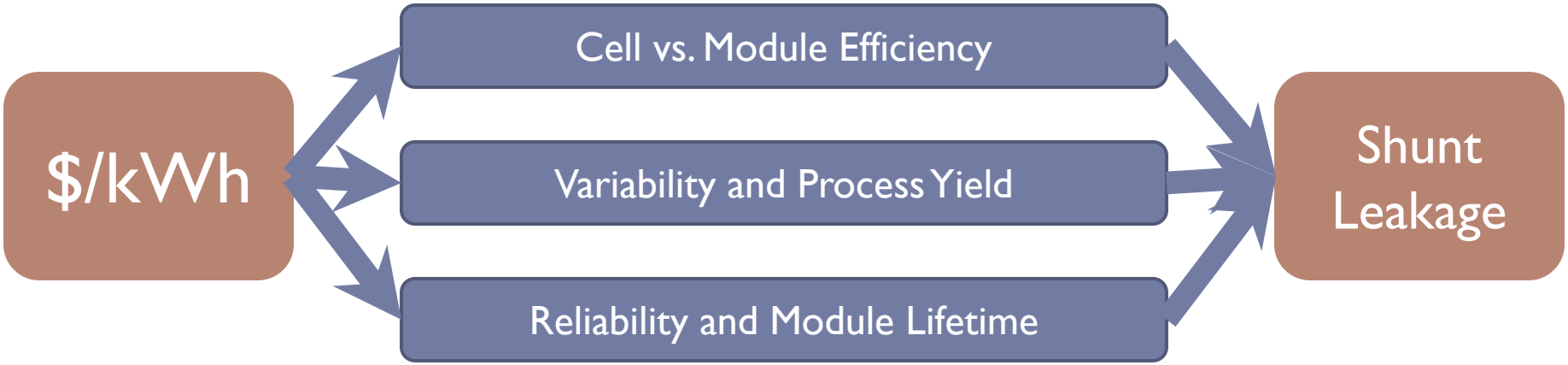
# A Physical Model for Non-Ohmic Shunt Conduction and Metastability in Amorphous Silicon Solar Cells

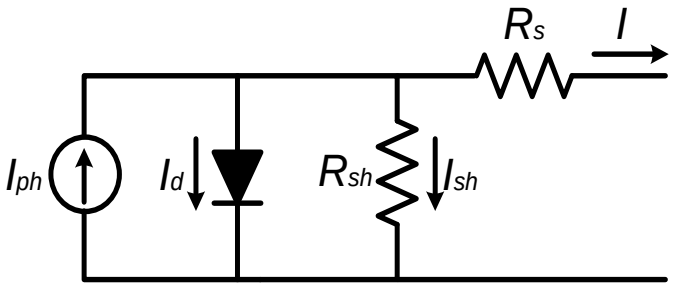
S Dongaonkar[1], Karthik Y[2], S Mahapatra[2], and M A Alam[1]

[1]Electrical & Computer Engineering, Purdue University

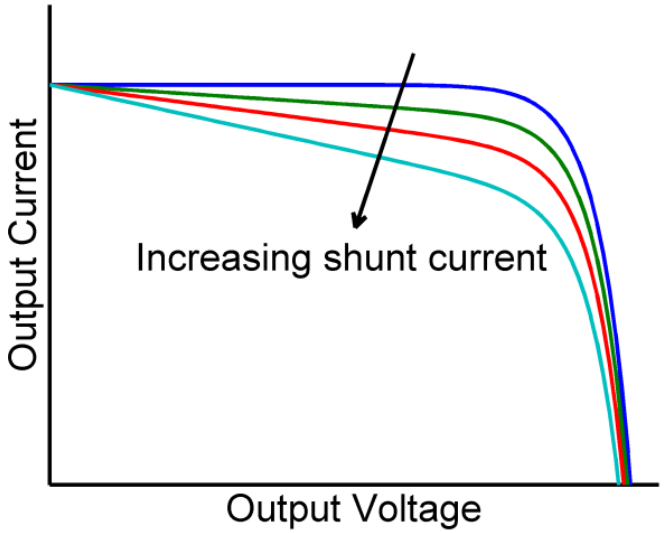
[2]Electrical Engineering, IIT Bombay, India

