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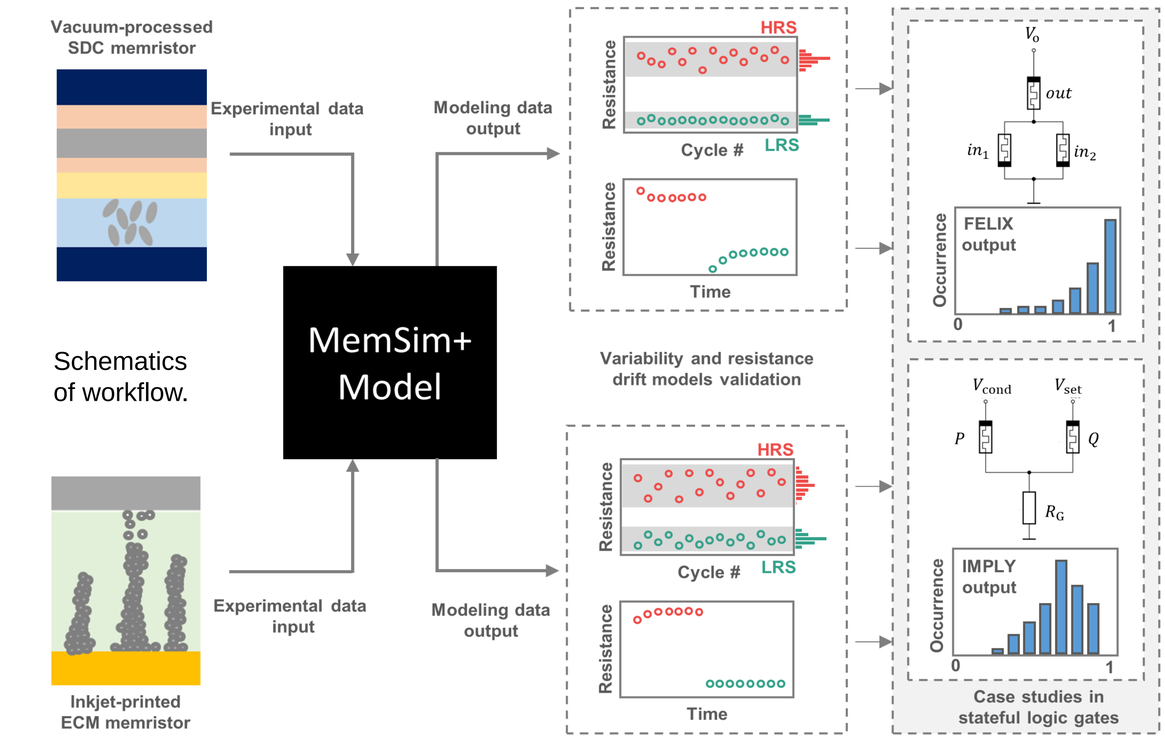
MemSim+: Realistic Behavioral Model for ReRAMs Capturing Non-Idealities

1) MemSim+:Concept description [1]



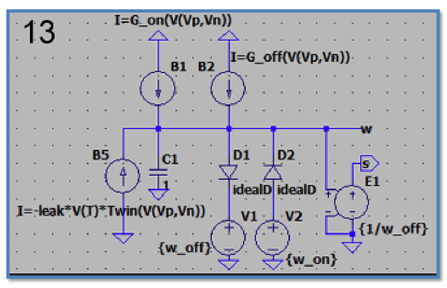
MemSim+: It captures cycle-to-cycle (C2C) and device-to-device (D2D) variations in key parameters, such as high and low resistance states, threshold voltages, resistance drift, and switching dynamics.

