On the Resolution of Ultra-fast NBTI Measurements and Reaction-Diffusion Theory

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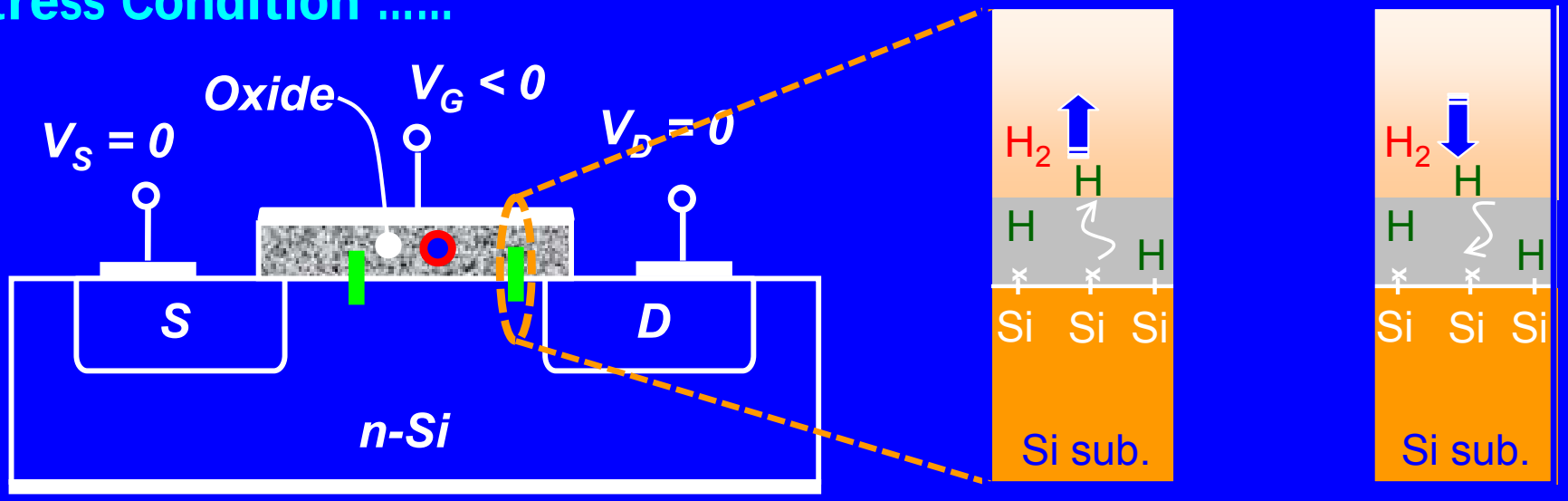
Negative Bias Temperature Instability

Stress Condition .....



Results .....

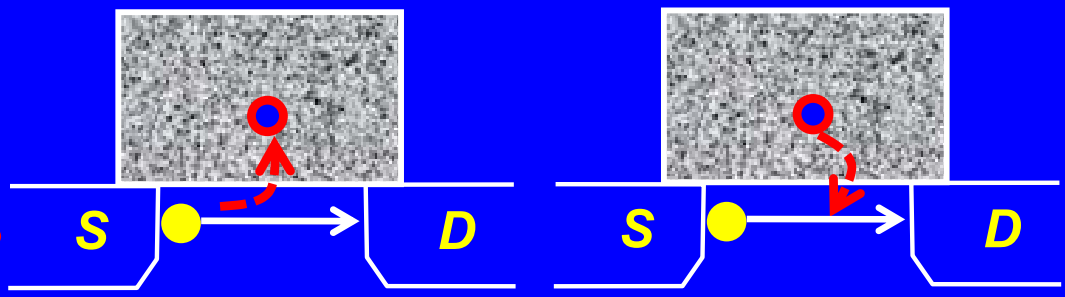
Interface Defects N_{IT}

Oxide Defects N_{OT}

Origin .....

Reaction-Diffusion Theory?