# Introduction



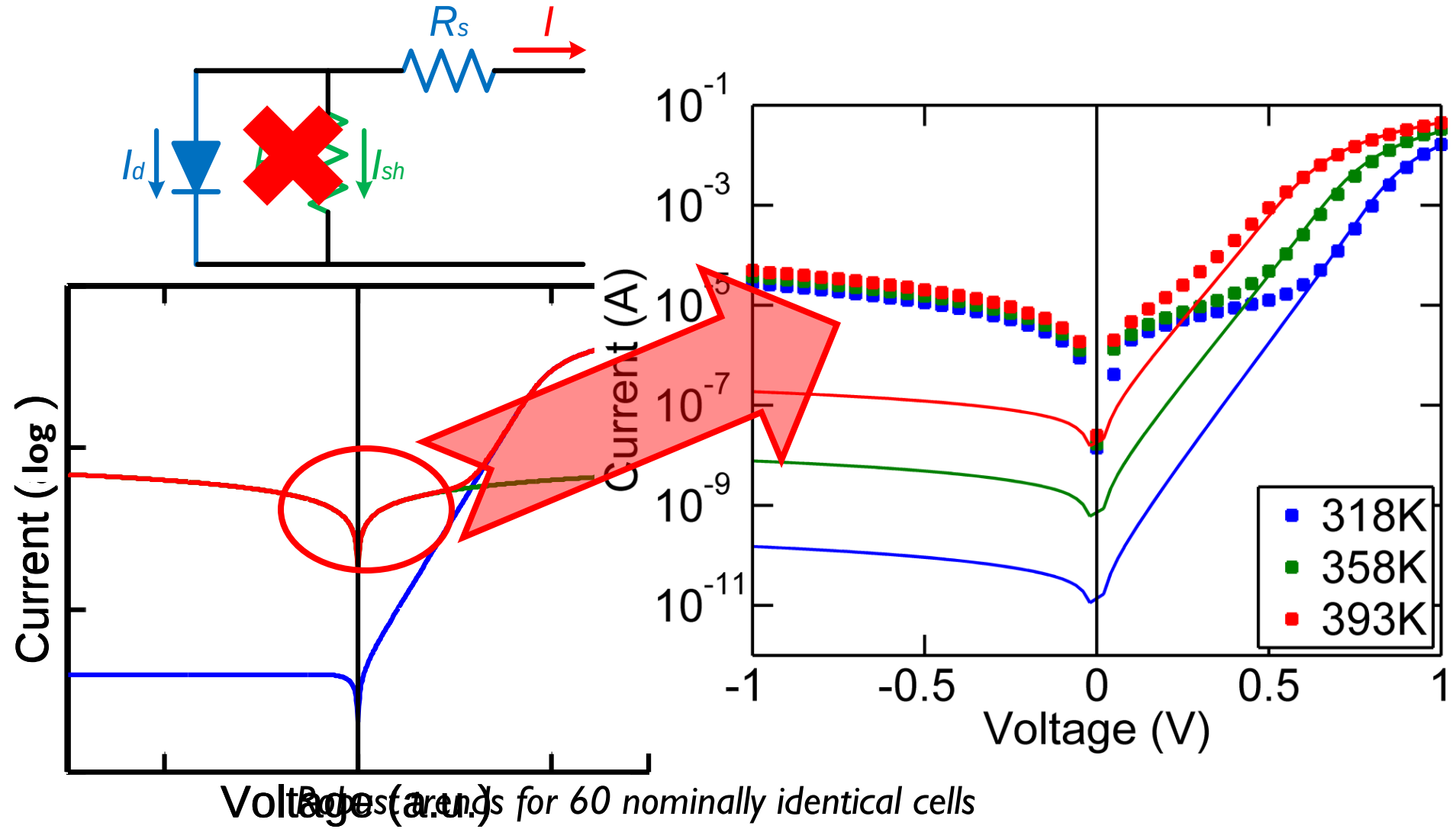




$$I_{sh} = V_A / R_{sh}$$




*Shunt losses are significant but the understanding of $I_{sh}$ remains empirical*

