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Panel II: Prospective Materials for Memory Applications

Materials for ReRAM

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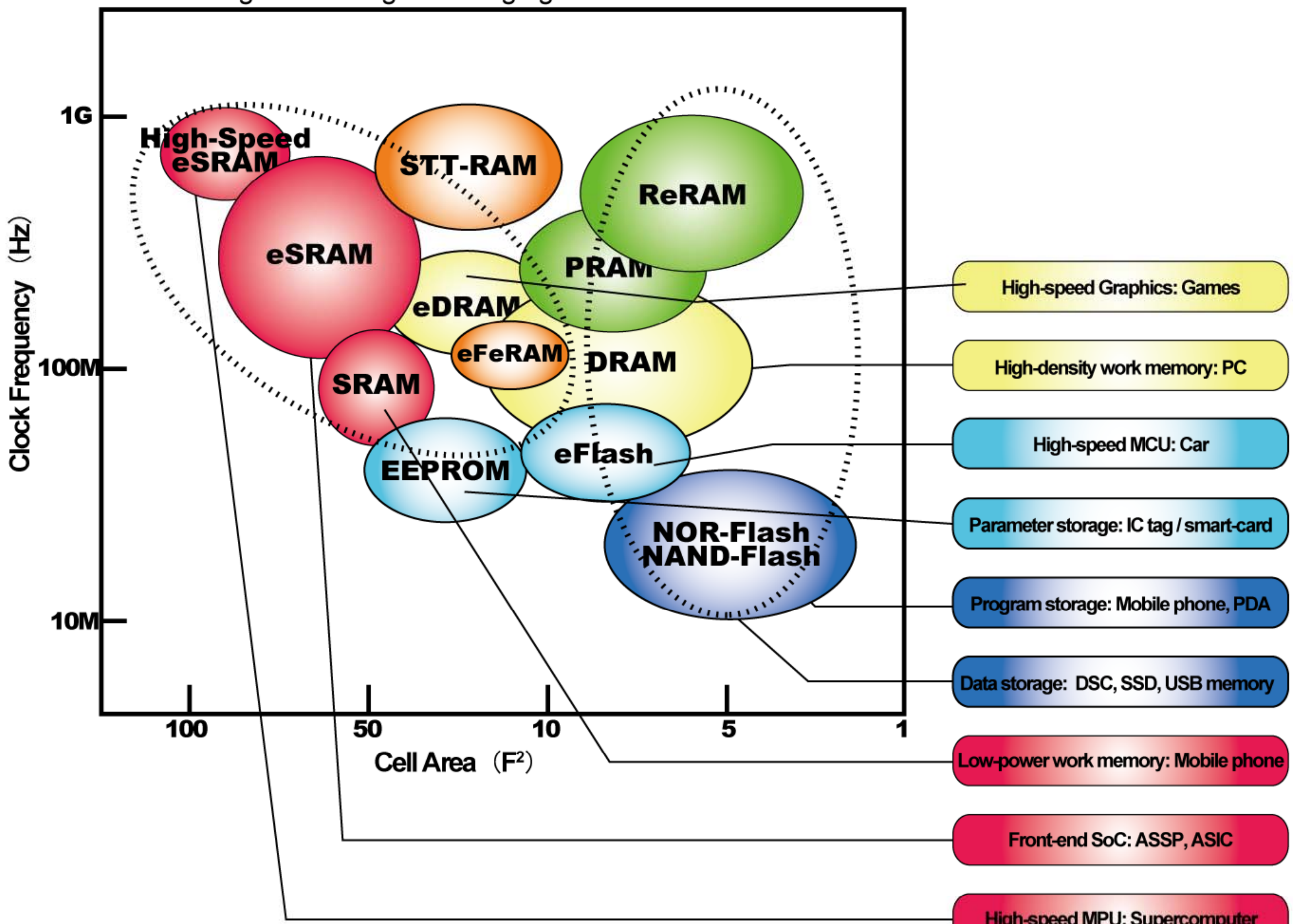
Role-sharing Positioning of Emerging Research Memories



