Three-terminal memory device based on channel doping by electric field driven oxygen intercalation

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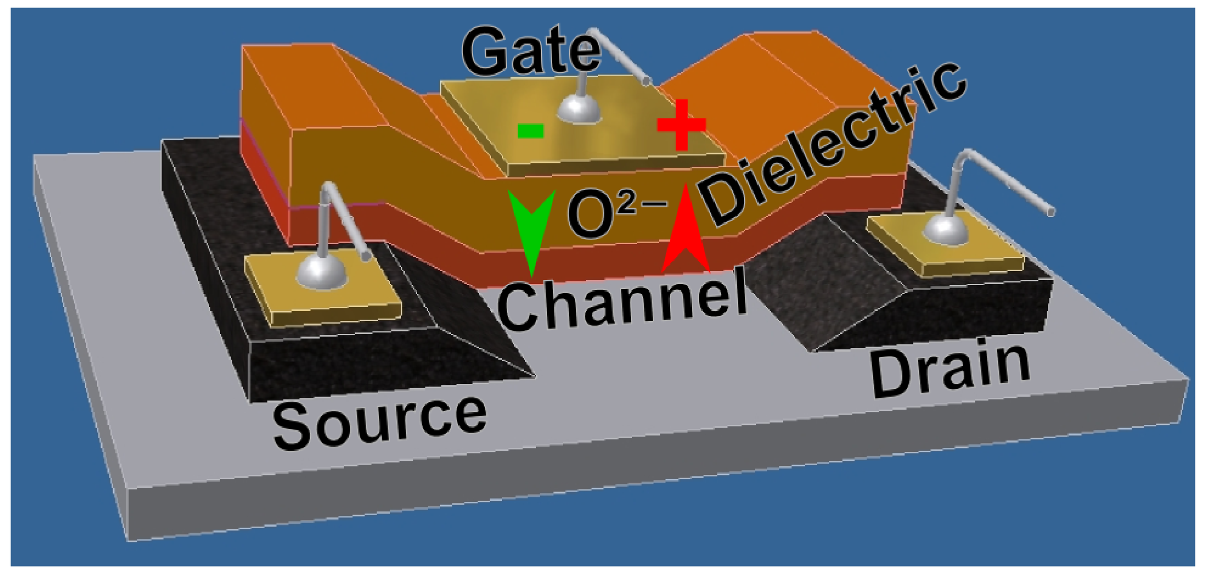
Introduction

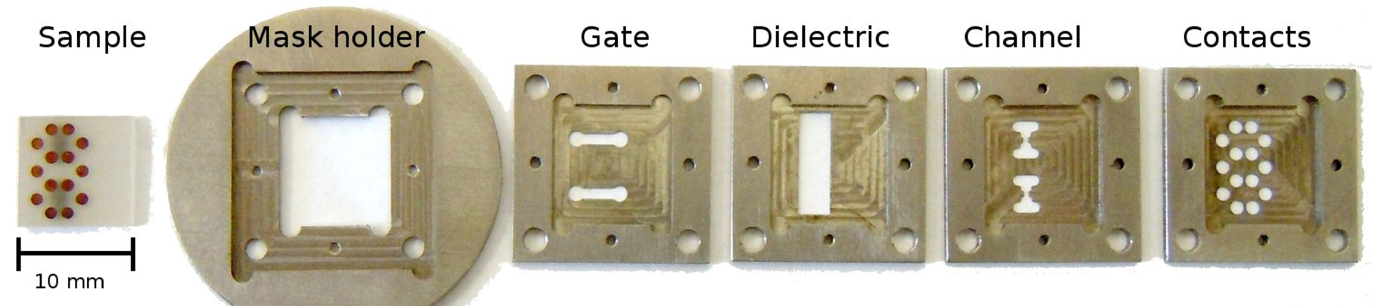
- Resistive memory could become the successor of EEPROM and DRAM
- Wide range of oxides show bipolar resistive switching
- Oxygen anion migration in a strong electrical field even at room temperature and below
- Extended lattice defects play dominant role
- Little knowledge compared to high-temperature behavior (SOFC)

Three-terminal device



- Transistor-like, similar to a FET
- Oxygen ion migration in and out of the channel through the dielectric, controlled by gate electrode
- Resistance change between source and drain through doping effect of oxygen anions

