resistor connected to circuit by control switches. Transient resistor during threshold switch is also included. It would shunt previous resistors and change the resistance of either "state" when threshold voltage is exceeded. All comparisons in macromodel are realized by an Op-amp.

Temperature is calculated in (II) part. It simulates Joule heat and temperature rising. An integration circuit is used to realize following equation,

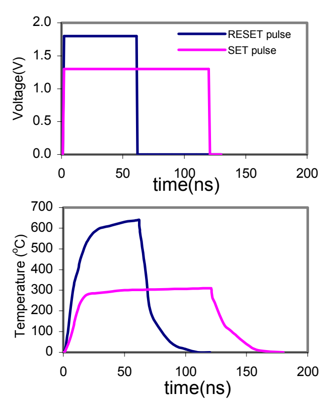
$$T = \int_{t0}^{t1} \frac{W_{joule} + W_{disper}}{C \times V} dt \qquad (1)$$

Where C is specific heat, V is volume of active area, W_{joule} is power produced by joule heating and W_{disper} is power dispersed by electrode.

When $T>T_m$ (melting point), the material would melt and switch to high resistor is on; When T_c (glass transition temperature) $<T<T_m$, material would begin to crystallize. The crystalline volume is calculated by Johnson-Mehl equations [2] in part III.

According to percolation model of conduction [2], when the volume of crystal exceeds a certain value, low resistor in bi-stable circuit would be switched on.

Results and Discussion:



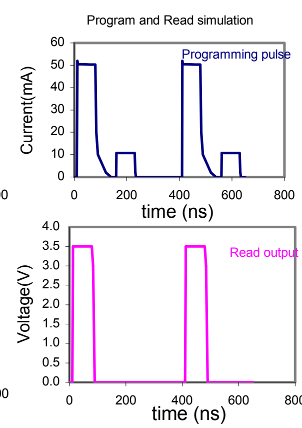


Fig1. Temperature profile   Fig2. Program and read

Conclusions: By including the physical model in CRAM macromodel, we successfully simulated not only the I-V curve, but also heating and crystallizing condition inside CRAM cells. Finally, we integrated macromodel with standard memory circuit and it was proved to function well.

References

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