# A closer look at dark IV




*Backgrounds for 60 nominally identical cells*

# Space-Charge-Limited Shunt

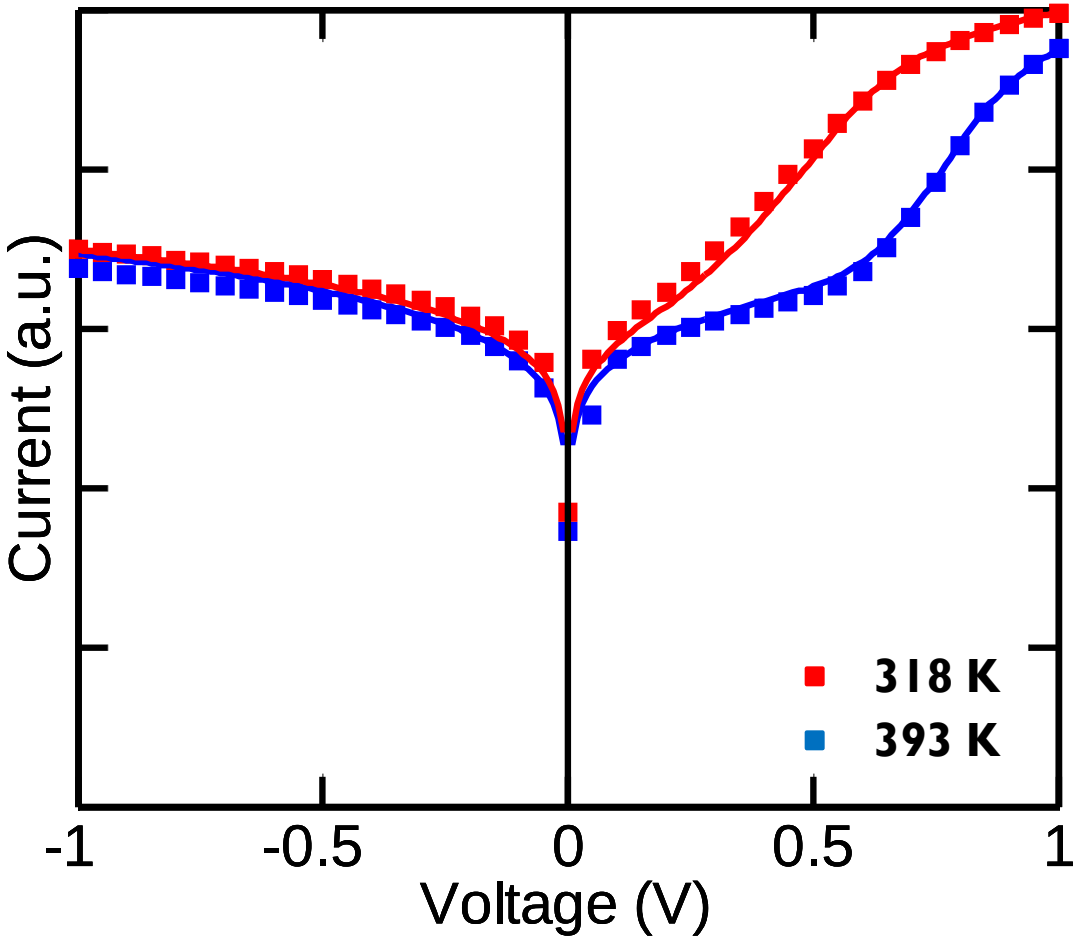
***Space Charge Limited Current***

$$I_{SCL} = A\varepsilon\mu_c(\gamma)\frac{V^{\gamma+1}}{L^{2\gamma+1}}\#$$

$$I_d = I_0\left[\exp\left(qV/nk_BT\right)-1\right]$$

$$I_{sh} = A\varepsilon\mu_c(\gamma)\frac{V^{\gamma+1}}{L_{sh}^{2\gamma+1}}$$

