Comprehensive Physical Model of Dynamic Resistive Switching in an Oxide Memristor

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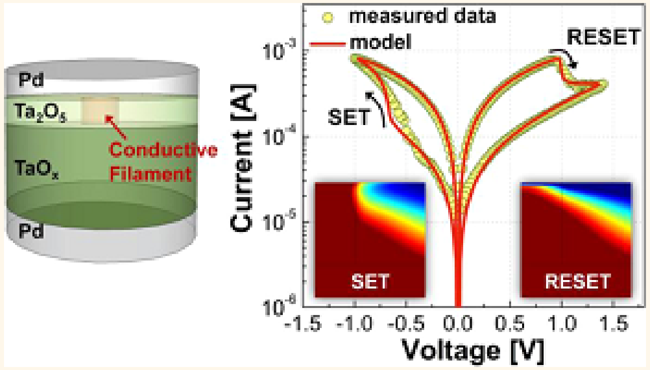
ABSTRACT Memristors have been proposed for a number of applications from nonvolatile memory to neuromorphic systems. Unlike conventional devices based solely on electron transport, memristors operate on the principle of resistive switching (RS) based on redistribution of ions. To date, a number of experimental and modeling studies have been reported to probe the RS mechanism; however, a complete physical picture that can quantitatively describe the dynamic RS behavior is still missing. Here, we present a quantitative and accurate dynamic switching model that not only fully accounts for the rich RS behaviors in memristors in a unified framework but also provides critical insight for continued device design, optimization, and applications. The proposed model reveals the roles of electric field, temperature, oxygen vacancy concentration gradient, and different material and device parameters on RS and allows accurate predictions of diverse set/reset, analog switching, and complementary RS behaviors using only material-dependent device parameters.



MŰEGYETEM 1782

András Magyarkuti
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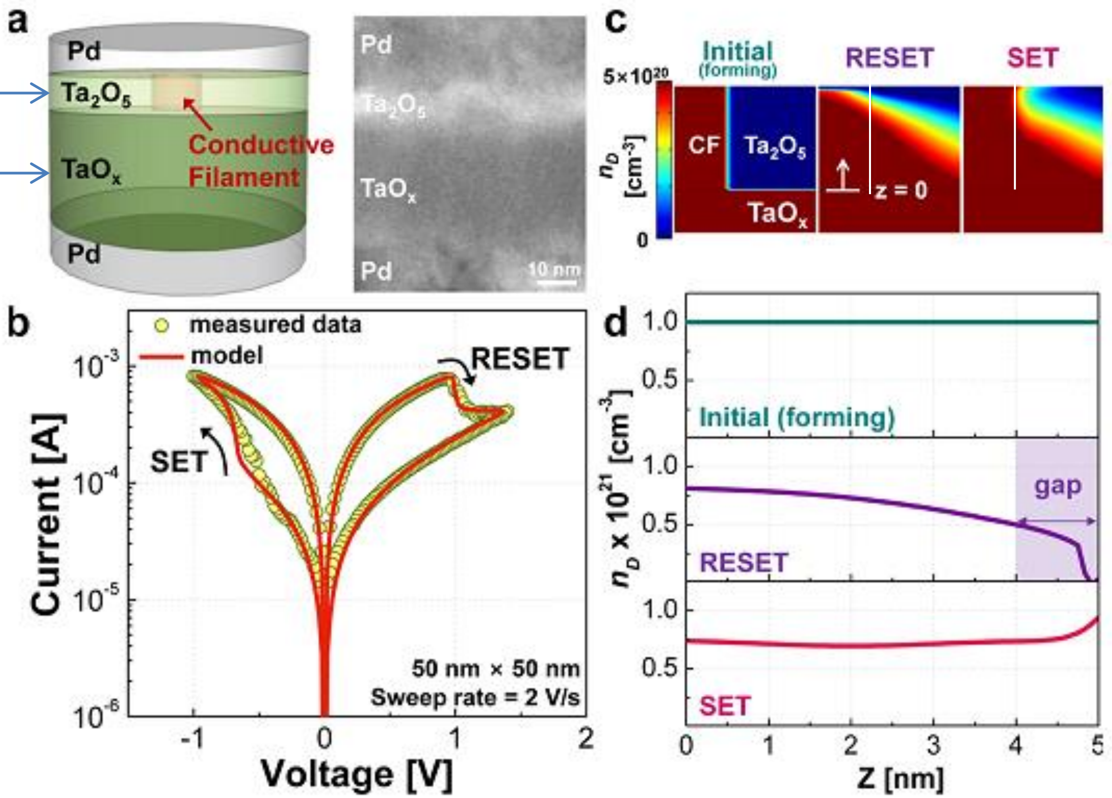
Tantalum-oxide based bilayer memristor

High resistivity
Lower resistivity



- Conductive Filament:

  High oxygen vacancy concentration → local electrical conduction becomes metallic

Model calculations

• Dependent variables		• Constants	
n_D	Concentration of V_o [cm^{-3}]	a	Hopping distance, 0.1 nm
T	Temperature [K]	f	Escape-attempt frequency, 10^{12} Hz
ψ	Potential [V]	E_a	Diffusion barrier, 0.85 eV

- **Oxygen vacancy transport**

Eq.(1) $$\frac{\partial n_D}{\partial t} = \nabla \cdot (D\nabla n_D - v n_D + DSn_D \nabla T)$$