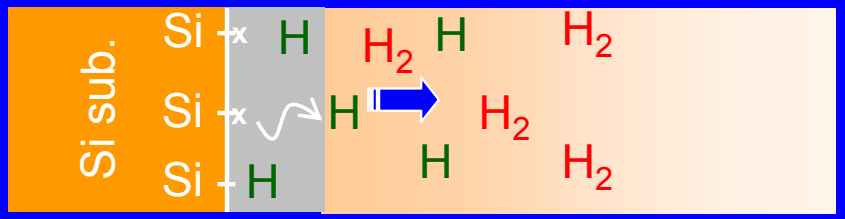
Oxide defects and dielectric %N?



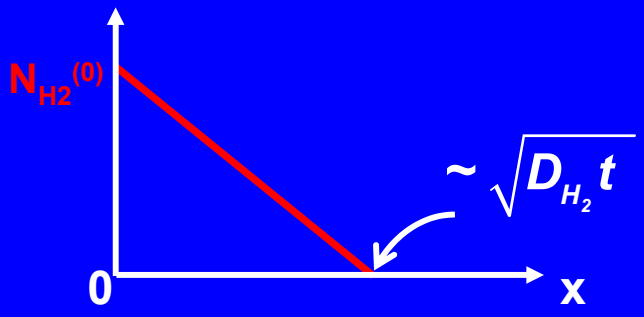
Outline

- R-D Model for N_{IT}
- Signatures of NBTI
- NBTI Modeling
- Implication in AC Analysis
- Conclusion

RD Model for N_{IT} Generation



Alam, IRPS (T) 05; Krishnan, APL '06
Islam, TED '07



a) Reaction $\frac{dN_{IT}}{dt} = k_F [N_0 - N_{IT}] - k_R N_{IT} N_H^{(0)} \sim 0$ Si-H $\leftrightarrow$ $Si^+ + H$

b) H-H_2 Conversion $N_{H_2}^{(0)} \sim \left[N_H^{(0)} \right]^2$ H $\leftrightarrow$ H_2

c) Diffusion $N_{IT} \sim \frac{1}{2} N_{H_2}^{(0)} \times \sqrt{D_{H_2} t}$ H_2 Diffusion

$$N_{IT} \sim \left(\frac{k_{F0} N_0}{k_{R0}} \right)^{2/3} \exp\left(-\frac{E_A}{k_B T} \right) t^{1/6}$$

