RESISTIVE SWITCHING MEMORIES: A KINETIC MONTE CARLO SIMULATION

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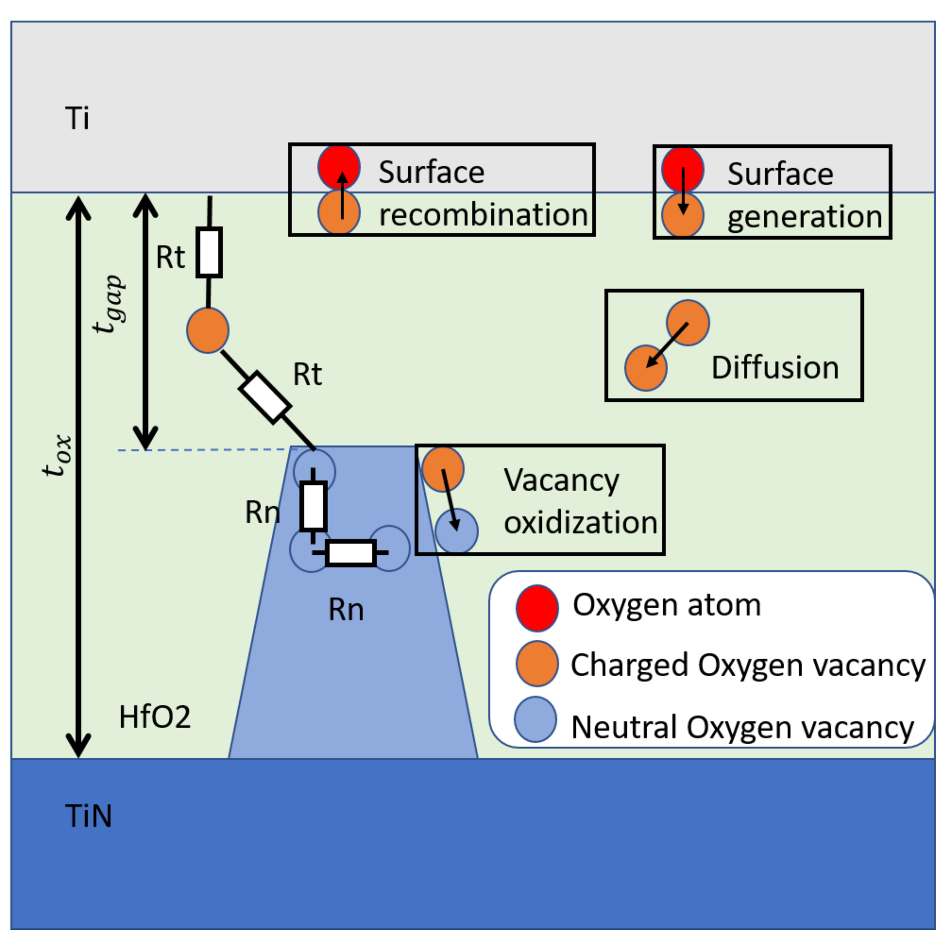
Motivation

The attention on next generation nonvolatile memory (NVM) with high density, low cost, fast access, low energy consumption and high performance with long endurance and retention is increasing because of the scaling problem facing in silicon Flash memory industry. Resistive switching memories (RRAM) is a promising candidate as the future NVMs. Compared to the prevailing Flash memory technology, the emerging memory devices should have many advantages:

- Fast response. The reading and writing latencies are expected to be < 100 ns.
- High density. A simple two-terminal device is favorable, since it is compatible with multilayer cross-bar structure.
- Low energy consumption. Energy consumption in operation is to be < 1μJ/bit.
- Long retention. Information is expected to be stored in the positions of atoms rather than electrical charge as in Flash memory. Because the mass of an atom is much larger than an electron, the emerging devices are more stable and relatively immune to environment such as heat or radiation.