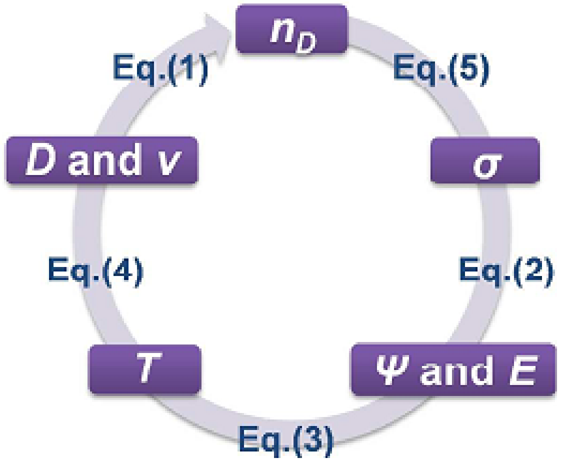
- **Current continuity**

Eq.(2) $$\nabla \cdot \sigma \nabla \psi = 0$$

- **Heat (Joule heating)**

Eq.(3) $$-\nabla \cdot k_{th} \nabla T = J \cdot E = \gamma \cdot \sigma \,|\nabla \psi|^2$$

(γ = 1 for DC, and γ = 2 for AC simulation)



- **Parameters** - Eqs.(4)

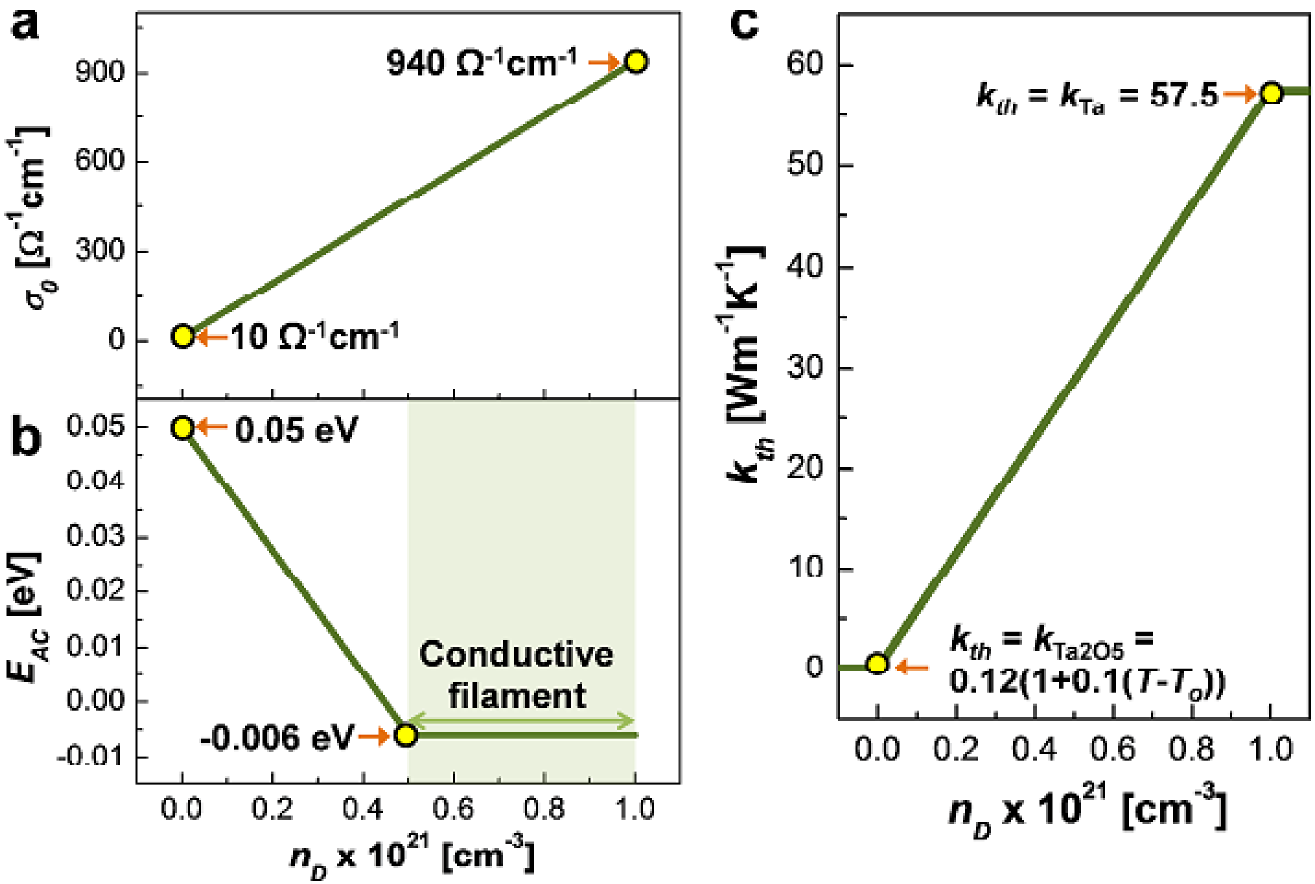
$D = 1/2 \cdot a^2 \cdot f \cdot \exp(-E_a / kT)$	Diffusivity of V_o [cm^2s^{-1}]
$v = a \cdot f \cdot \exp(-E_a / kT) \cdot \sinh(qaE / kT)$	Drift velocity of V_o [cm/s]
$S = -E_a / kT^2$	Soret diffusion coefficient [1/K]