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- **Signatures of NBTI**
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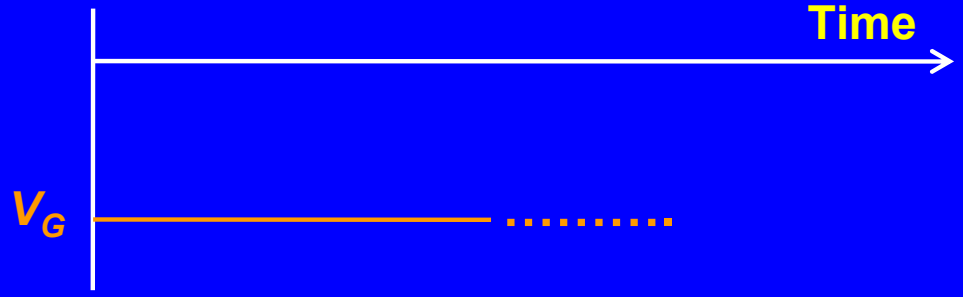
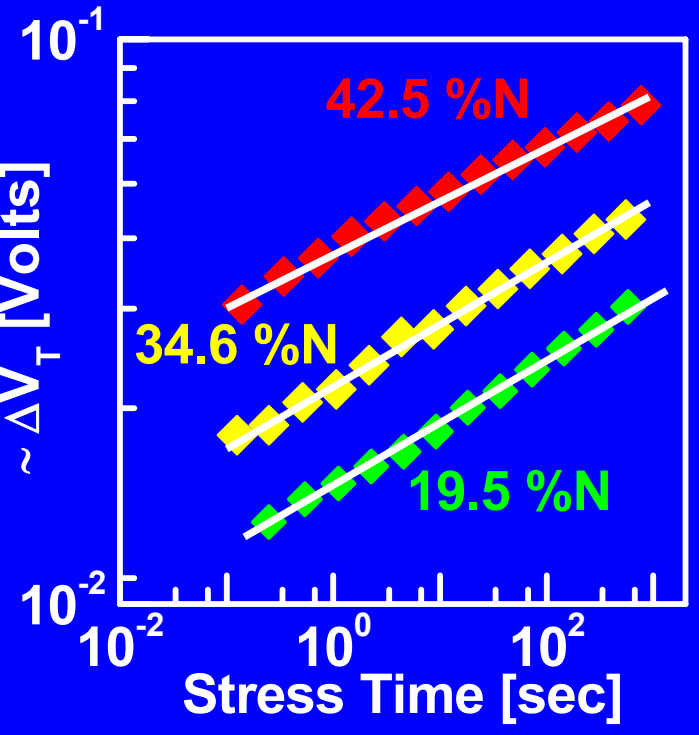
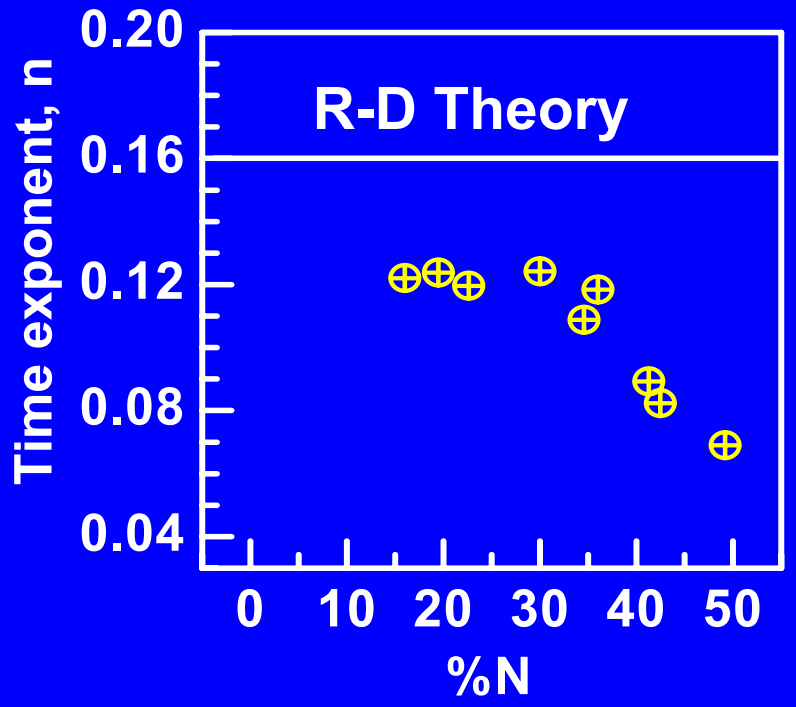
NBTI Signatures - 1: Stress Time