$$I_{dark} = I_d + I_{sh}^{*}$$

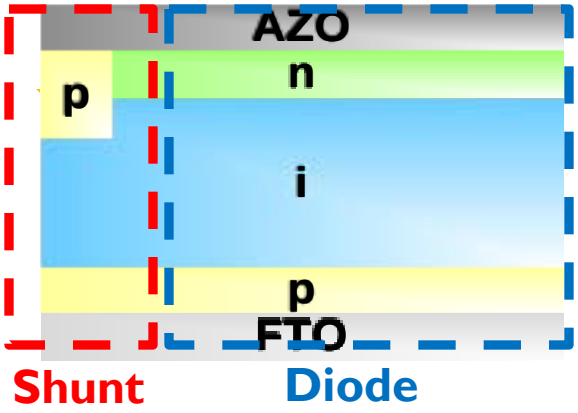





#A Rose, Phys. Rev. 1955

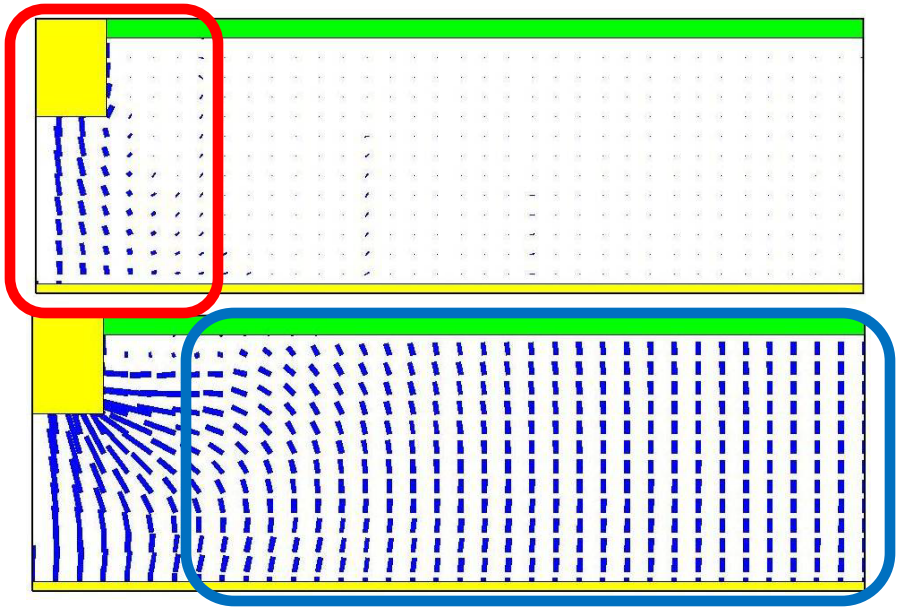
*S. Dongaonkar et al., EDL 2010

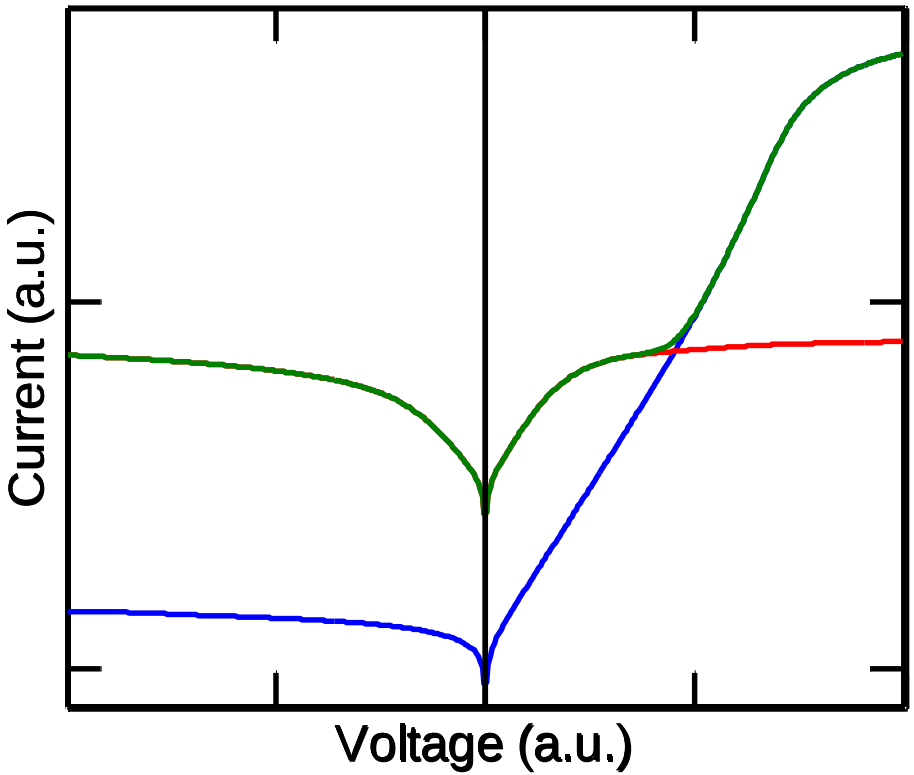
# Physical model for SCL shunt




Local metal (Al) incorporation from top contact

Al diffusion at moderate temperature reported*