Revised by Akinaga, AIST, ver.4.0, (originally proposed by NEC)

Q: Current status and metrics of ReRAM technology

- ☐, CMOS compatibility (materials, process…)
- ☐, No physical scaling limit (in principle)

  strong competitiveness in price / recording-bit

- ☐, Ultra-fast operation, ~ 10 [ns]
- ☐, Large ON / OFF ratio, ~ 10^3
- ☐, (tolerably) low-power operation, ~ 0.1 [mA]
- ☐, (tolerably) high endurance, ~ $10^{6\sim9}$ R/W
- ☐, (tolerably) good retention, ~ 150 ℃

Background

New engineered materials play a critical role in the development of future memories. One of the important goals of materials research for memory technologies is a clear identification of the physical mechanism of memory operation. Next, an optimized materials system has to be synthesized, including e.g. precise control of composition, doping, defects etc. For a given memory technology, it is essential to optimize a 'base' materials system. For example, resistance switching effects have been reported for many families of materials, and it is highly desirable to identify one or two optimal materials for practical implementations.

Reproducibility of results is serious problem with some emerging research materials. Also, stability of a material system with respect to endurance of the memory device is an important issue. Details of sample preparation, electrode materials, interfacial properties need to be thoroughly analyzed for addressing the endurance and reproducibility challenges.

For practical applications, synthesis of materials systems with optimized operational parameters should be achieved by taking into account the costs, which may also influence materials selection. For example organic/polymer materials are potential candidates for future memories, as they may offer lower-cost integration solutions.

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Correction of misapprehension about the operation mechanism of binary-metal-oxide ReRAM

Filament model (Fuse-Antifuse operation)

vs (conflicting)

Interface model
(incl. Schottky Barrier height modulation)