2) MemSim+ model descriptions

$$v(t) = \left[R_{\text{on}}(1 - \frac{D(t)}{w_{\max}}) + \frac{R_{\text{off}} - R_{\text{on}}}{w_{\max} - w_{\min}}(w_{\max} - w(t))(1 - \frac{D(t)}{w_{\max}})\right] \cdot i(t).$$

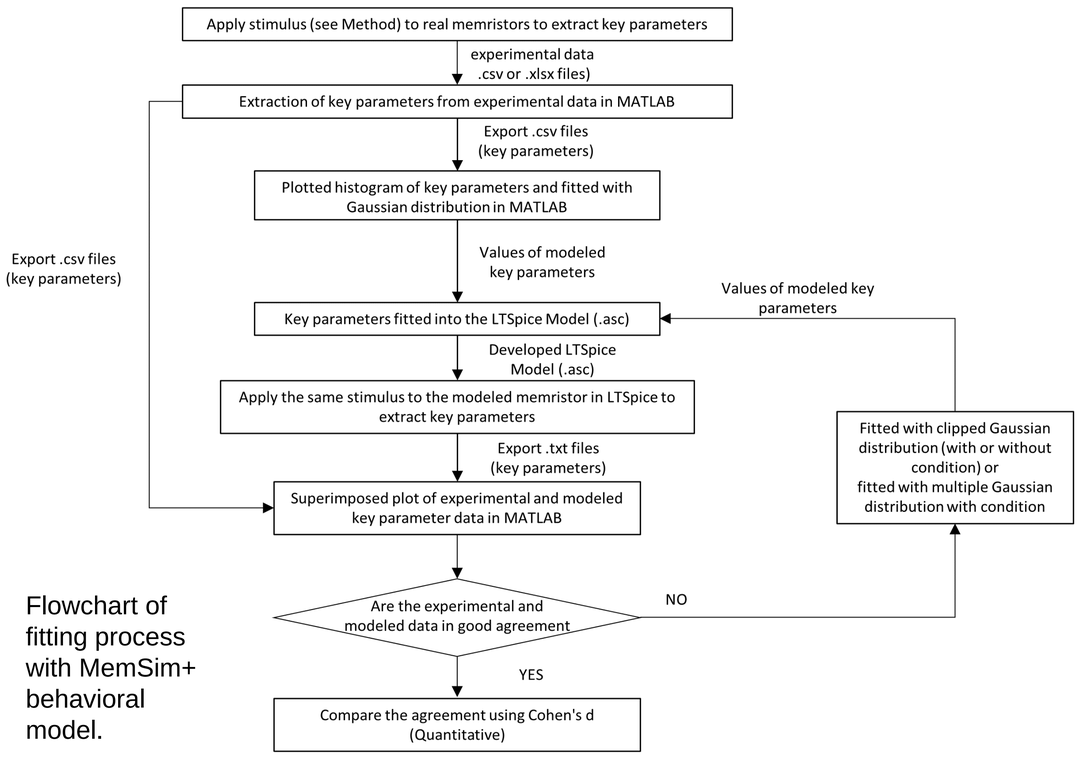
$$\frac{\mathrm{d}w(t)}{\mathrm{d}t} = \begin{cases} k_{\text{off}} \cdot \left(\frac{v(t)}{v_{\text{off}}} - 1\right)^{\alpha_{\text{off}}} & , 0 < v_{\text{off}} < v(t) \\ \Theta(t) & , v_{\text{on}} < v(t) < v_{\text{off}} \\ k_{\text{on}} \cdot \left(\frac{v(t)}{v_{\text{on}}} - 1\right)^{\alpha_{\text{on}}} & , v(t) < v_{\text{on}} < 0, \end{cases}$$

$$\frac{\mathrm{d}\Theta(t)}{dt} = -\frac{\Theta(t)}{\tau} + \begin{cases} \theta_{\text{off}} \cdot k_{\text{off}} \cdot \left(\frac{v(t)}{v_{\text{off}}} - 1\right)^{\alpha_{\text{off}}} & , 0 < v_{\text{off}} < v(t) \\ 0 & , v_{\text{on}} < v(t) < v_{\text{off}} \\ \theta_{\text{on}} \cdot k_{\text{on}} \cdot \left(\frac{v(t)}{v_{\text{on}}} - 1\right)^{\alpha_{\text{on}}} & , v(t) < v_{\text{on}} < 0, \end{cases}$$



LTspice represntation

3) Fitting: key parameters (R_{on}, R_{off}, v_{on}, v_{off}, etc.)