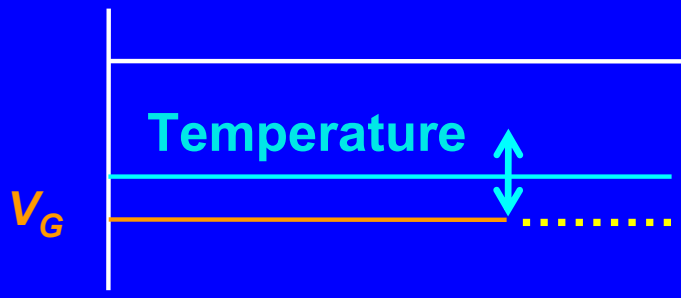


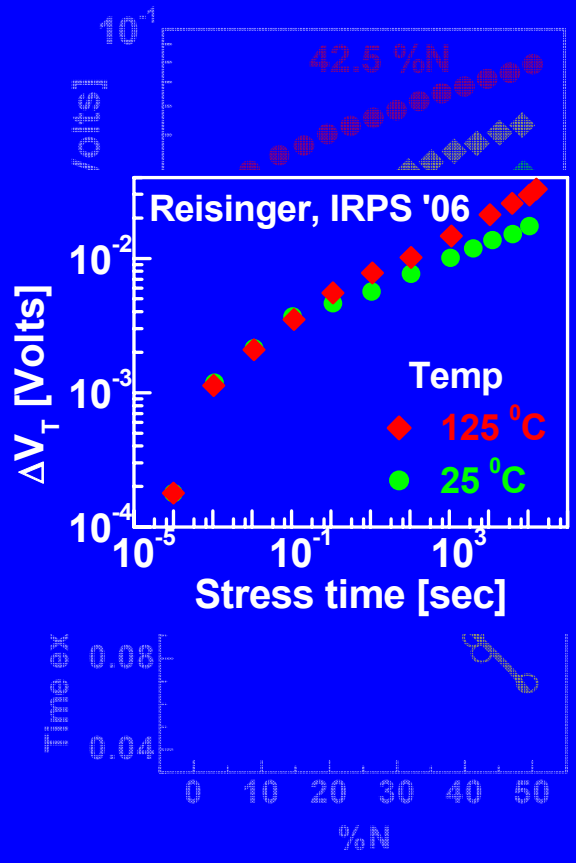


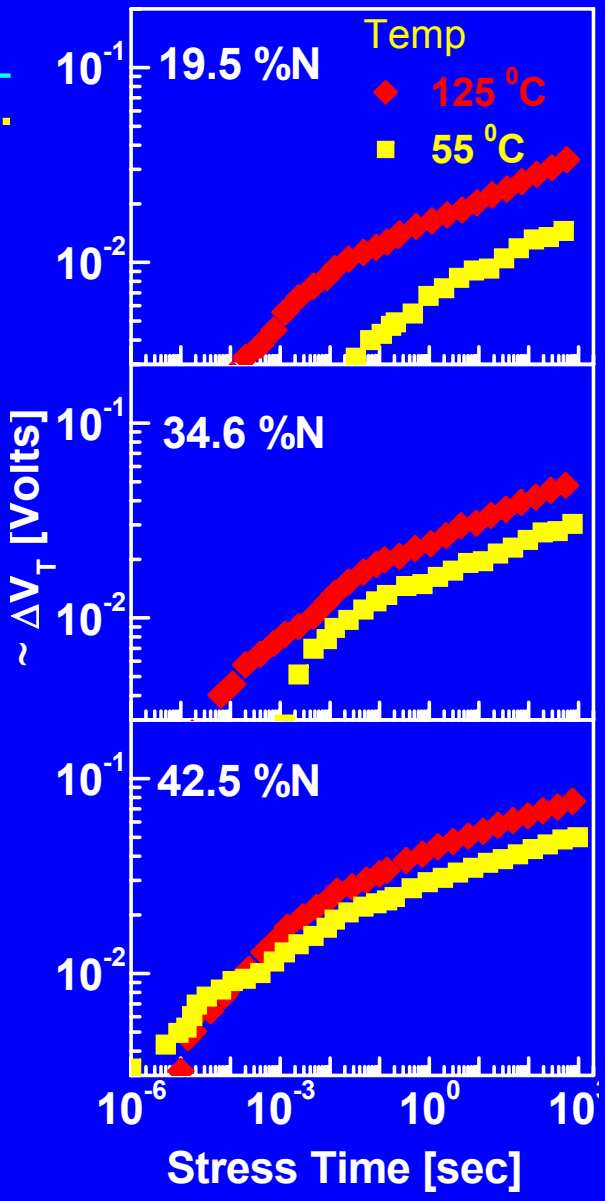


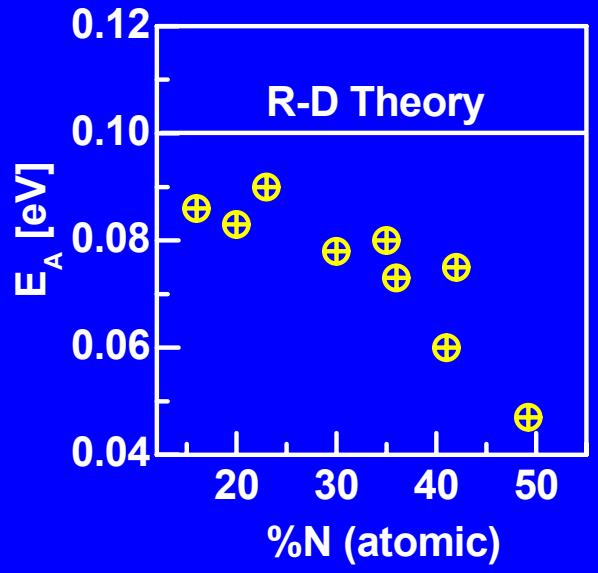
- Universal existence of power-law at long t_{STS}
- Time exponent reduces with %N