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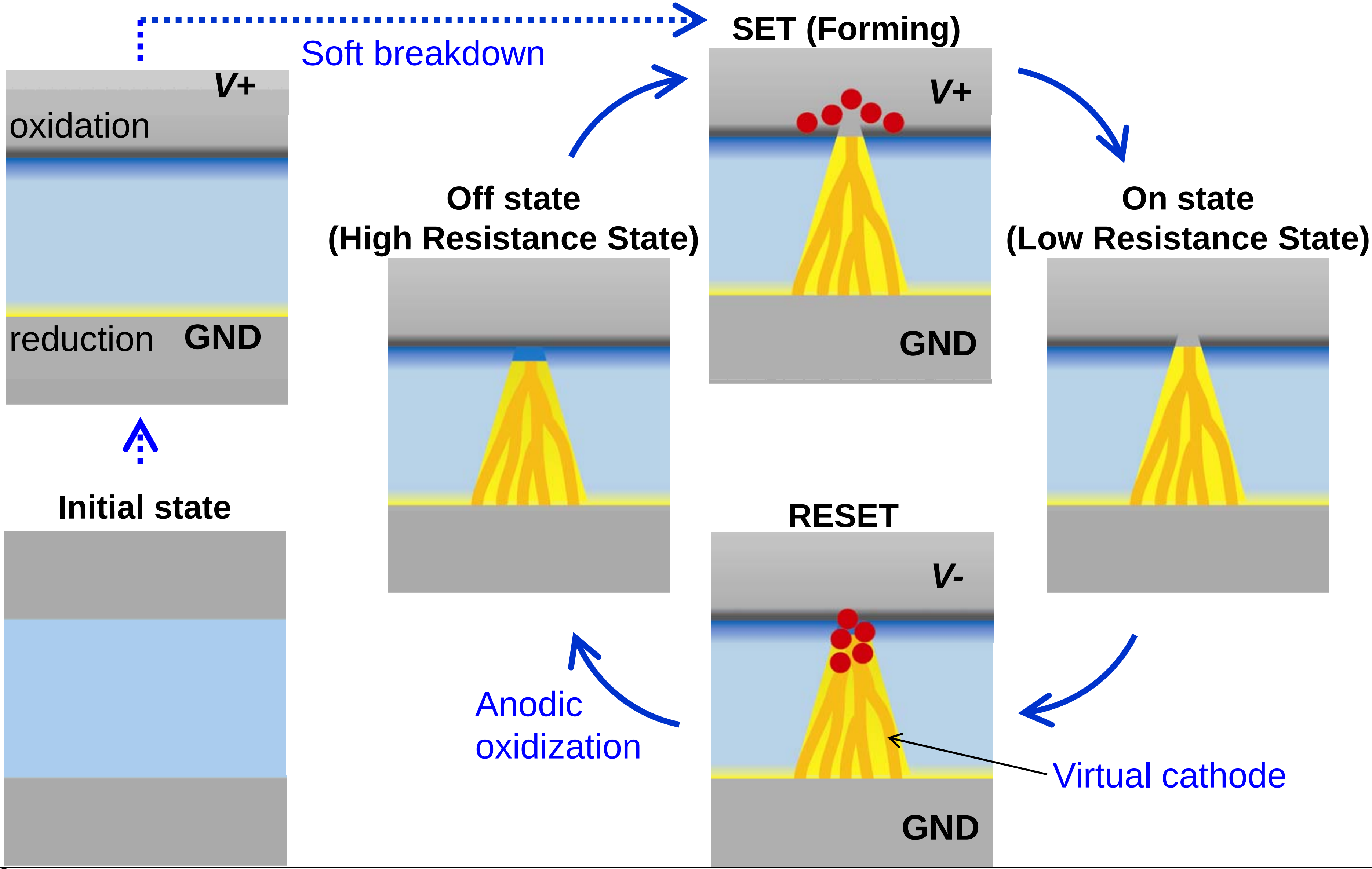