Sample preparation

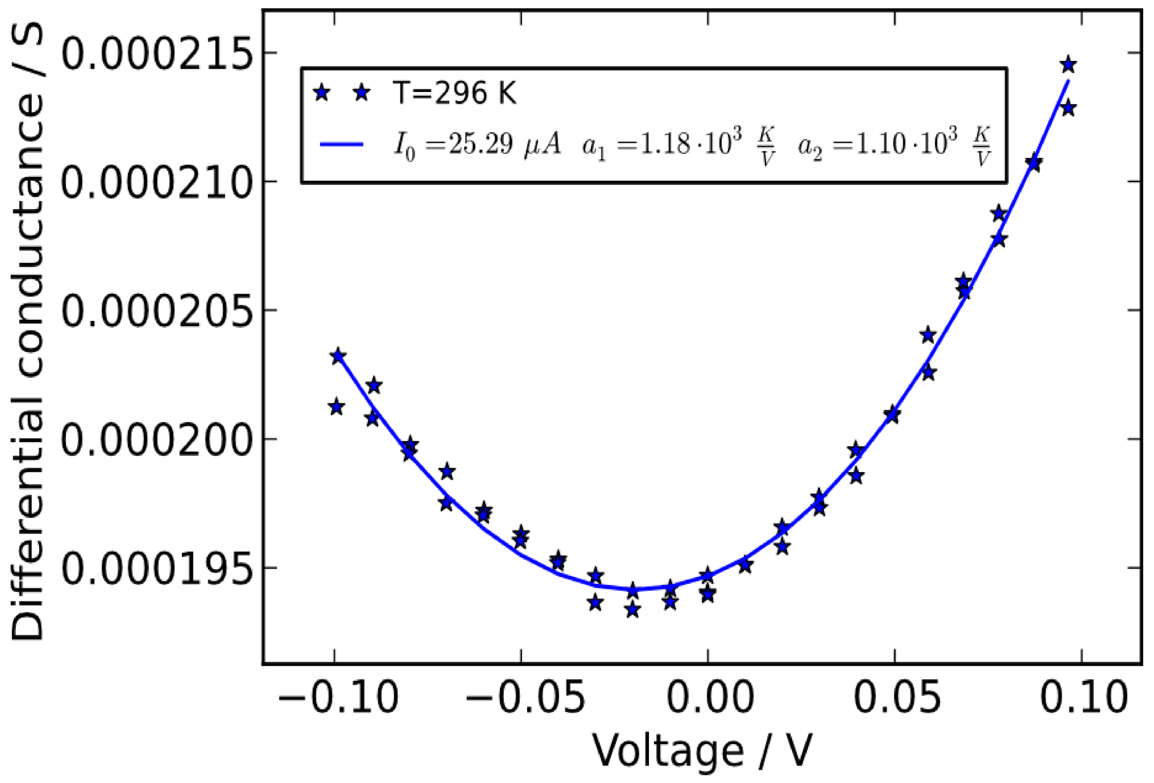


Deposition with high-pressure oxygen sputtering at 800 °C on SrTiO3 (100) substrate, structuring with in-situ masks

Gate	$La_{1.85}Sr_{0.15}CuO_{4+\delta}$	20 nm
Dielectric	$SrTiO_3$	10 nm
Channel contacts	$La_{1.85}Sr_{0.15}CuO_{4+\delta}$	20 nm
Channel	$La_2CuO_{4+\delta}$	5 nm
Passivation	$SrTiO_3$	5 nm
Contacts	Silver	400 nm

Measurements

Electronic conduction of the dielectric



$$I(U)=I_0\left(\exp\left(\frac{a_1 U}{T}\right)-\exp\left(\frac{-a_2 U}{T}\right)\right) \quad (1)$$

