Bipolar resistive switching in oxides for memory applications

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resistance change effect after suitable electrical stimulation

- Phase Change RAM (PCRAM) -- resistance difference between the amorphous and the crystalline state, ex.: GeSbTe
- Conductive Bridge RAM (CBRAM), Elec-trochemical Metallization Memory (ECM) or Programmable Metallization Cells (PCM) -- the electrochemical formation and rupture of very thin metal filaments of Ag or Cu in an ion-conducting material, ex.: GeSe or GeS
- Resistance change Random Access Memory (RRAM) -- drift of anions, typically oxygen ions (often the oxygen vacancy motion), in transition metal oxides and a subsequent valence change in the cation sublattice. We name this class Valence Change Memories (VCM).

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resistance switching in MIM devices

Hickmott (1962)
-- hysteretic resis-tance change in $Al/Al_2O_3/Al$ MIM structures after application of voltage pulses

Gibbons JF, Beadle WE (1964) -- NiO
Simmons JG, Verderber RR (1967) -- SiO

- ◆ mainly on relatively thick films
- ◆ high voltage is needed.
- ◆ Mostly unipolar

Unipolar and bipolar modes

SET (forming process)-- high resistive "OFF" state ➔ low resistive "ON" state
RESET -- ON state back to the OFF state
a compliance unit of the measurement unit to avoid damage to the sample
V set > V reset and I reset > I set

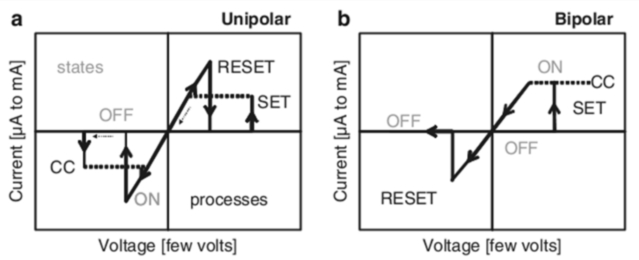

Fig. 4.1 Comparison of unipolar (**a**) and bipolar (**b**) switching characteristics. For the bipolar switching SET and RESET processes occur at different polarity. The states ON and OFF received after the switching processes SET and RESET are indicated in *gray*. CC is a current compliance used to limit the current preventing damage to the memory element

Bipolar switching

◆ the first report of bipolar switching:
Hiatt and Hickmott (1965)
bistable switching of Nb_2O_5 with Nb and Bi electrodes

In MIM structure must include some asymmetry for the bipolar switching characteristics.
The origin of asymmetry:

◆ different electrode materials
◆ a graded composition of the isolator
◆ voltage polarity during the initial electroforming step

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memory elements in thin film form

◆ In single crystals, the progress of the chemically reduced region can be directly observed and it may take several hours at room temperature to form the conducting filament.
◆ In thin films it will occur on a much shorter timescale and voltages in the range of 1–5 V may be sufficient.

In the late 1990s
compatibility and integration with CMOS processing
multiple levels of resistance states ➔ multibit memory devices

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Theory for the resistance change

In the transition metal oxides , oxygen vacancies frequently have a higher mobility than the cations.

➜

Under bias voltage oxygen vacancies as a positively charged species are attracted by the cathode.

➜

Most of the electrodes are not permeable for oxygen

➜

oxygen-deficient region is formed in the vicinity of the cathode.

➜

As an accommodation process to compensate for the oxygen deficiency electrons emitted from the cathode get trapped.

Example: TiO2

results in a reduction of the Ti-ion

➜ $ne^{-} + Ti^{4+} \rightarrow Ti^{(4-n)+}$ for Ti-oxide typically for $n > 1.5$ in $TiO_{2-2/n}$

reduced valence state changes the oxide into a metallically conducting phase

➜

expands into the bulk of the material and forms a “virtual cathode”, which moves toward the anode

At the anode an oxidation reaction is observed,

$$O_o \rightarrow V_o + 2e^- + \frac{1}{2}O_2$$

which may result in the evolution of oxygen or the oxidation of the electrode material.

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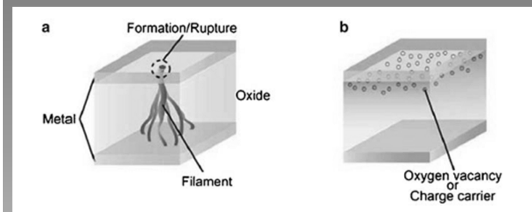

Fig. 4.2 First-order classification of bipolar switching effects. (**a**) Filamentary conduction path, (**b**) homogeneously distributed interface effect (after [16])

The geometrical location of the material property change responsible for the switching event can serve as a first-order classification of the bipolar switching effects.

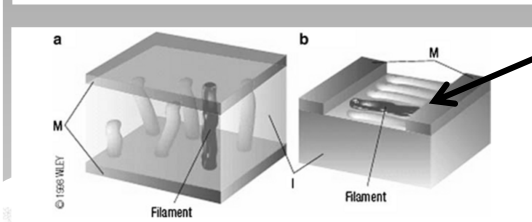

Fig. 4.3 Schematic image of the filamentary conduction in MIM structures. The red-colored filament indicates the lowest resistance path responsible for the ON state resistance. (**a**) Vertical arrangement between two metal electrodes M (**b**) horizontal arrangement between two metal electrodes M (after [16])

Can be observed by an OM

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