NBTI Signatures - 2: Temperature



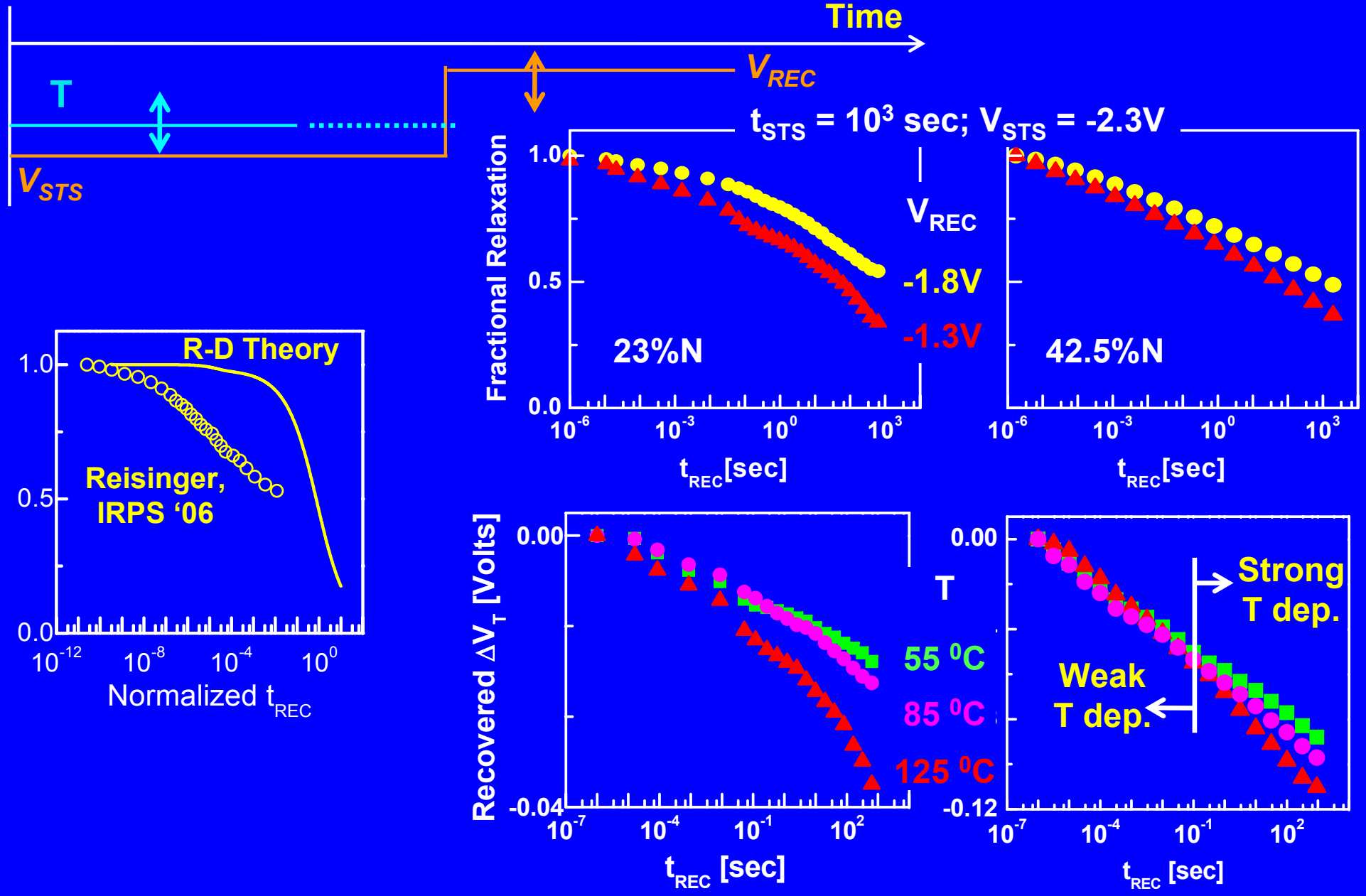






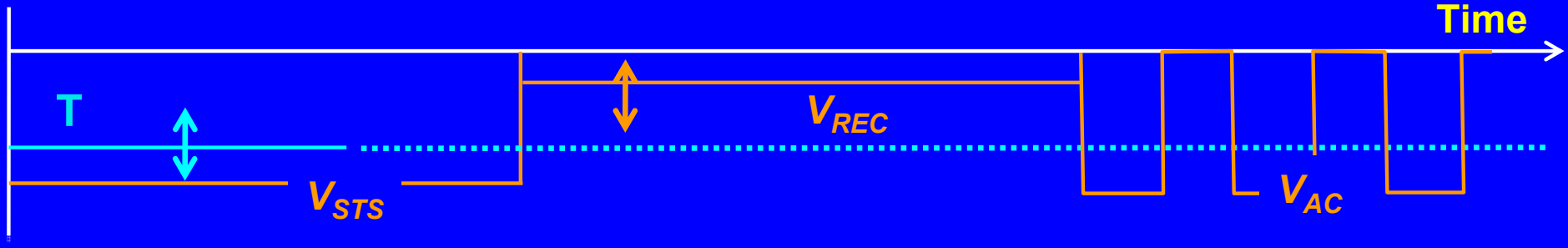
- %N reduces T dependence
- Effect more visible in short t_{STS}