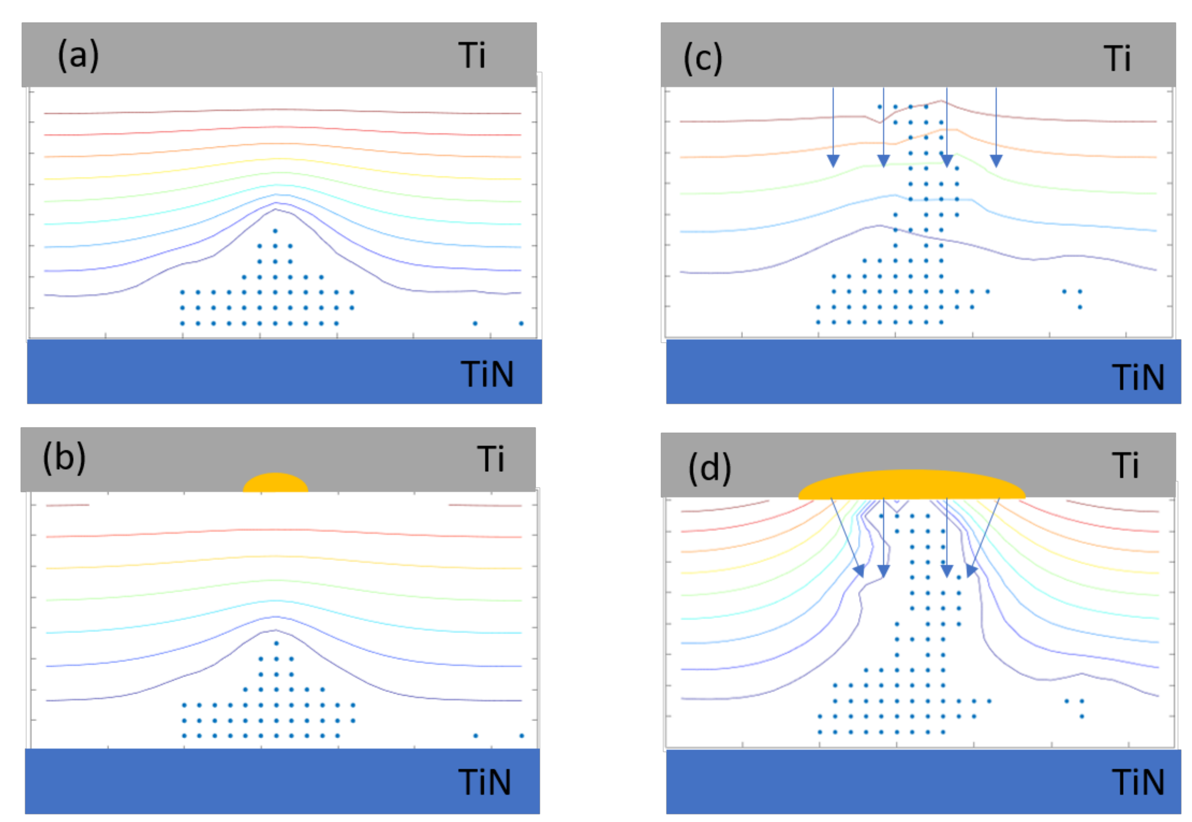
Simulation Model



- Ti/ HfO_2 /TiN system is considered.
- HfO_2 shows resistive switching behavior: when a voltage is applied on a thin HfO_2 film. The resistance can switch from a high to a low resistance value.
- Mechanism of switching: Oxygen vacancies are generated in the system, and then diffuse guided by the electric field.
- Conductive filaments consist of oxygen vacancies in the oxide layer.
- Information is stored in positions of atoms, which provides a long-time retention.