*M S Haque et al., Sol. En. Mat. & Sol. Cel. 1996

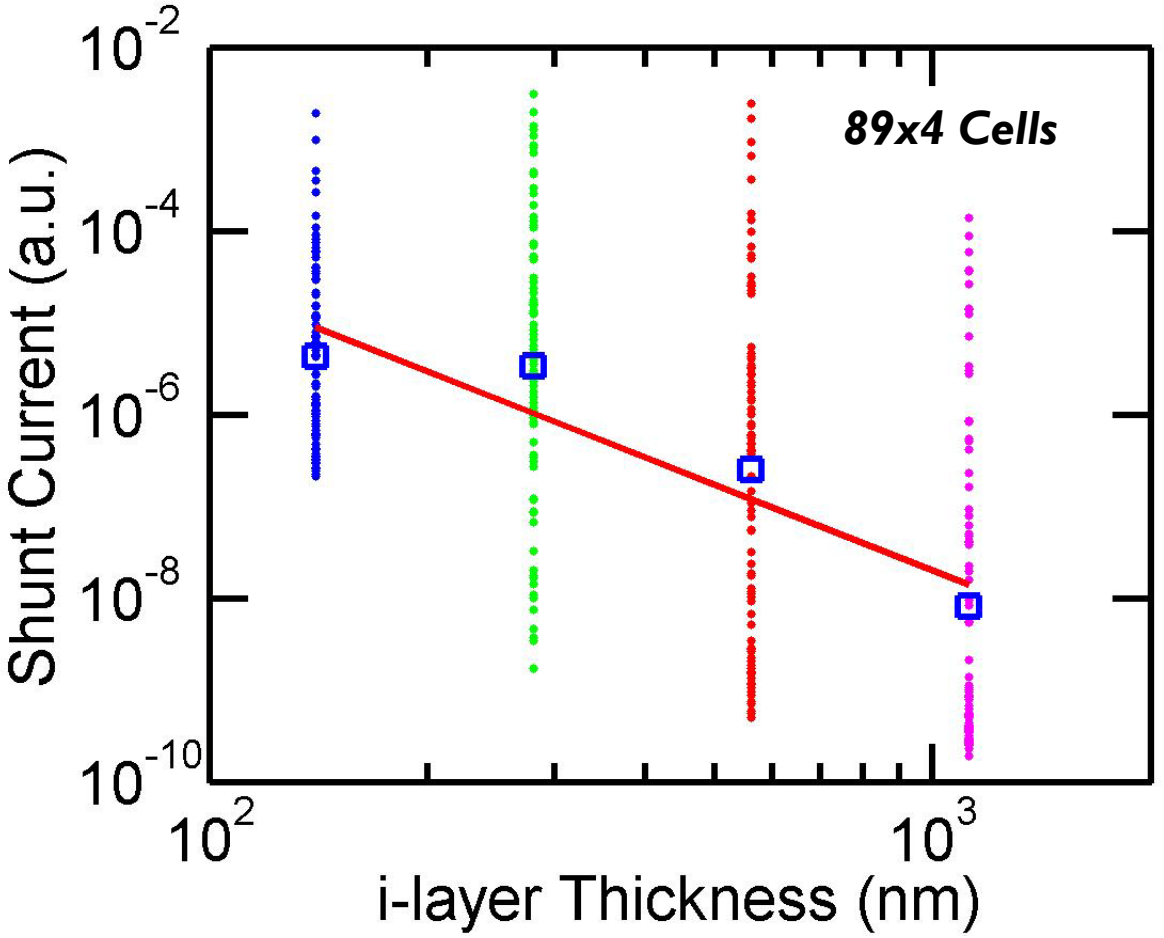
# Predictions – Thickness Dependence

$$I_{SCL} = A\varepsilon\mu_c(\gamma)\frac{V^{\gamma+1}}{L^{2\gamma+1}}$$

$$\langle I_{sh} \rangle_{GM} \propto L^{-3.1}$$

Spread in $I_{sh}$ is due to spread in area $A$

Can be checked using imaging methods
e.g. thermography#






