Memresistive switching in Ag_2S solid electrolyte

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Nanophysics seminar

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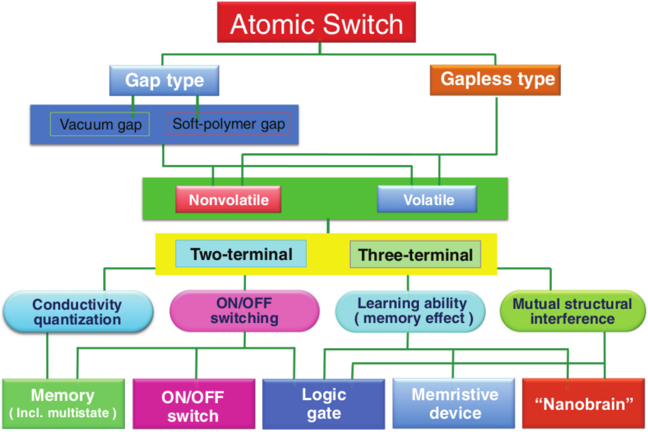
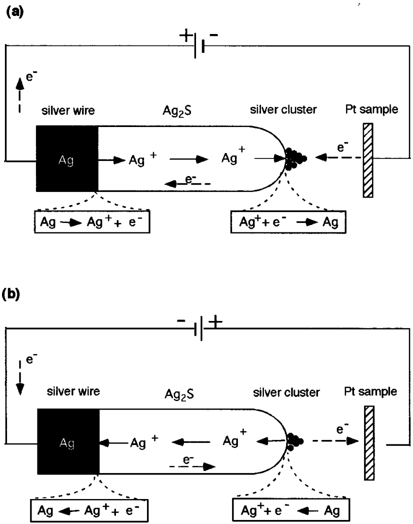
Classification [1]



[1] T. Hasegawa et al., *Atomic Switch: Atom/Ion Movement Controlled Devices for Beyon Von-Neumann Computers*, Adv.Mat. **24**, 252 (2012)

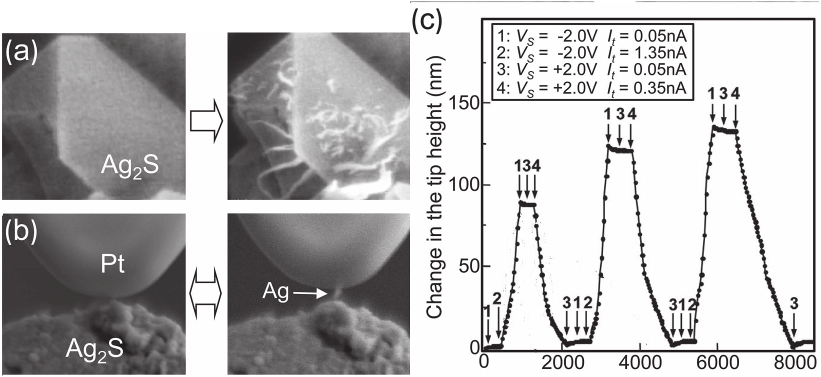
Gap-type atomic switch

- e^- injection into an Ag_2S crystal: reduction of cations, precipitation on the surface
- SEM: controlling the position and irradiation time of the e^- beam: Ag nanodots can be formed in a patterned structure
- STM mode [2] or crossbar structure



[2] K. Terabe et al., JAP, **91**, 12 (2002)