Model calculations

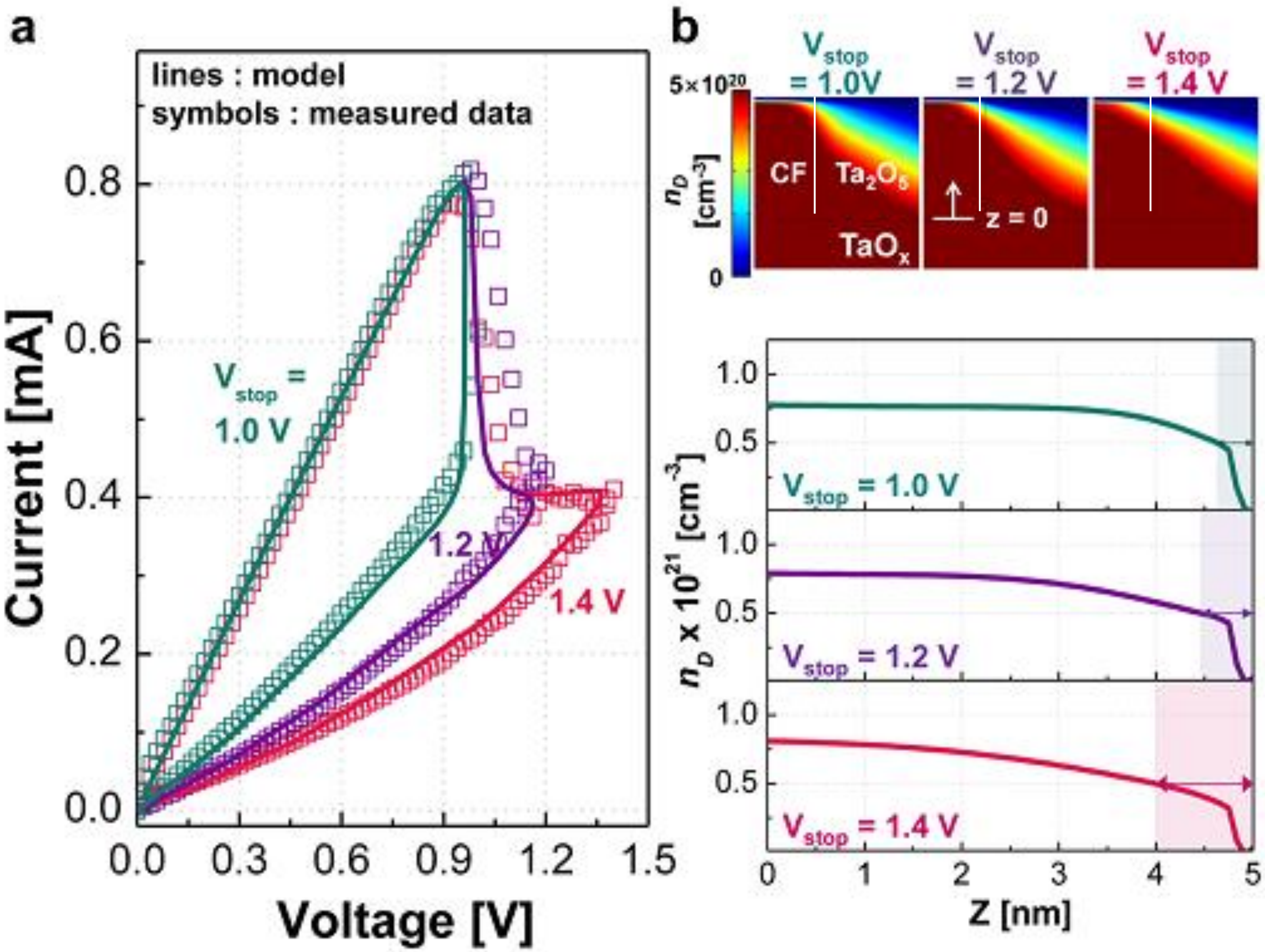
- **Parameters from measurements and assumptions** - Eq.(5)

$$\sigma = \sigma_0 \exp(-E_{AC}/kT)$$ Conductivity [$\Omega^{-1}cm^{-1}$]

$$k_{th} = k_{th0}(1+\lambda(T-T_0))$$ Thermal conductivity [$Wm^{-1}K^{-1}$], T_o = 300 K, λ = 0.1