#V Sittinger et al., TSF 2006

# Predictions – Hole transport

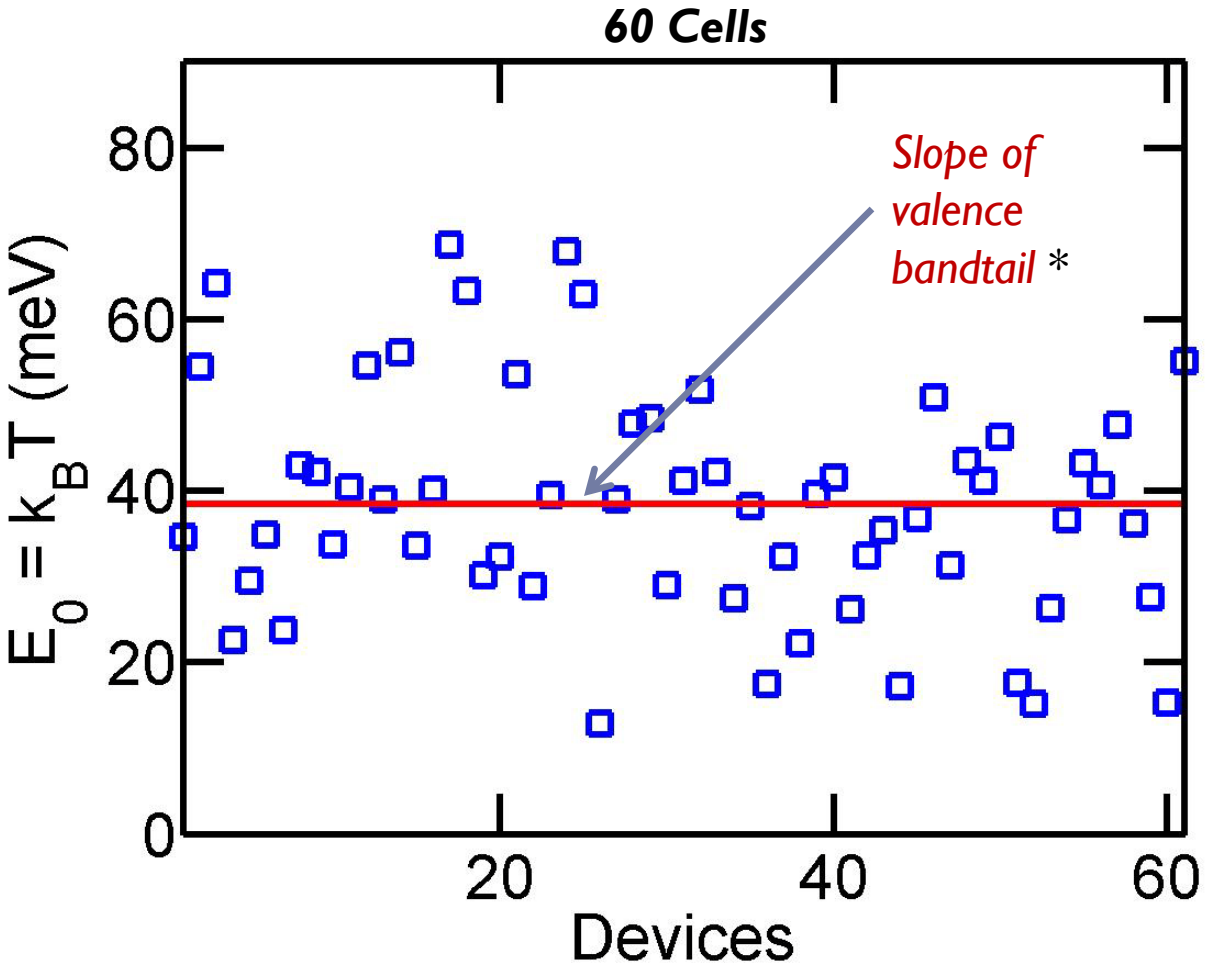
***Hole injection***

$$I_{SCL} = A\varepsilon\mu_c(\gamma)\frac{V^{\gamma+1}}{L^{2\gamma+1}}$$

Exponentially distributed shallow traps

$$\gamma = E_0 / k_B T \quad \dagger$$

$$E_0 = \gamma k_B T = (\beta - 1) k_B T$$

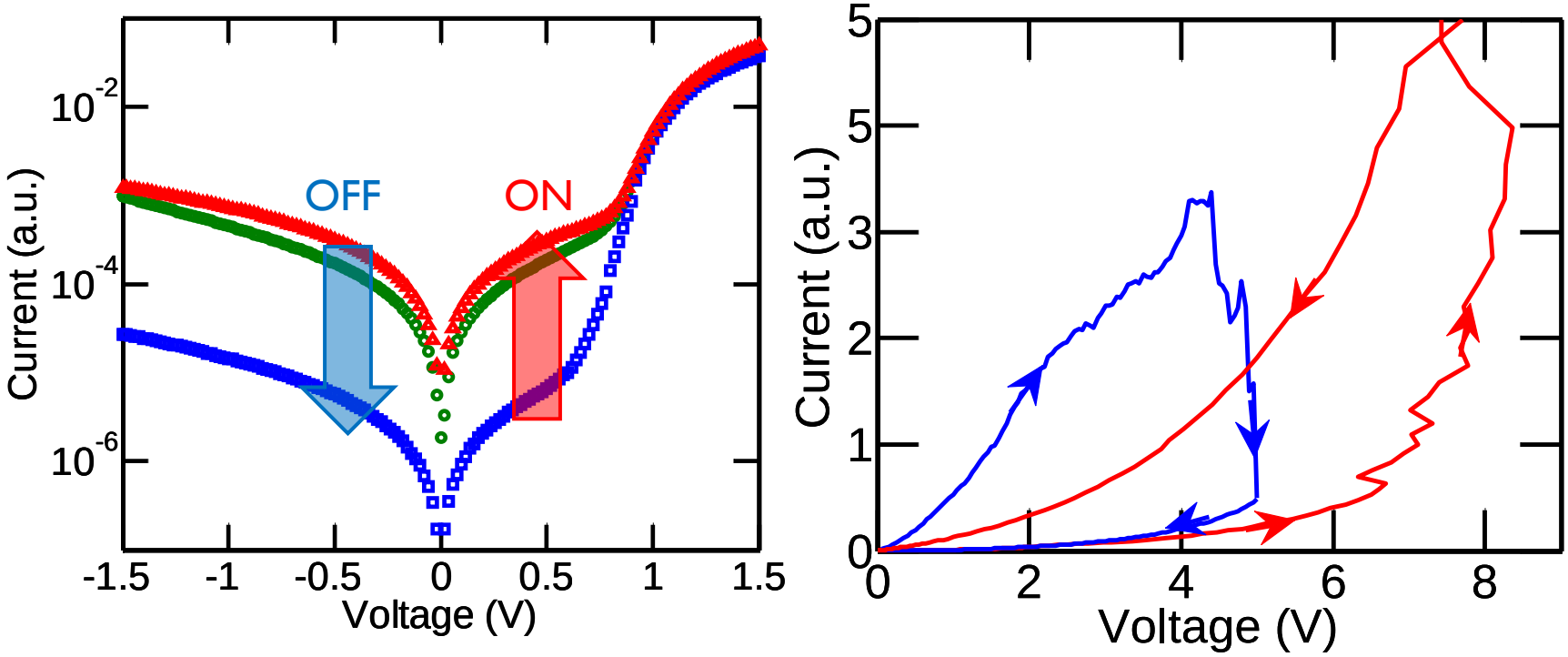