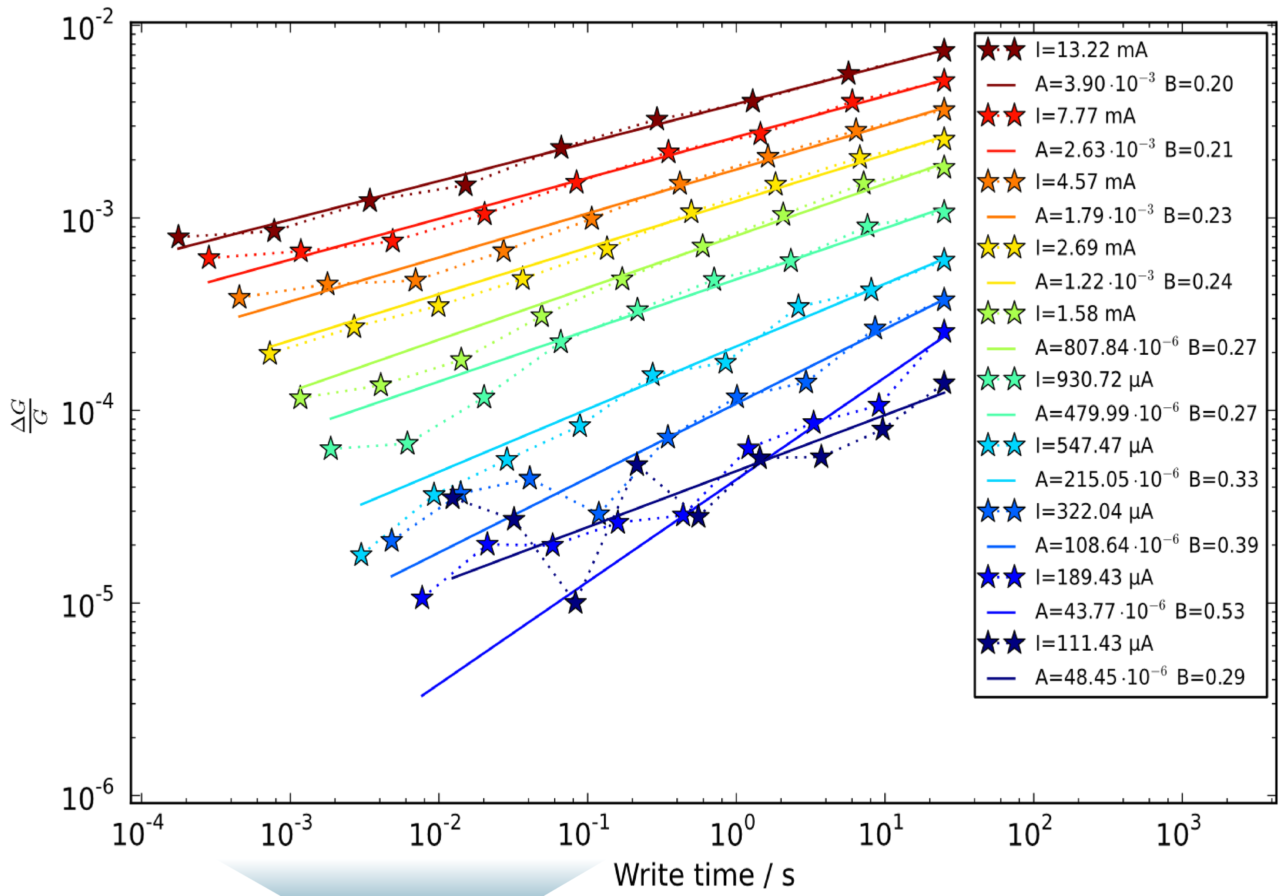
$$\frac{dI}{dU}(U)=\frac{I_0}{T}\left(a_1\exp\left(\frac{a_1 U}{T}\right)+a_2\exp\left(\frac{-a_2 U}{T}\right)\right) \quad (2)$$

I: Current, dI/dU: Differential conductance
T: Temperature
U: Voltage
I_0, a_1, a_2: Numerical factors (depend on temperature)

Similar to Butler-Volmer equation or Shockley equation, describing electron transfer kinetics in an electrochemical cell respectively diode

Switching kinetics

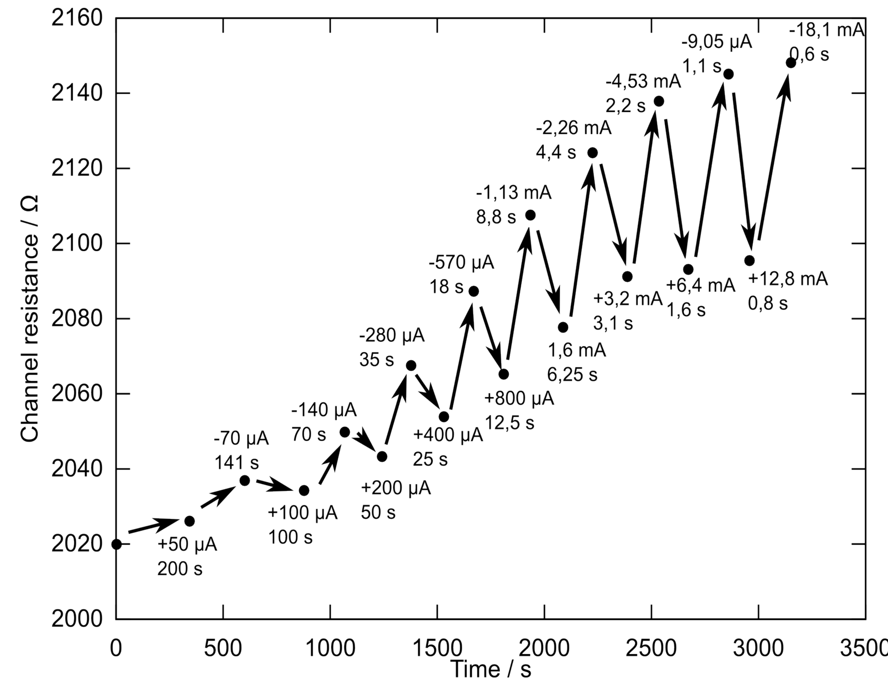
Writing with varying current I and time t and measuring subsequent change of channel conductance