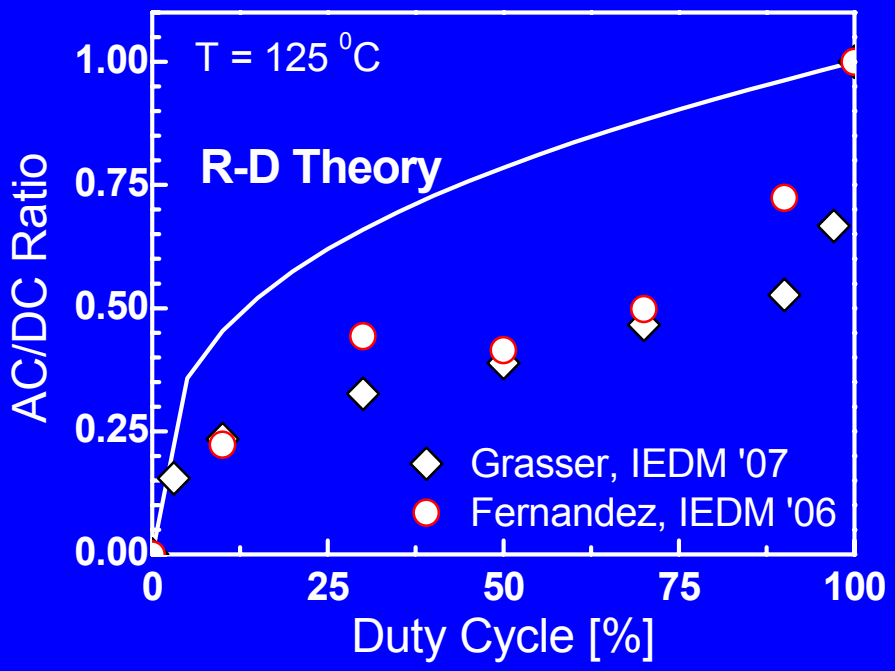
NBTI Signatures - 3: Relaxation

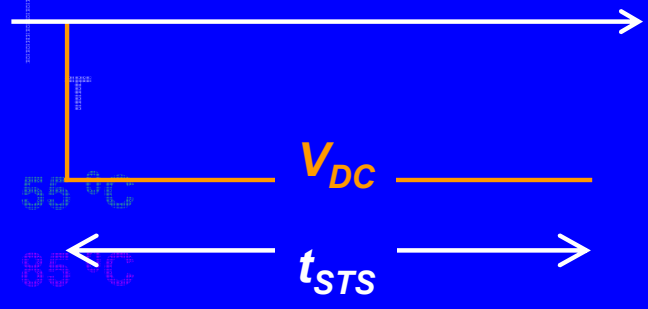


- Relaxation not always logarithmic…