* R A Street, Cam. Univ. Pr., 1991

† A Rose, Phys. Rev. 1955

# Nonvolatile metastable switching

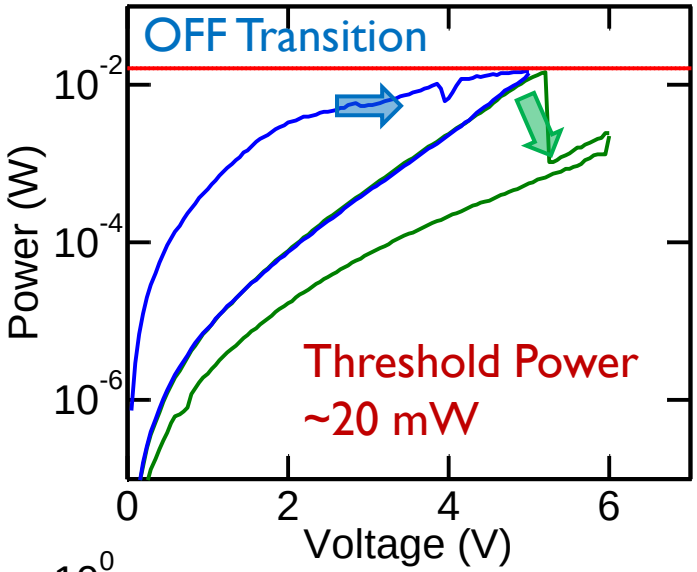


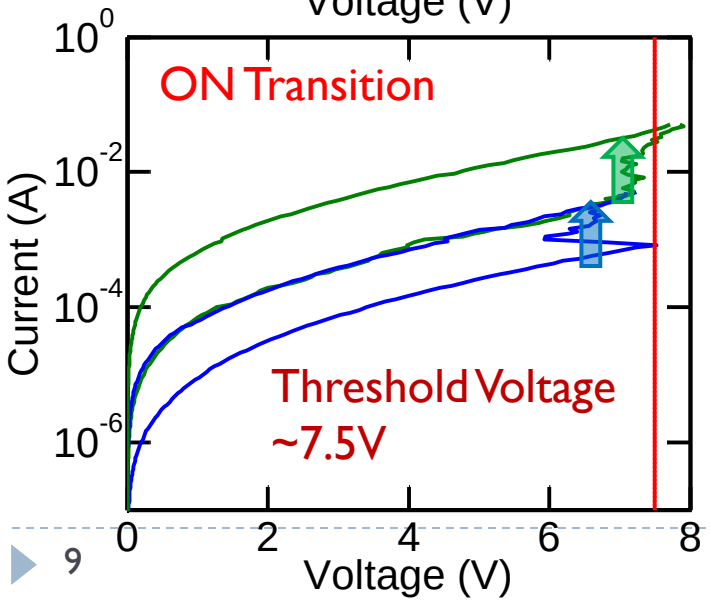

Fast reverse bias current and voltage sweeps induce switching

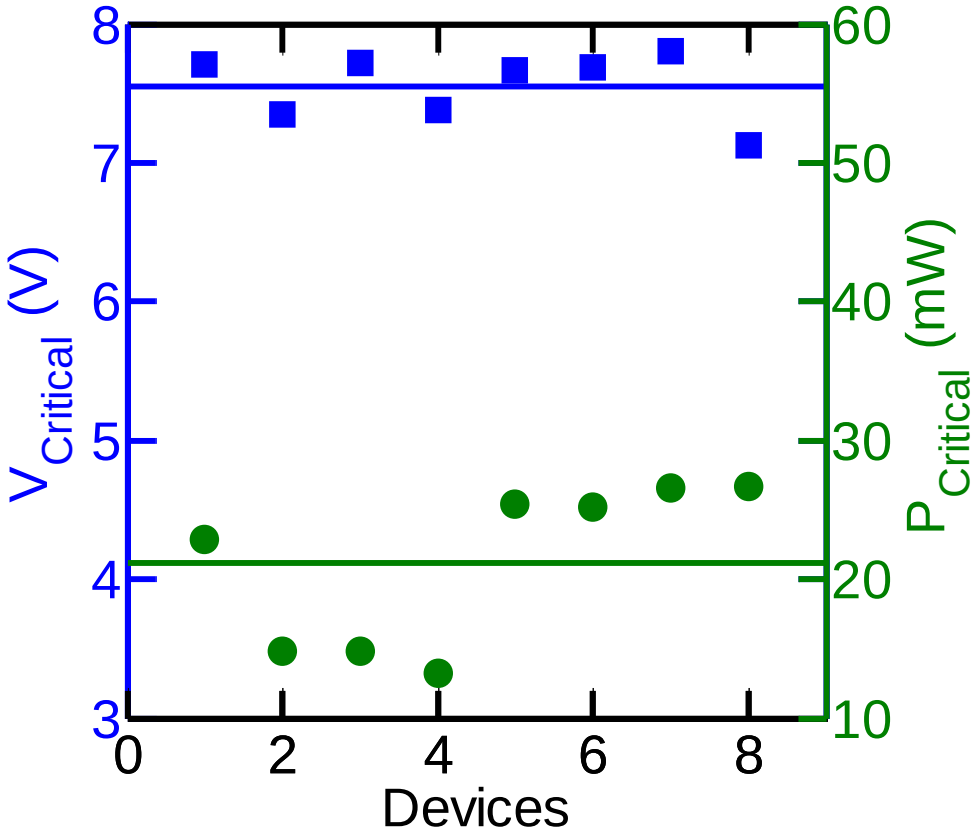
OFF/ON states remain stable (nonvolatile) in room temperature storage