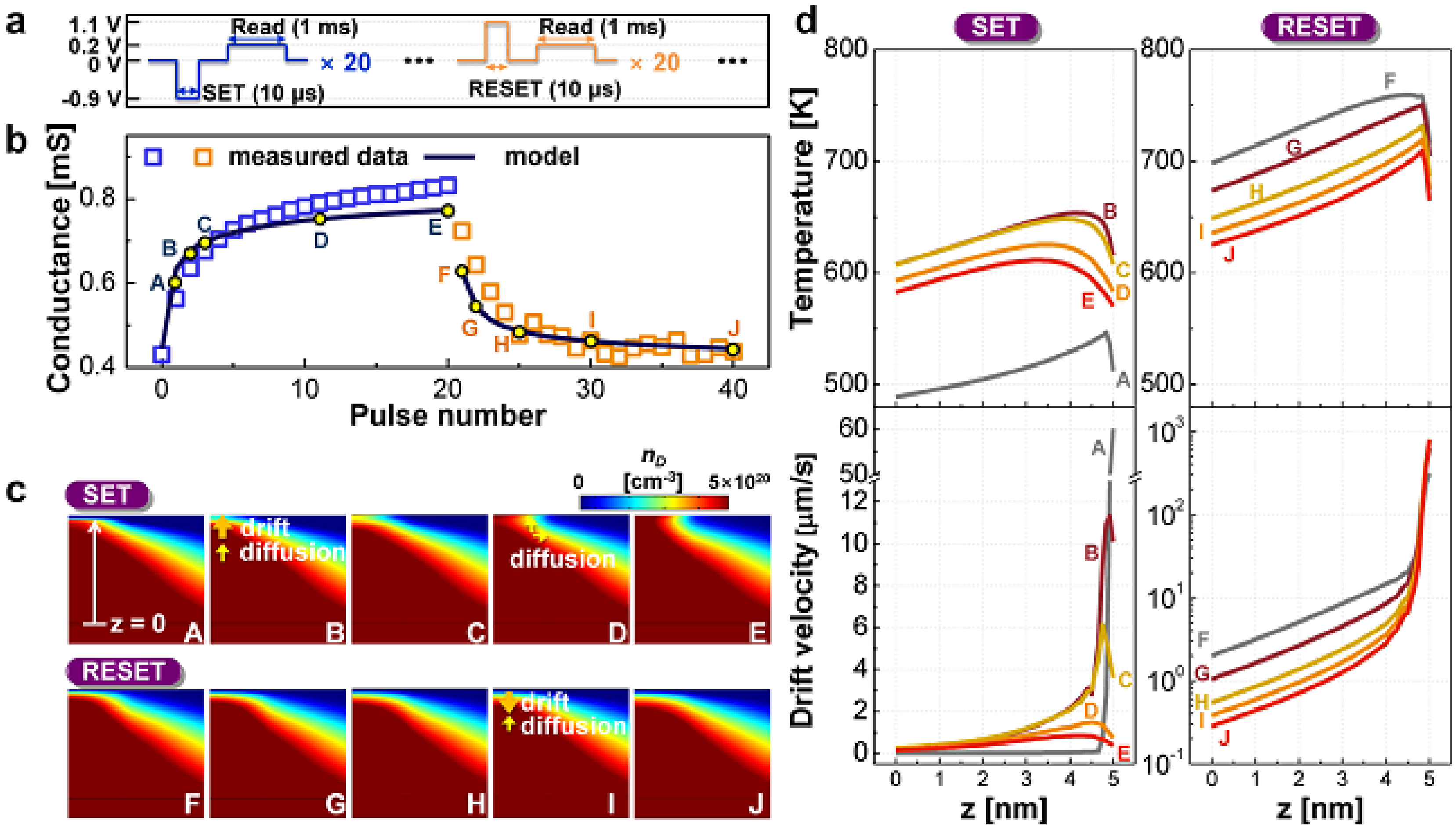
V_{stop} dependence



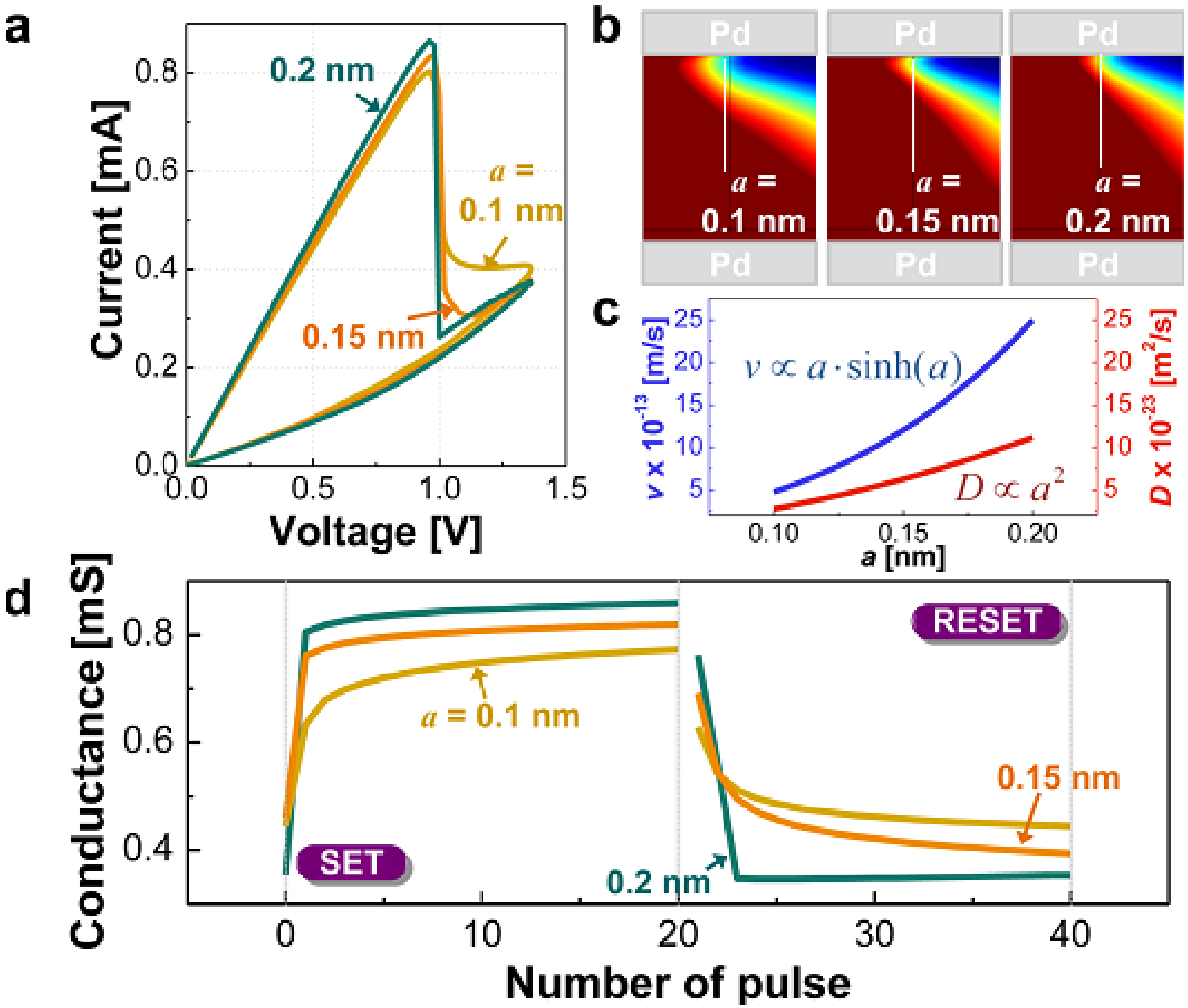
$V_{stop} \leftrightarrow$ Gap length