Gap-type atomic switch - STM mode



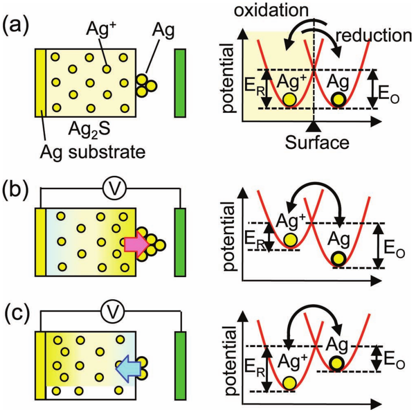
$$\frac{dI}{dt} = Aexp(-D \cdot It)$$

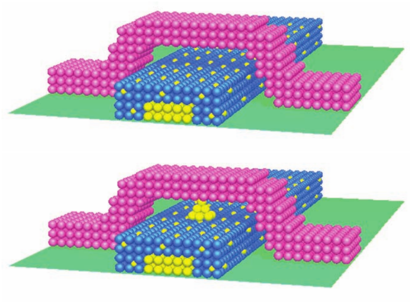
$\frac{dI}{dt}$ does not depend on bias

A, D : coefficients

It: tunnel current

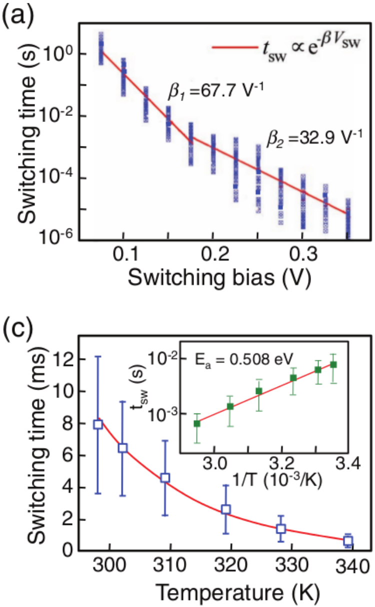
Gap-type atomic switch - crossbar structure



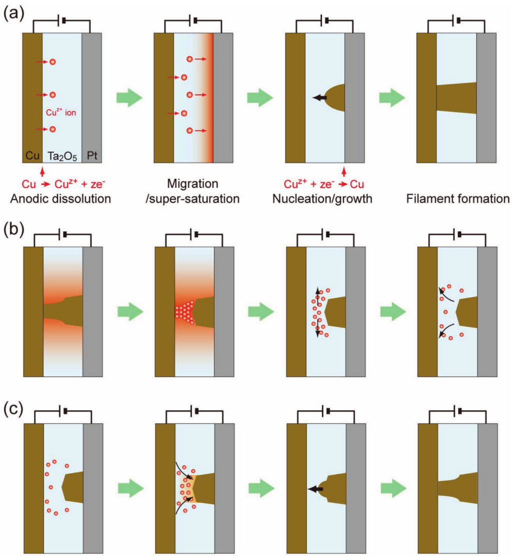


- 10^5 switches
- switching time: R decreases from 1 MΩ to 12.9 kΩ

Crossbar structure - switching time



Gapless-type atomic switch



- conductive path is made in an ionic conducting material
- forming process
- electric field-driven activated hopping
- min. switching time: 5 ns
- Ag_2S: on/off ratio: 10^5, switching speed: 1 ms

Shortest switching time

Cu bridge in an insulator [3]

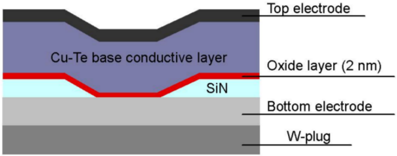
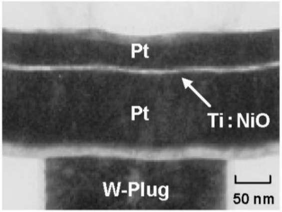


Table 1. Typical parameters and key features.

FEOL	180-nm CMOS
Active cell area	40 nmϕ
Set pulse width Set current Set voltage	5 ns 110 μA +3 V
Reset pulse width Reset current Reset voltage	1 ns 125 μA −1.7 V
Resistance read voltage	+0.1 V
Endurance	10^7 cycles

redox reactions: Ti-doped NiO [4]

- 5 ns switching time
- series transistor: current limiter during the set
- symmetric, unipolar
- long reset time, large reset current



[3] K. Aratani et al., IEEE Int. Electron Dev. Meeting, 2007, pp 783-786
[4] K. Tsunoda et al., IEEE Int. Electron Dev. Meeting, 2007, pp 767-770

Towards a quantitative description of solid electrolyte conductance switches[5]

Theory: Hebb and Wagner model

$$-eV = \varepsilon_F'' - \varepsilon_F' = \mu_e'' - \mu_e' \tag{1}$$

': Ag electrode, ": Pt electrode

$$\mathbf{j}_e = \frac{\sigma_e}{e}\nabla\mu_e \tag{2}$$

$$\mathbf{j}_{Ag^+} = -\frac{\sigma_{Ag^+}}{e}\nabla\mu_{Ag^+} \tag{3}$$

local thermodynamic equilibrium:

$$\mu_{Ag} = \mu_{Ag^+} + \mu_e \tag{4}$$

$$-eV = (\mu_{Ag}'' - \mu_{Ag}') - (\mu_{Ag^+}'' - \mu_{Ag^+}') \tag{5}$$

$t >> 0$:

$$\nabla\mu_{Ag^+} = 0, j_{Ag^+} = 0 \tag{6}$$

$$\nabla\mu_e = \nabla\mu_{Ag}, j_{total} = j_e \tag{7}$$

[5] Morales-Masis, Ruitenbeek et al., Nanoscale, **2**, 2275 (2010)