Distribution functions to fit R_{on}, and R_{off} of the SDC technology

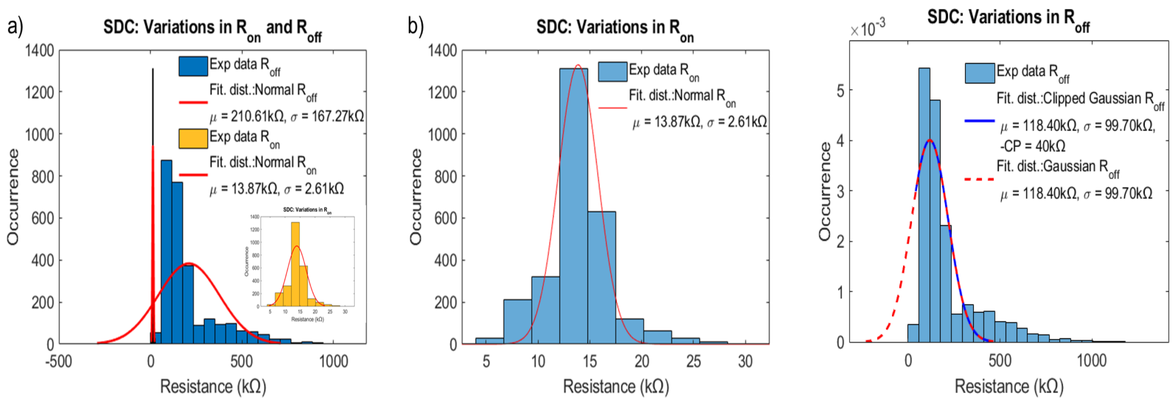
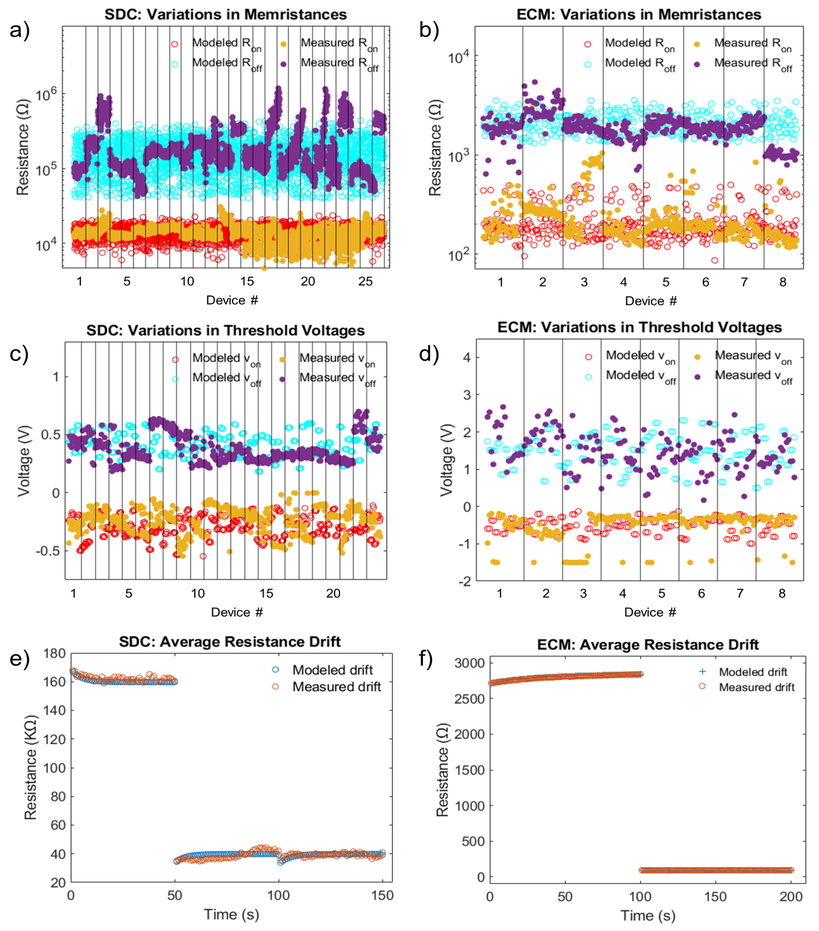