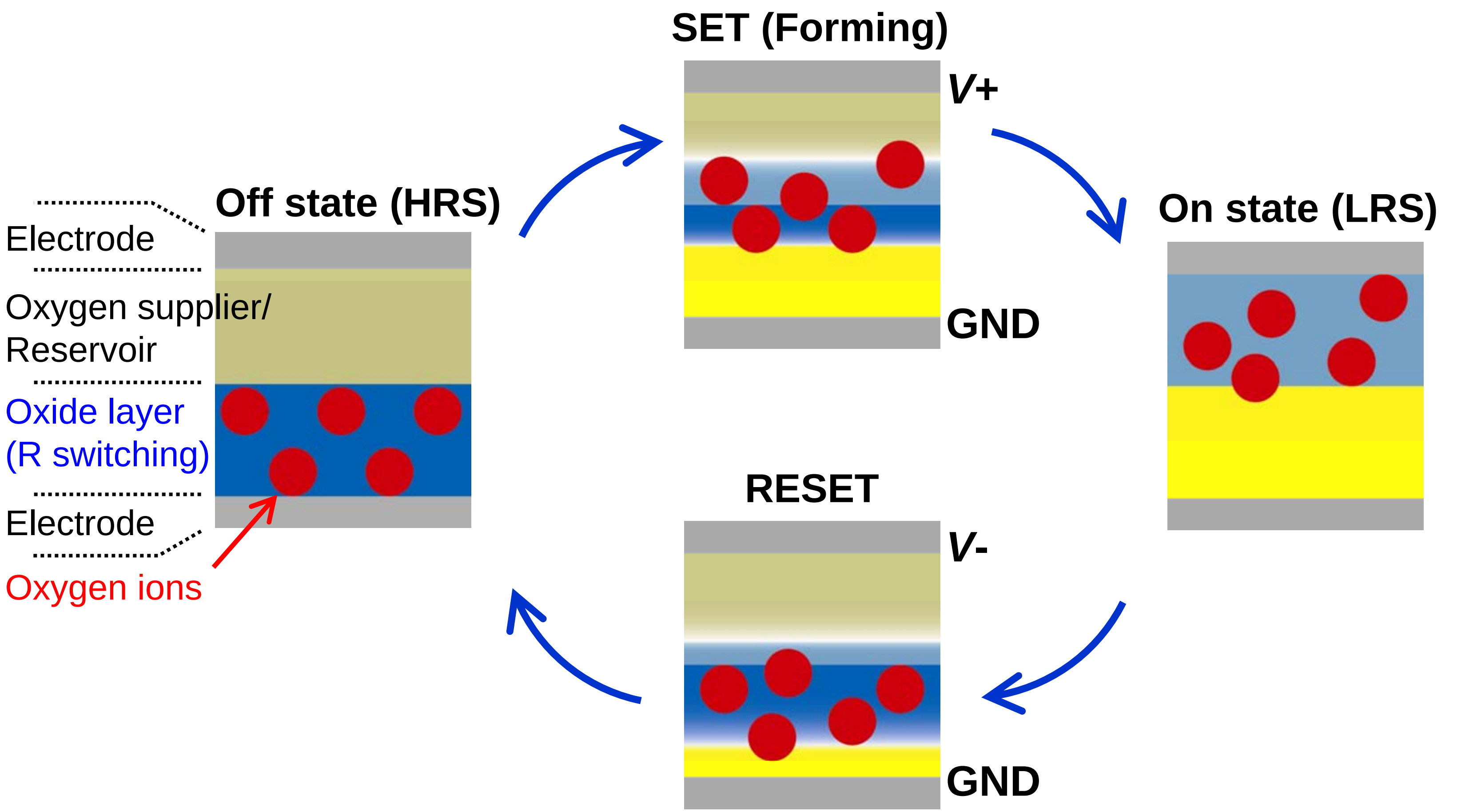
Operation mechanism of ReRAM