Towards a quantitative description of solid electrolyte conductance switches

$$e\mathbf{j}_{total}(\mathbf{r}) \cdot d\mathbf{r} = \sigma_e d\mu_{Ag} \tag{8}$$

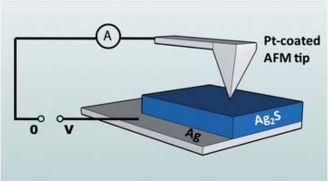
$$e\int_{r''}^{r'} \mathbf{j}_{total}(\mathbf{r}) \cdot d\mathbf{r} = -\frac{e}{K} I \tag{9}$$

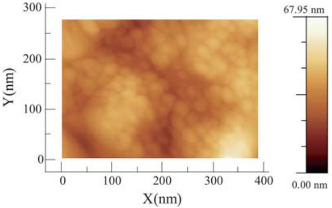
$\sigma_e = \sigma_0 e^{(eV/kT)}$

$$I(V) = K\sigma_0 \frac{k_B T}{e}\left(e^{(eV/K_B T)} - 1\right) \tag{10}$$

in AFM geometry: $K = 2\pi a$

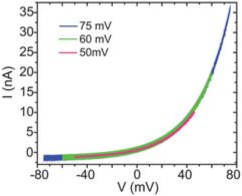
Towards a quantitative description of solid electrolyte conductance switches

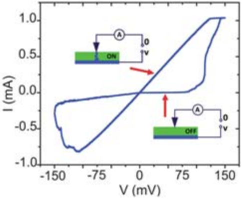


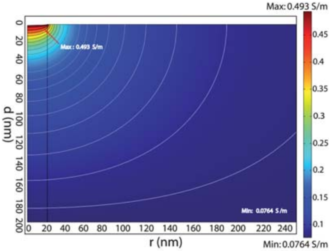


- deposition of Ag_2S: sputtering Ag in Ar/H_2S plasma on top of a Ag film
- Ag_2S layer thickness: approx. 200 nm, with 30 nm roughness, 5x5 mm^2
- Ag : 100 nm, 10x10 mm^2
- room temperature measurements

Towards a quantitative description of solid electrolyte conductance switches



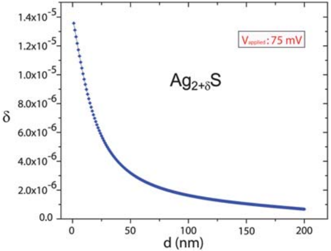




tip contact radius: a = K/(2π) = 12nm

Simulation:

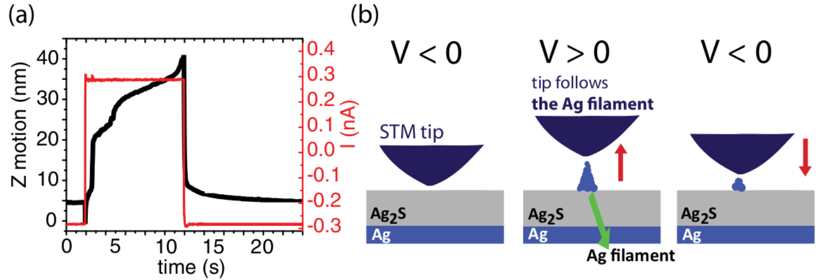
$$\delta = n - p = 2K_i^{1/2} sinh\left(\frac{e(V_0 - V(d))}{kT}\right)$$



- supersaturation
- nucleation within the silver sulfide

Bulk and surface nucleation processes in Ag2 S conductance switches[6]

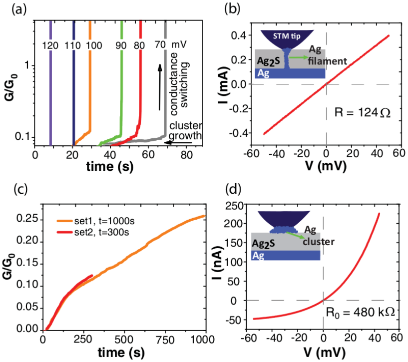
the tip is not in contact with the Ag_2S film ⇒ gap-type measurement