Analog switching behavior

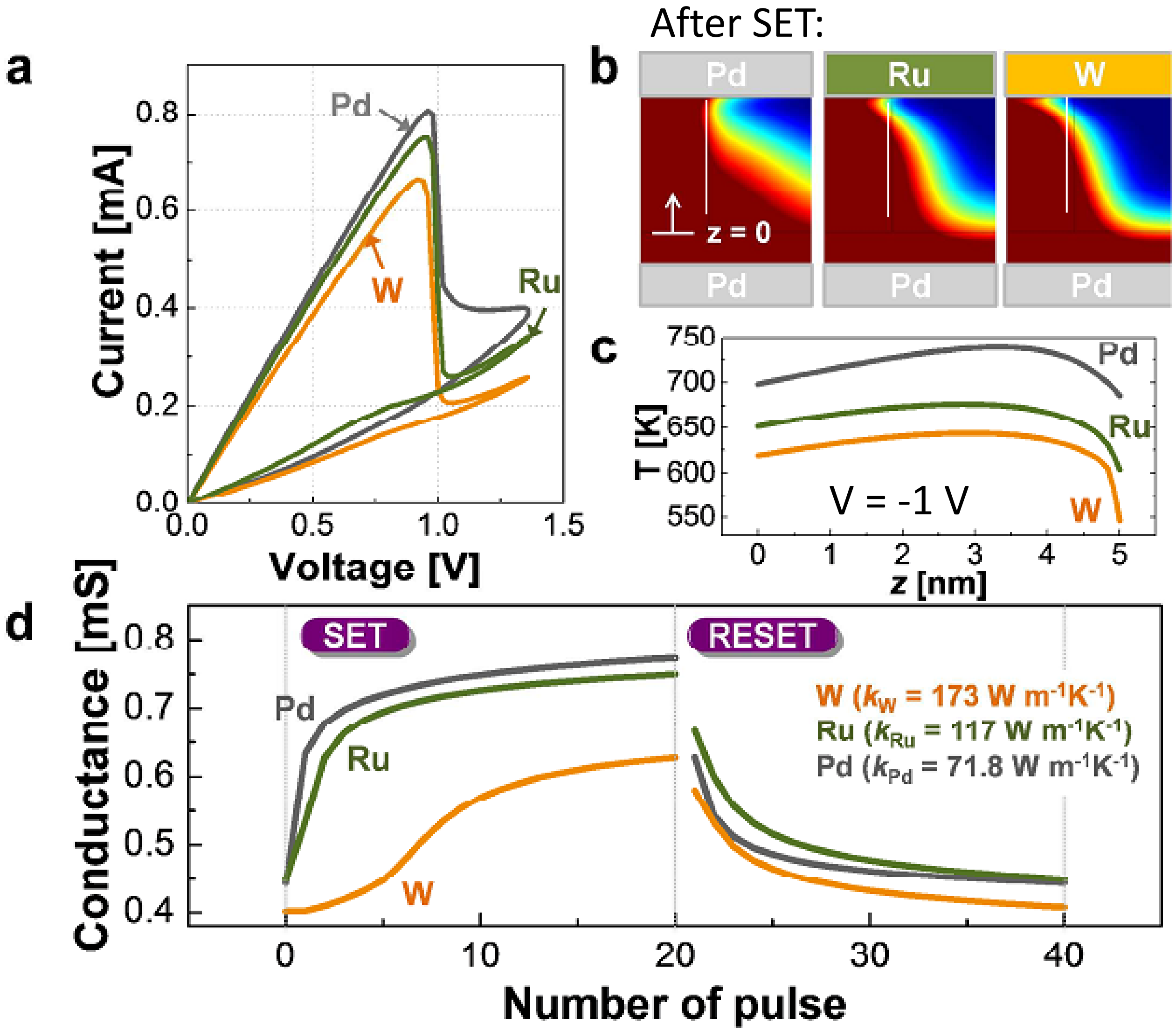
At the center of the CF



Hopping distance dependence