*Switching in shunt current is metastable*

# Features of Switching Behavior



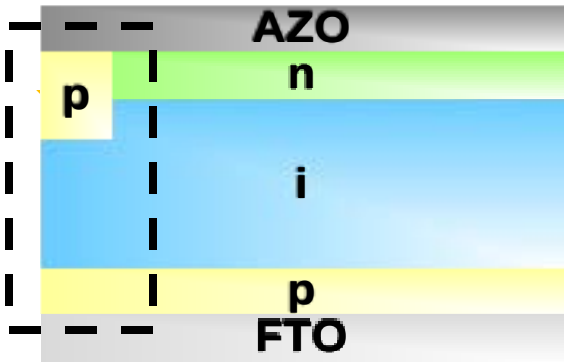



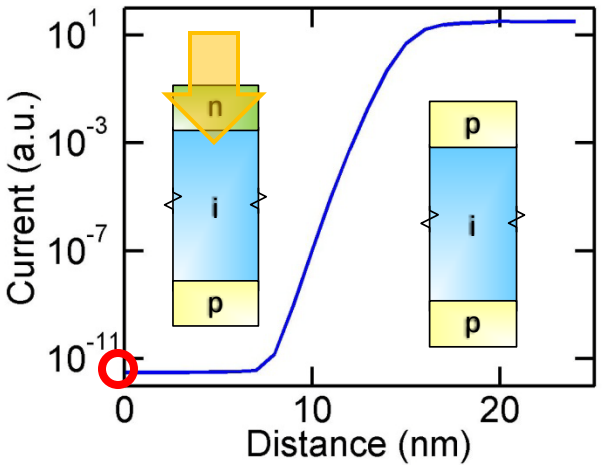




*The switching thresholds are consistent across 8 devices*

# Switching Mechanism

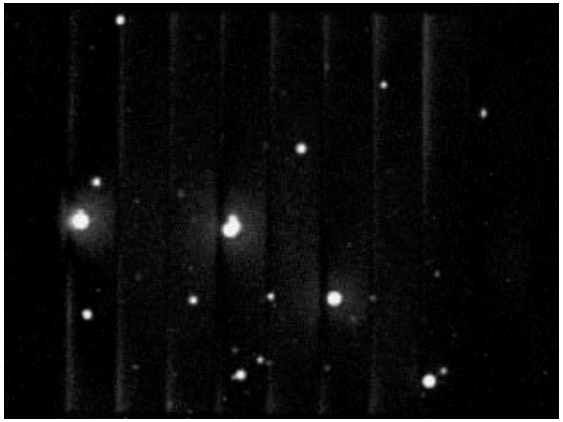
## ON Transition




Voltage driven migration of Al in a-Si:H matrix known in resistive RAM *

## OFF Transition



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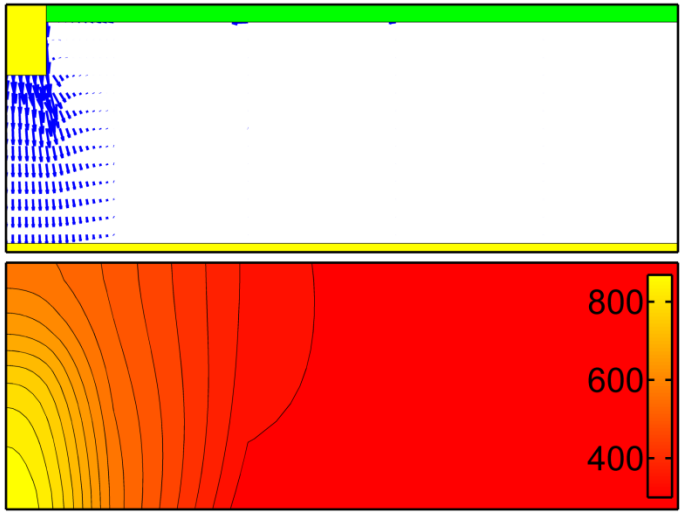


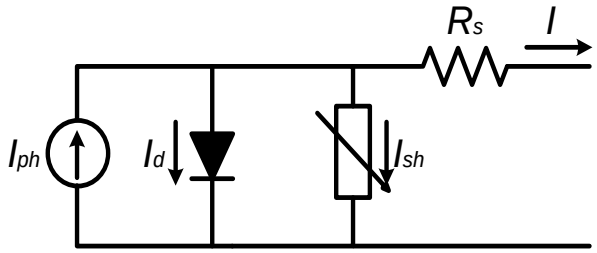

Local heating at shunt path carrying highest current in reverse bias



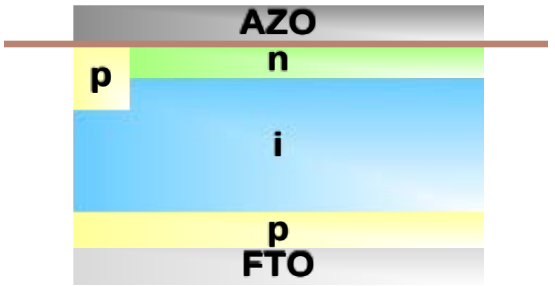
*A Avila, et al., Sol. St. Elec. 2000

#V Sittinger, Th. Sol. Film 2006

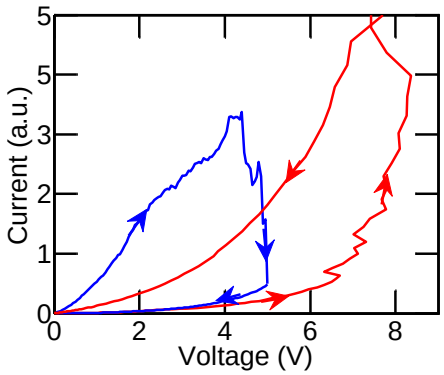
# Conclusions



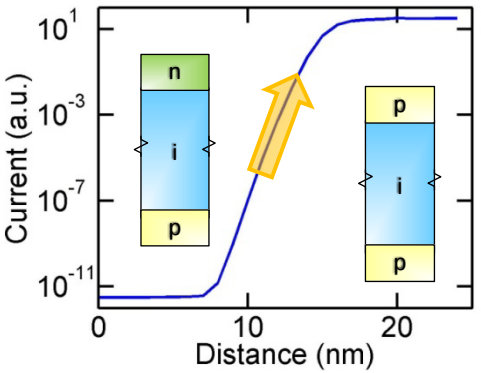

1. *Non-Ohmic shunt current element*




2. *Shunt formation ←→ Contact metal diffusion*



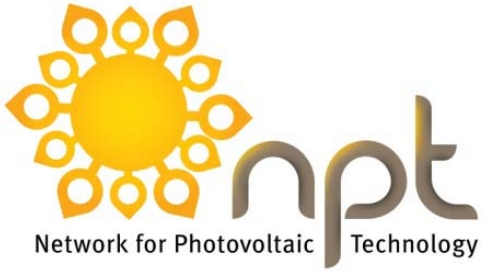

3. *Shunt current switching is metastable*




4. *Metastability in Ish ←→resistive RAM*

# Acknowledgement


Funding


Resources



Discussions

Dr. M. Frei and Dr. D. Wang, Applied Materials

# References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