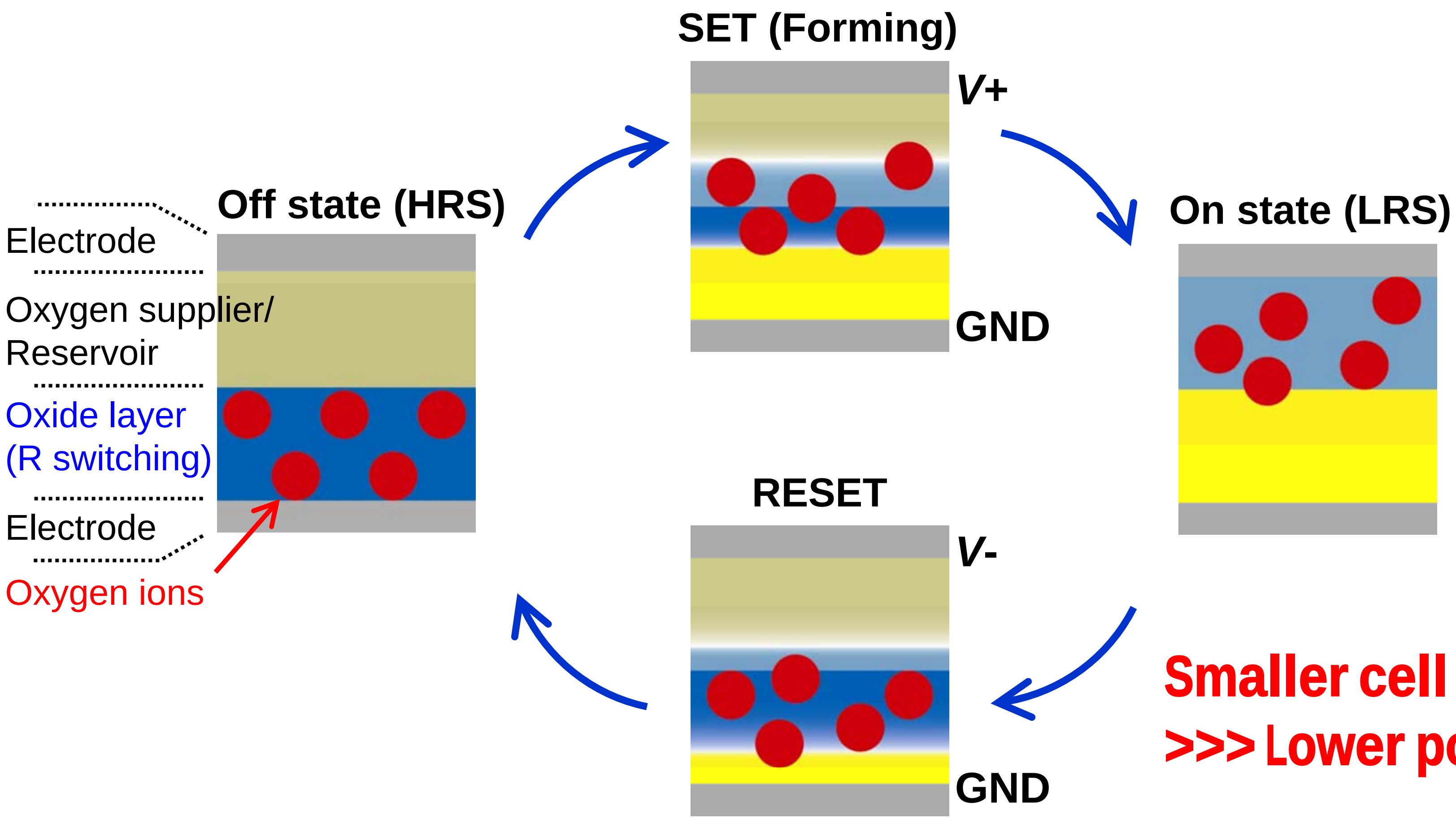


Operation mechanism of ReRAM (sub 20nm-node)



In the nano-meter ReRAM device, the filament model does NOT conflict with the interface model. The electrochemical reaction at the interface brings about the non-volatile resistance switching.

Operation mechanism of ReRAM (sub 20nm-node)



Smaller cell size
>>> Lower power!

Key issues: To select proper combination of the electrode and the oxide layer
Ellingham diagram (Gibbs Free Energy diagram) gives us the guiding principle.
We can control the active cell size at will in the operation.

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Demonstration of Fast & Low-power operation

achieved by selecting the combination of Ta and CoO
to fabricate the electrochemically active interface.