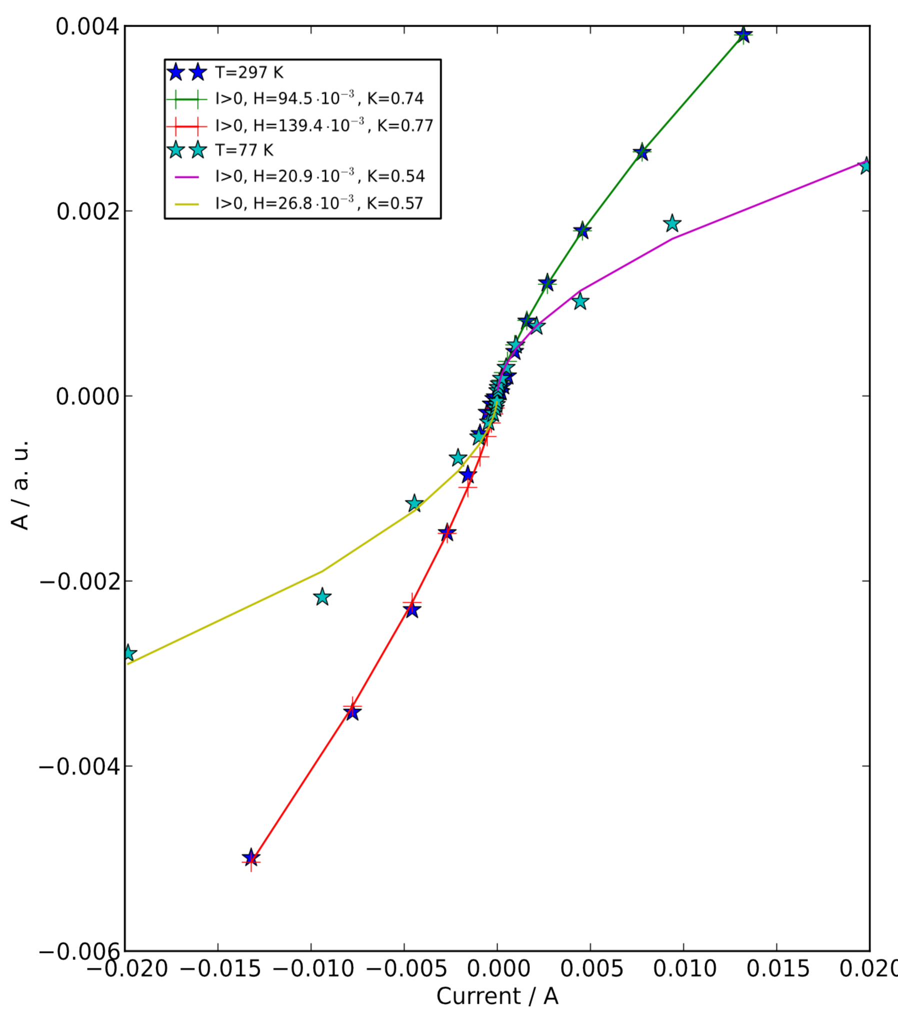
$$\frac{\Delta G}{G}(I,t)=A(I)t^B \quad (3)$$

$$A(I)=H\,I^K \quad (4)$$

ΔG/G: Absolute value of relative conductance change
t: Write time
I: Absolute write current
A: Current-dependent numerical factor
H, K, B: Numerical factors, different for I>0 and I<0 and changing with temperature



Resistance change caused by writing with current of alternating direction and increasing value



Conclusions

- Parameter A in eq. (3) is proportional to the ionic transport speed
- Parameter B in eq. (3) is related to depletion/saturation of ion source and sink
- For sufficient large *U*, eq. (1) simplifies to

$$I=I_0\exp\left(\frac{aU}{T}\right) \quad (5)$$

- An equation of the form of eq. (4) can be derived if eq. (5) is assumed for both ionic and electronic current with parameters $I_{0,el}$ and a_{el} resp. $I_{0,ion}$ and a_{ion}:

$$I_{ion}=I_{0,ion}\left(\frac{I_{el}}{I_{0,el}}\right)^{\frac{a_{ion}}{a_{el}}} \quad (6)$$

- Parameters still depend on sample geometry
- Measurements open a window to study ion and electron transport kinetics in films with nanometer-thickness under high field strengh in a large temperature range
- Outlook: Scaling down, improved geometry, reduce equations to geometry-independent paramenters, materials screening, role of paramenter B, trace ion movement (SIMS, TEM)

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