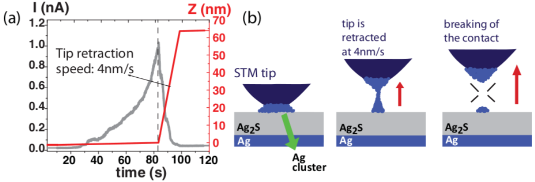
[5]Morales-Masis et al., Phys. Rev. B **84**, 115310 (2011)

Bulk and surface nucleation processes in Ag2 S conductance switches

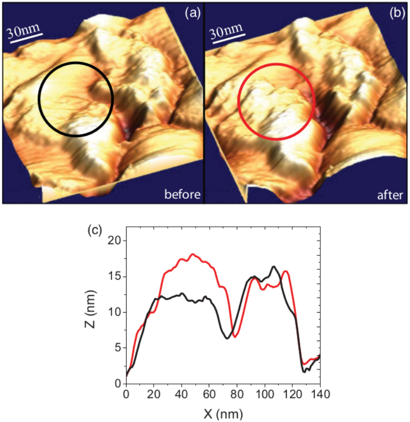
the feedback was too slow ⇒ gapless-type measurement
sample biased and current measured



two processes: nucleation and cluster formation

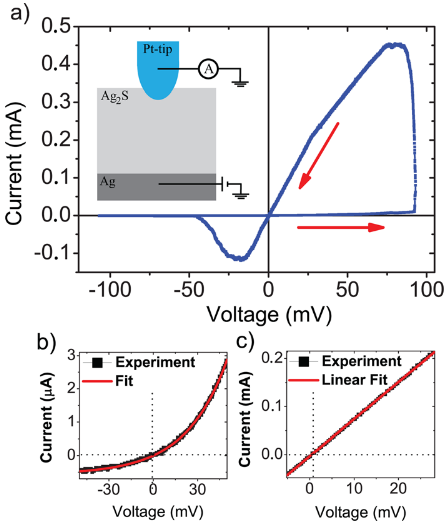


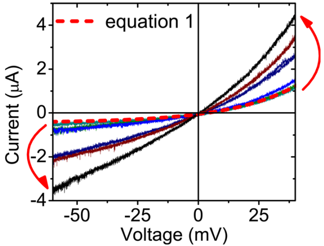
Bulk and surface nucleation processes in Ag2 S conductance switches



T=240K
100 s between the forming and the topography scan ⇒ cluster shrinks back to the Ag_2S

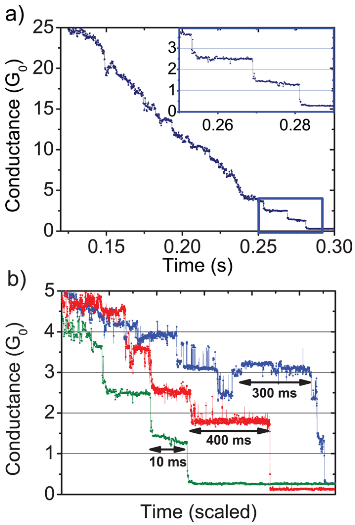
Quantized conductance steps in Ag_2S[7]

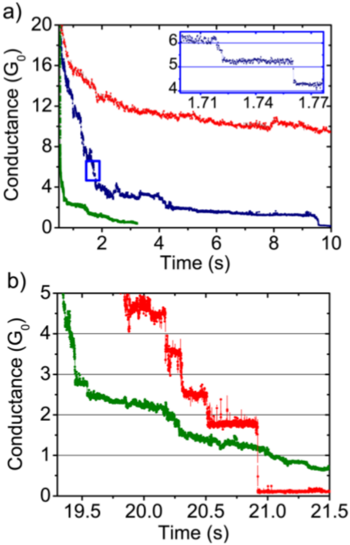




[7]Wanegaar, Ruienbeek et al., JAP, **111**, 014302 (2012)

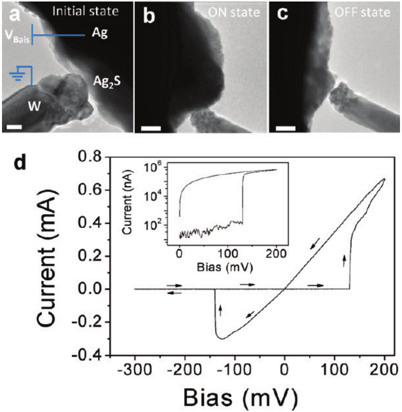
Quantized conductance steps in Ag_2S





Real-Time In Situ HRTEM-Resolved Resistance Switching of Ag2S Nanoscale Ionic Conductor [8]