Table 1. Values of MemSim+ model parameters of two memristor technologies

Technology	SDC Technology				ECM Technology			
Parameters	μ	σ	CP or Range	Type	μ	σ	CP or Range	Type
R_{off}	118.40 kΩ	99.70 kΩ	> 40 kΩ	$cG^{\text{SDC}}_{R_{\text{off}}}$	1933.15 Ω	648.62 Ω	>1300 Ω	$cG^{\text{ECM}}_{R_{\text{off}}}$
R_{on1}	13.87 kΩ	2.61 kΩ		$G^{\text{SDC}}_{R_{\text{on}}}$	248.25 Ω	167.92 Ω	[116.32, 230.00] Ω	$G^{\text{ECM}}_{R_{\text{on1}}}$
R_{on2}					170.57 Ω	26.28 Ω		$G^{\text{ECM}}_{R_{\text{on2}}}$
R_{on3}					413.56 Ω	216.15 Ω	[100, 500] Ω	$G^{\text{ECM}}_{R_{\text{on3}}}$

4) Data comparison: experiments and the model

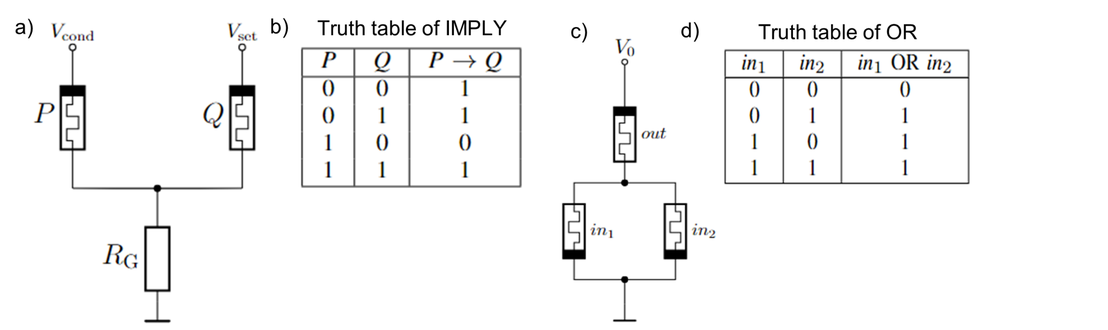


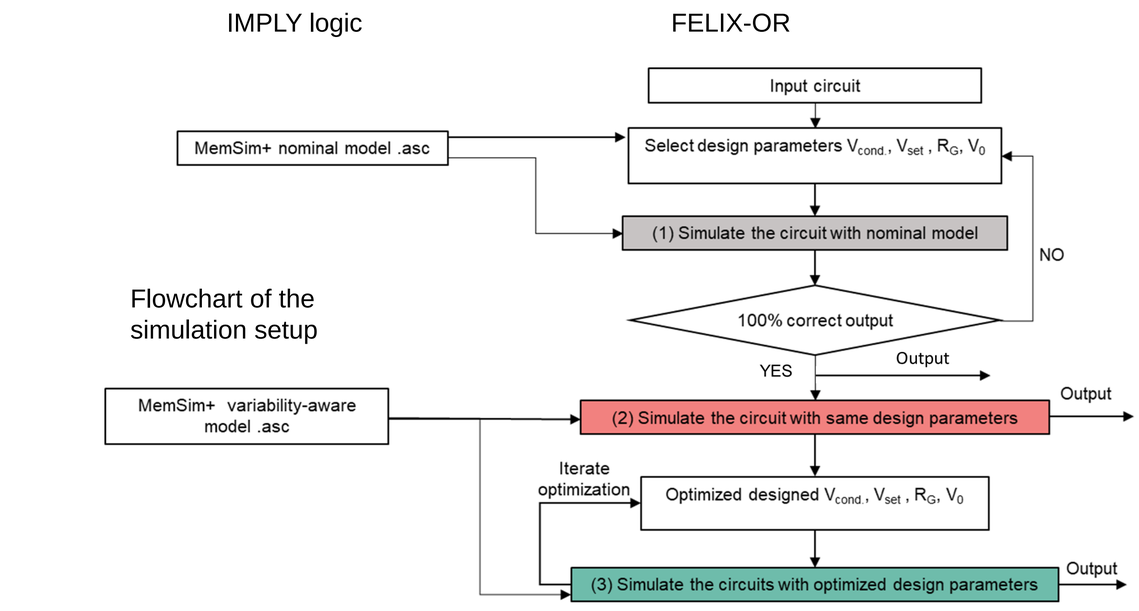
Validation:
Qualitative: visually by the left Figure
Quantitative: By Cohen‘s d

Cohen‘s d — Dissimilarity
d<0.5 small
d>0.5 mdium