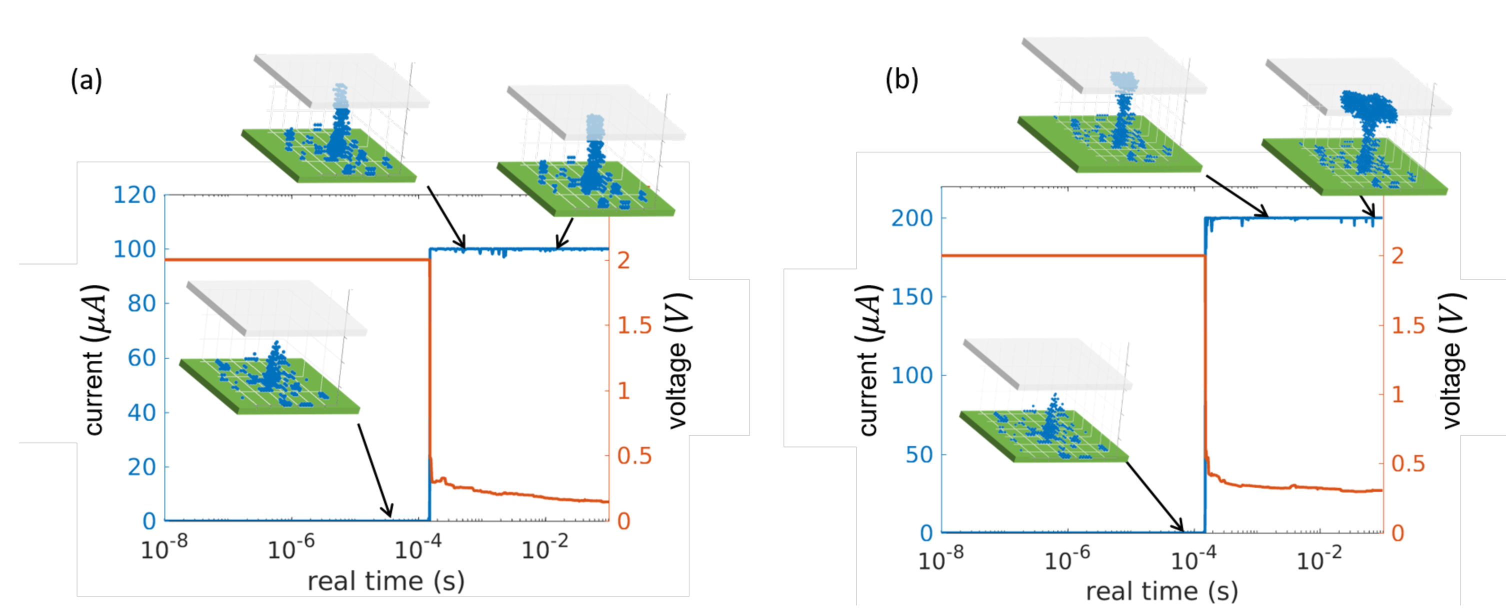
Surface Generation Model

- The kinetic Monte Carlo method is used. Generation, diffusion and recombination are considered.
- Event rates are determined by Arrehenius Law $r_i = r_0 \exp(-E_A/kT)$.
- Since the Ti in electrode is reactive with oxygen, the vacancy generation process is dominated by the surface generation process: oxygen vacancy in HfO2 is generated with the corresponding oxygen atom entering the Ti electrode directly.
- The generated oxygen atom can partially oxidize the Ti electrode and changes the electric field direction after the filament bridges two electrodes.