W tip grounded, Ag electrode biased



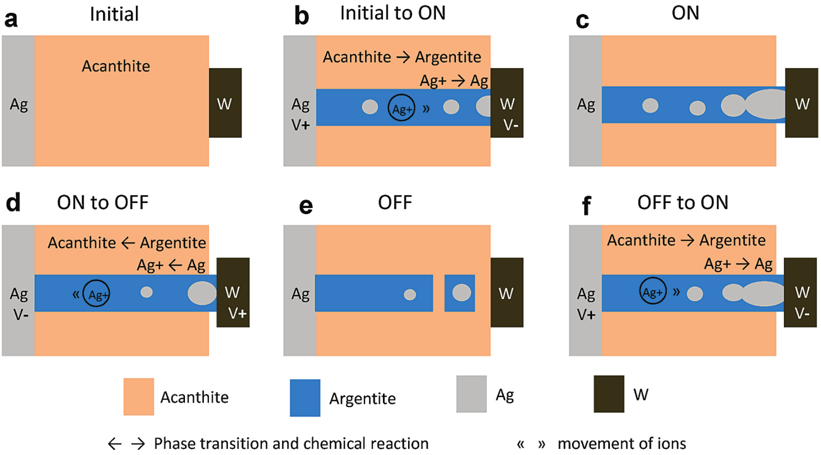
scale bar: a) 20 nm, b)-c) 50 nm

Sample preparation:

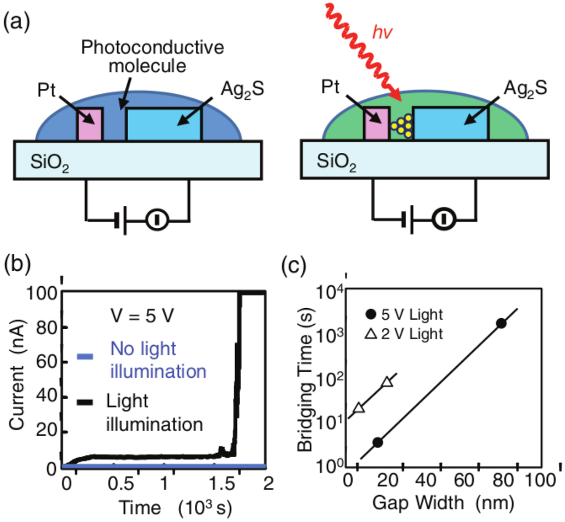
- d=0.5 mm Ag wire and S powder annealed in vacuum
- anneal: 200°C, 30 min
- sulfidized Ag wire annealed in argon (200°C, 30 min)
- Ag_2S scratched with a clean Ag wire, small pieces were transferred
- sharp W tip on a piezotube

[7] Xu et al., ACS Nano, **4**, 5 (2010)

Real-Time In Situ HRTEM-Resolved Resistance Switching of Ag2S Nanoscale Ionic Conductor

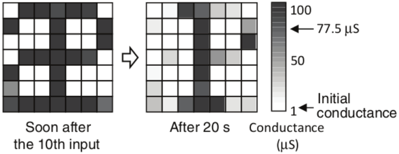


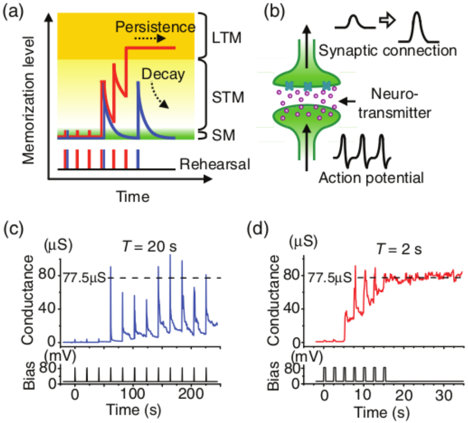
Applications - Photo sensing



Applications - Synaptic operations

- short-term plasticity (STP)
- long-term potentiation (LTP)





Bibliography

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4. K. Tsunoda et al., IEEE Int. Electron Dev. Meeting, pp 767-770 (2007)
5. Morales-Masis, Ruitenbeek et al., Nanoscale, **2**, 2275 (2010)
6. Wanegaar, Ruienbeek et al., JAP, **111**, 014302 (2012)
7. Morales-Masis et al., Phys. Rev. B **84**, 115310 (2011)
8. Xu et al., ACS Nano, **4**, 5 (2010)