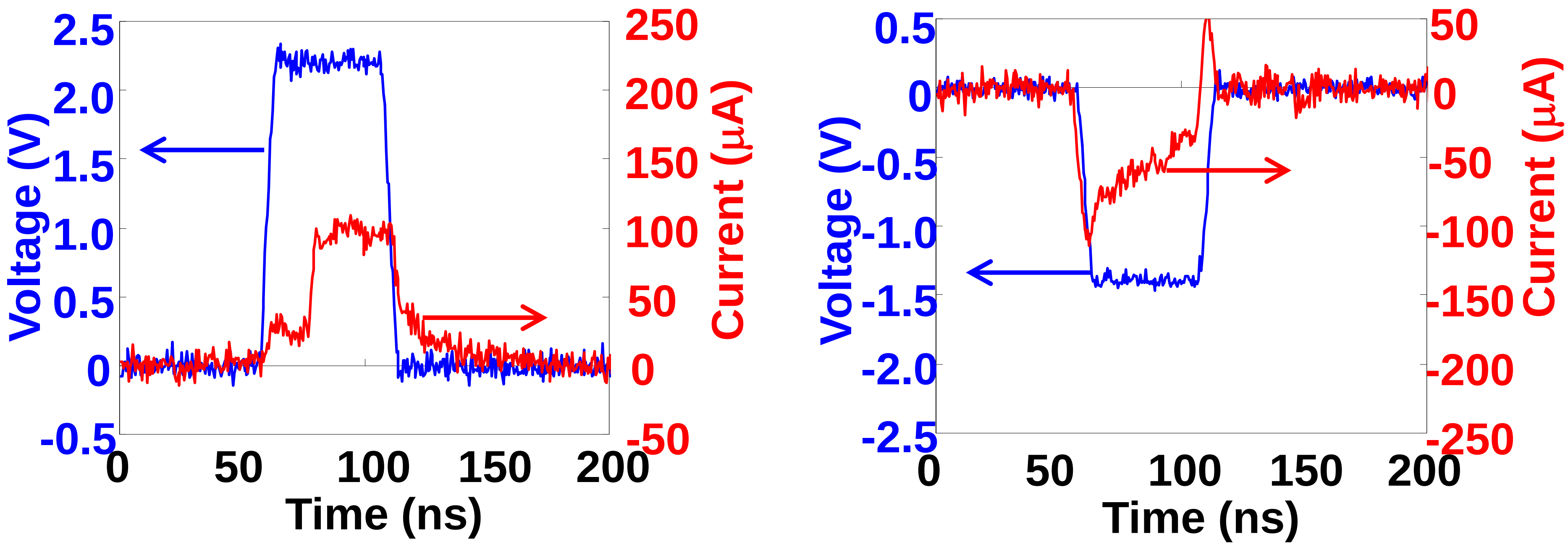

Fig. 4 Applied pulse voltage and writing current waveforms of **Ta/CoO**/Pt for (a) Set and (b) Reset. Set and reset conditions are 2.2 V 50 ns and -1.4 V 50 ns, respectively.

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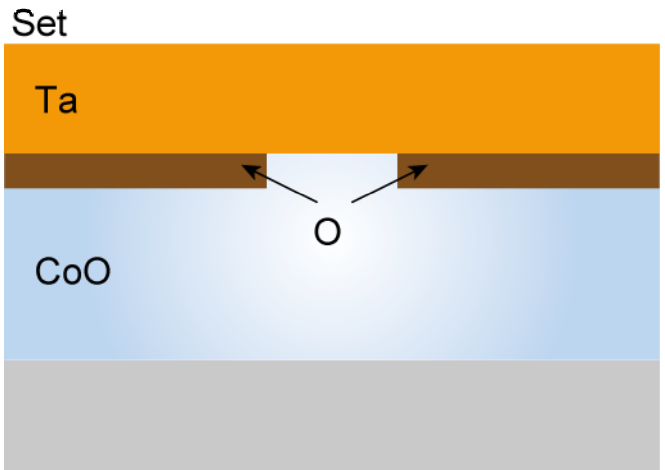
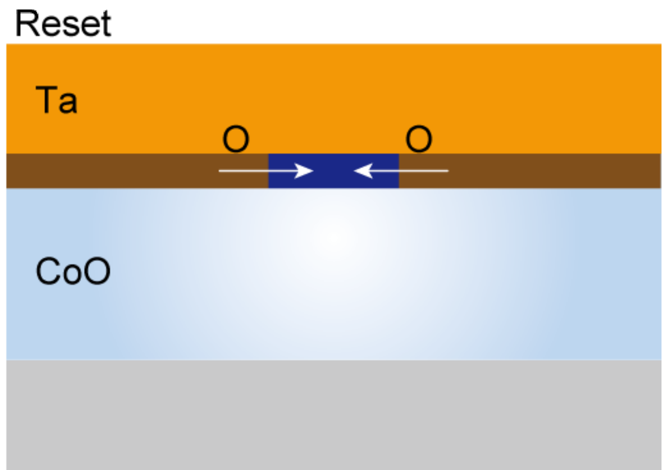


Soft breakdown
driven by the electric field



Current-induced oxidation

Key points:
The Reset current (Active cell size)
will be determined by the Set current.

Key issues: To select proper combination of the electrode and the oxide layer

We can control the active cell size at will in the operation.

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Reproducibility of results is serious problem with some emerging research materials. Also, **stability** of a material system with respect to endurance of the memory device is an important issue. Details of sample preparation, electrode materials, interfacial properties need to be thoroughly analyzed for addressing the endurance and reproducibility challenges.

For practical applications, synthesis of materials systems with optimized operational parameters should be achieved by taking into account the costs, which may also influence materials selection. For example organic/polymer materials are potential candidates for future memories, as they may offer lower-cost integration solutions.

What are the key materials challenges (the critical material properties) for ReRAM technologies?

STEP1:
To synthesize the highly-reproducible oxide interface

STEP2:
To decrease the operation current for higher endurance

STEP3:
To realize zero-current resistance switch
(Namely, ReRAM operated by Voltage)

These material challenges will open up the new and wider application area of ReRAM!

Thank you very much!

ご清聴ありがとうございました。