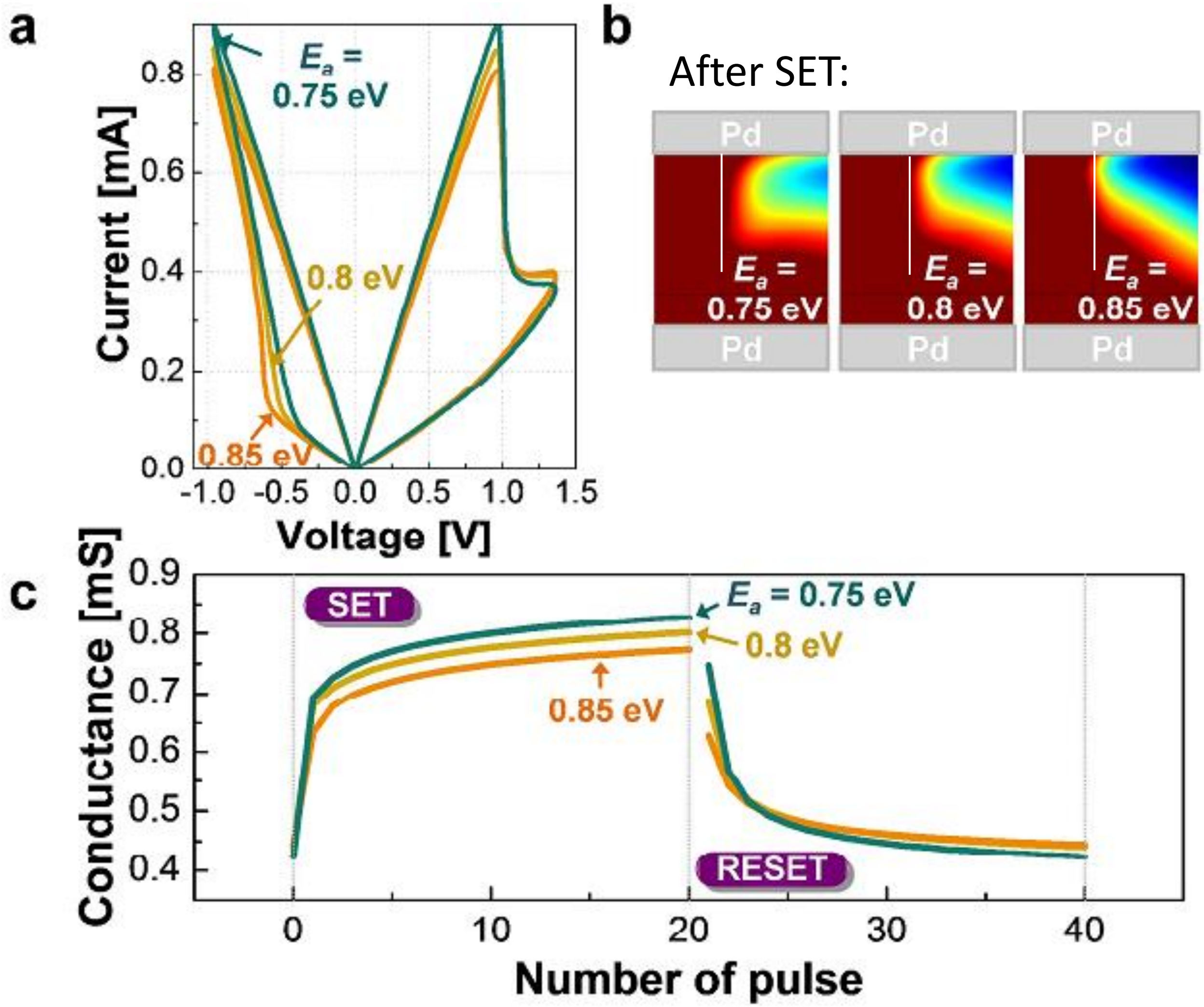
Top electrode dependence



Activation Energy dependence

Ea ↗

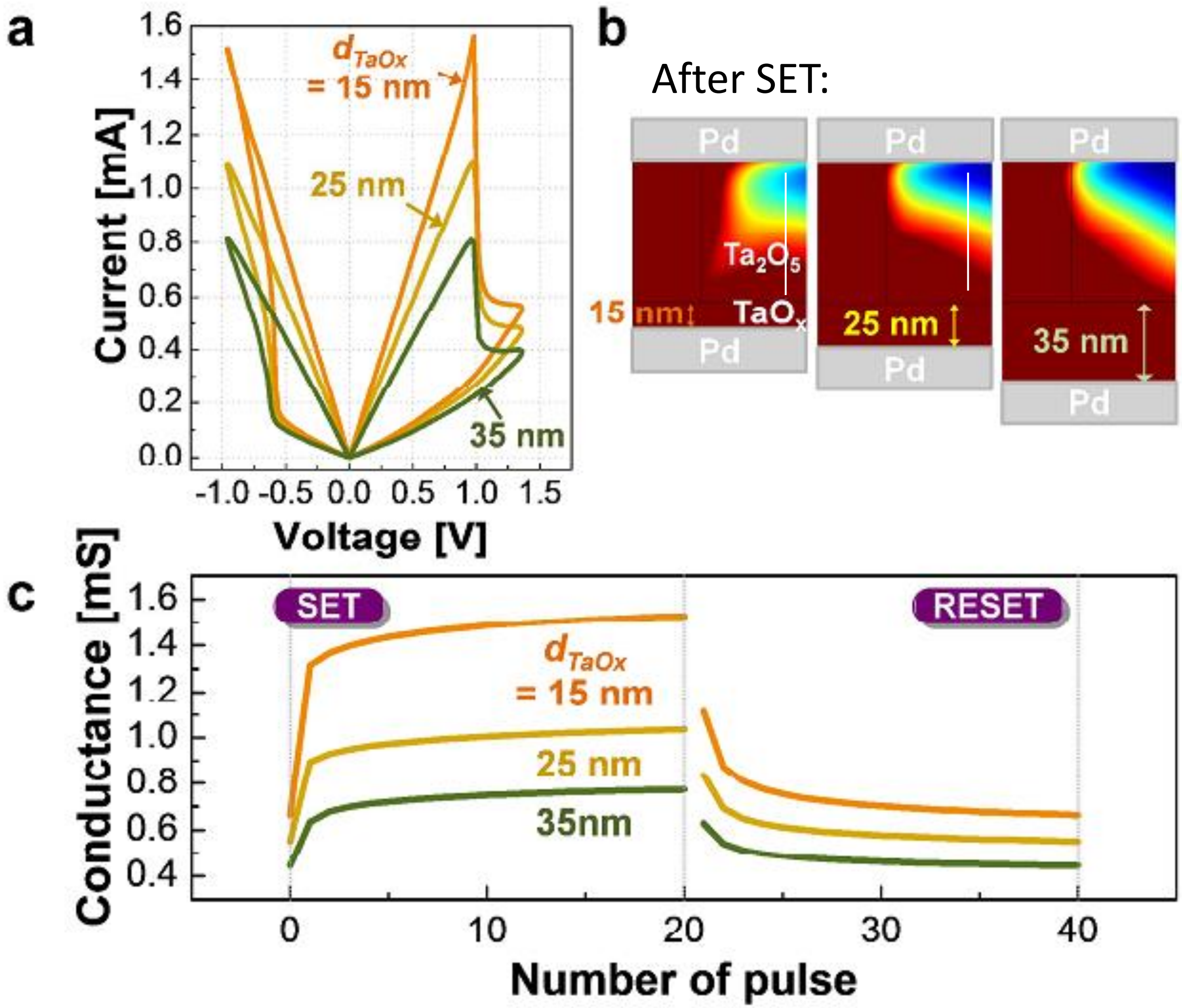