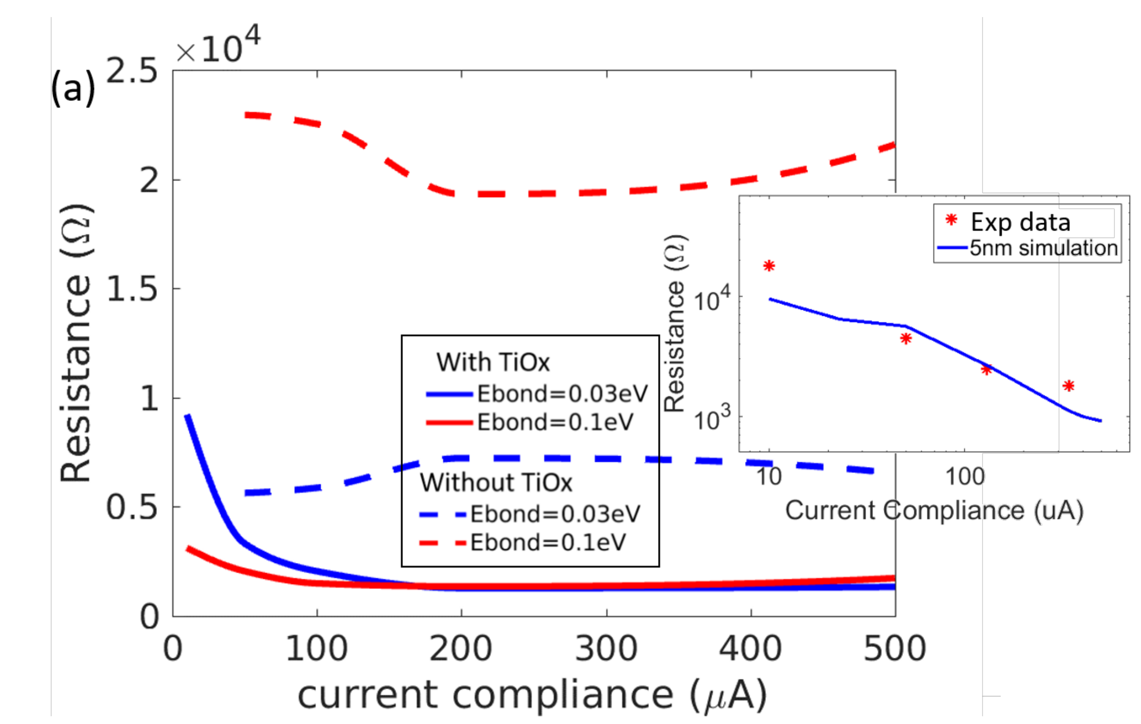
Simulation Results

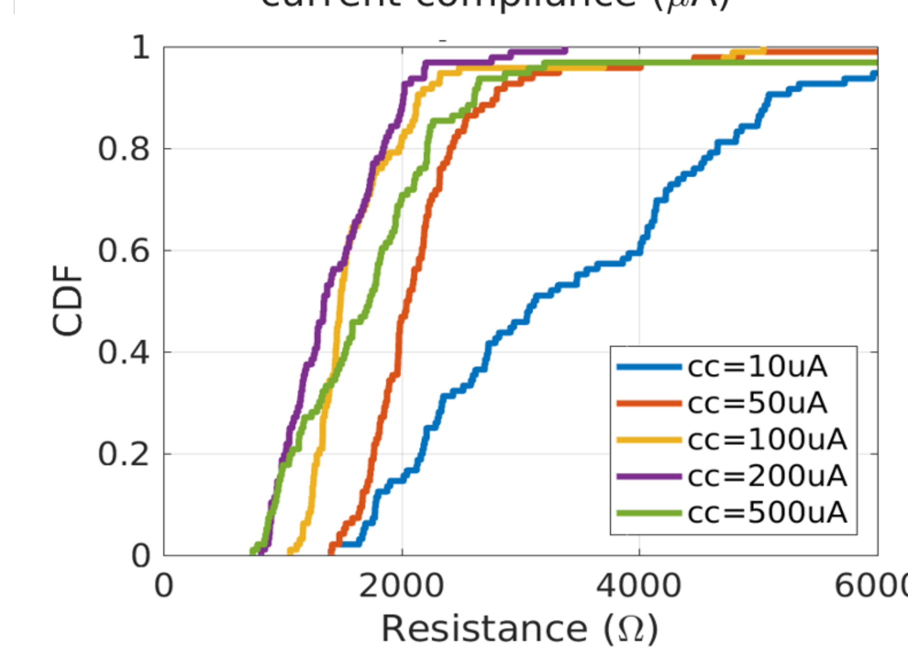
- Oxygen vacancies are generated at the top surface and diffuse to the bottom electrode.
- Vacancies form conductive filament in the oxide.
- Current through the memory cell rises at ~120 μs, and the resistance becomes low.
- The filament becomes thicker as the current compliance increases and the corresponding resistance decreases with increase in current compliance



Resistance vs. Current Compliance

- With the oxidized layer in Ti, the resistance can decrease with increase in current compliance; while without the oxidized layer in Ti, this observed phenomena is absent.
- Our simulation results match experimental data [2].
- At large current compliances, the decrease of resistance with increase in current compliance stops because of the Joule heating.
- The resistance change versus current compliance makes is easy to fabricate multilevel memory cells: one memory can store more than one-bit of information.





Future Work, References, and Acknowledgments

- External perturbations (e.g. mechanical stress) on resistive switching.
- Integration with quantum mechanical approaches (DFT and NEGF).

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[1] X. Xu, B. Rajendran and M. P. Anantram, IEEE Transactions on Electron Devices, 67 118 (2020).
[2] D. Garbin, E. Vianello, O. Bichlerfor, et. al. IEEE Transactions on Electron Devices, 62 2494 (2015)

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