d>0.8 high

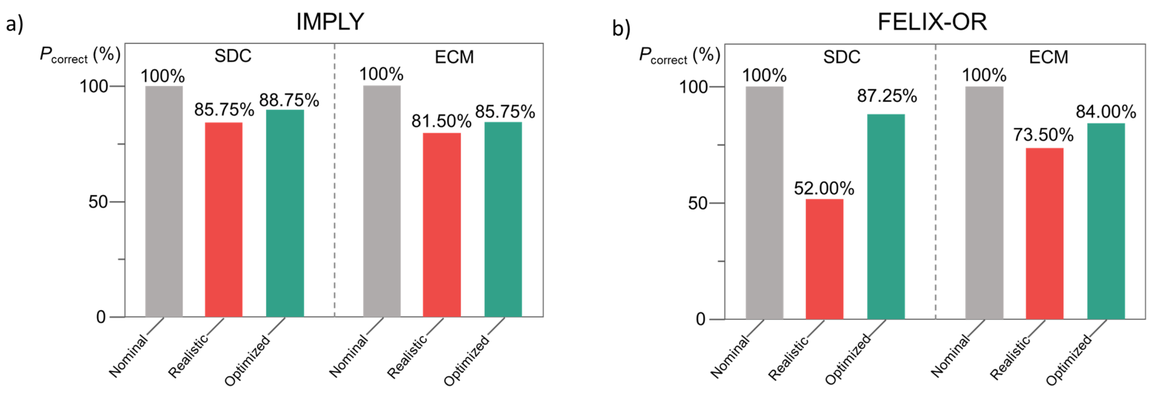
	SDC	ECM
R_{on}	0.0059	0.2469
R_{on}	0.4204	0.3157
v_{on}	0.4975	0.2108
v_{off}	0.3805	0

5) Case study: circuit-technology co-design





Overall correctness of simulated logical operations



6) Conclusions

- Bridging ideal and real memristor
- MemSim+ capture C2C and D2D variations and resistance drift in memristor
- Accurate modeling using clipped Gaussian and multiple Gaussian approach
- Variation-aware circuit-technology co-design significantly enhance the correctness probability

upto ↑ 35.25% for SDC FELIX-OR

References

[1]. **Gulafshan Gulafshan**, Hongrong Hu, David Raber-Radakovits, Luke Vassallo, Gabriel Cadilha Marques, JasminAghassi-Hagmann, and Nima Taherinejad. Realistic behavioral model for rerams capturing non-idealities. **Communications Materials**, 6(1):1–13, 2025.