Rratio ↘



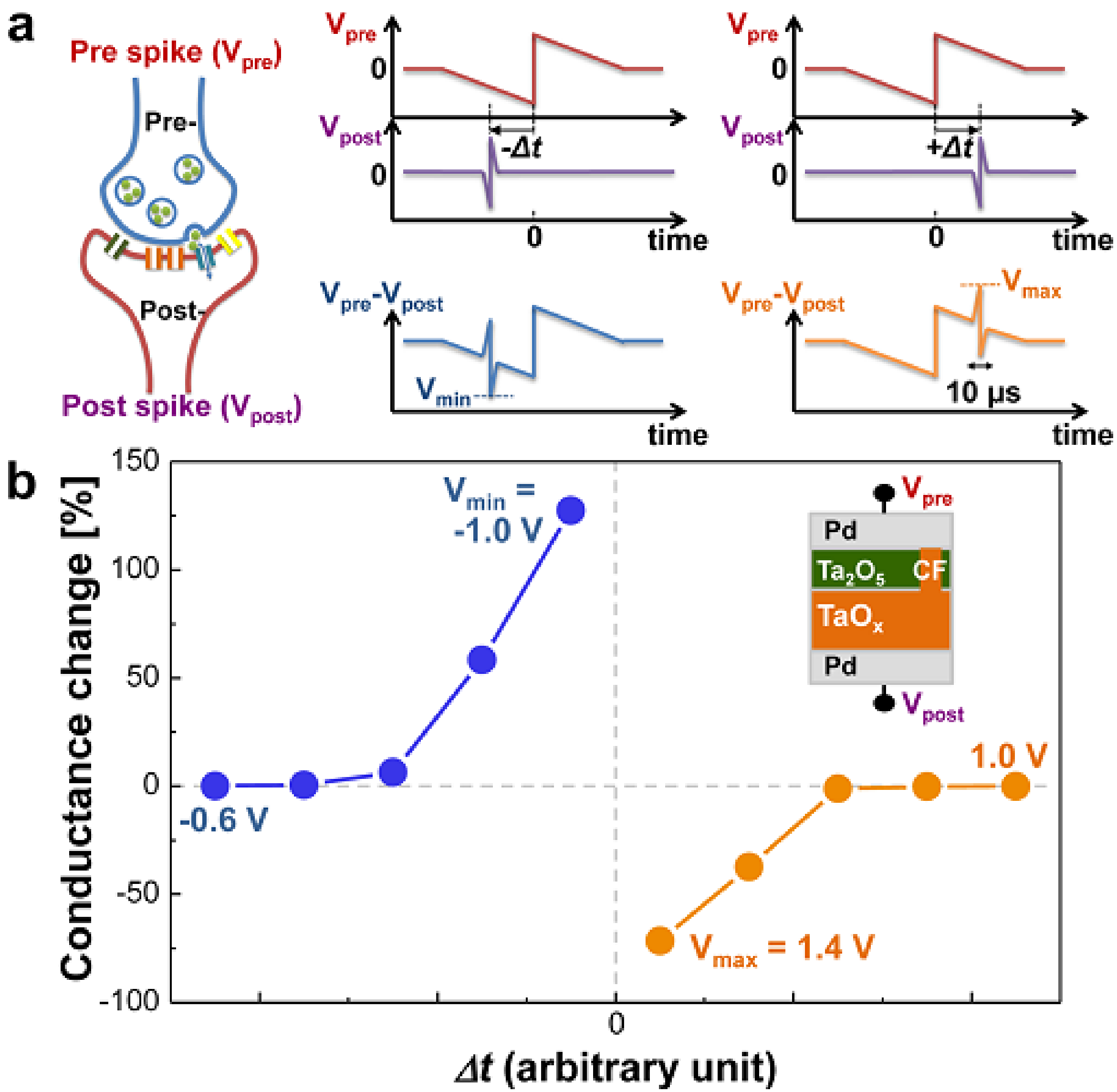
Layer thickness dependence

Rserial ↗

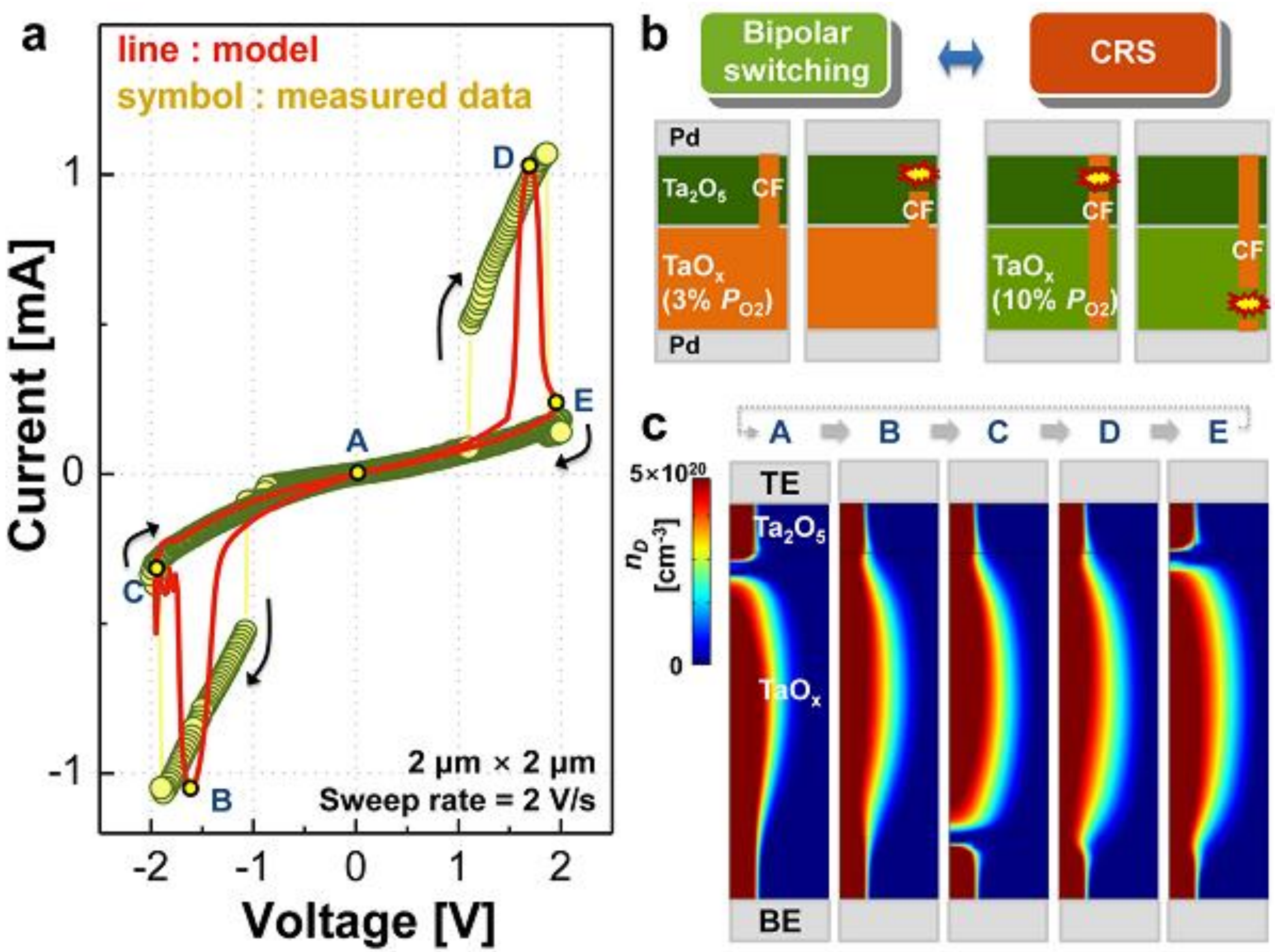
Rratio ↘



Spike Timing Dependent Plasticity



Complementary Resistive Switching



Thank you for your attention!