NBTI Signatures - 4: AC/DC Ratio

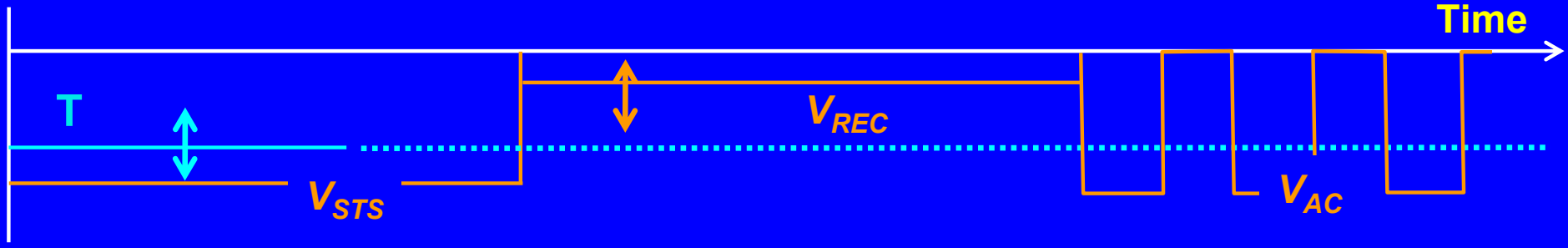


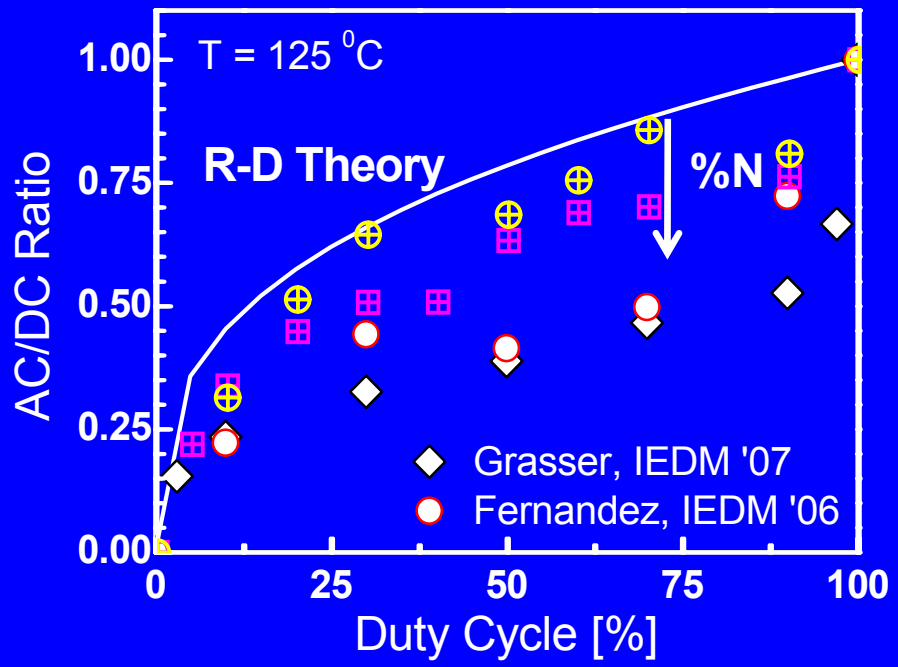


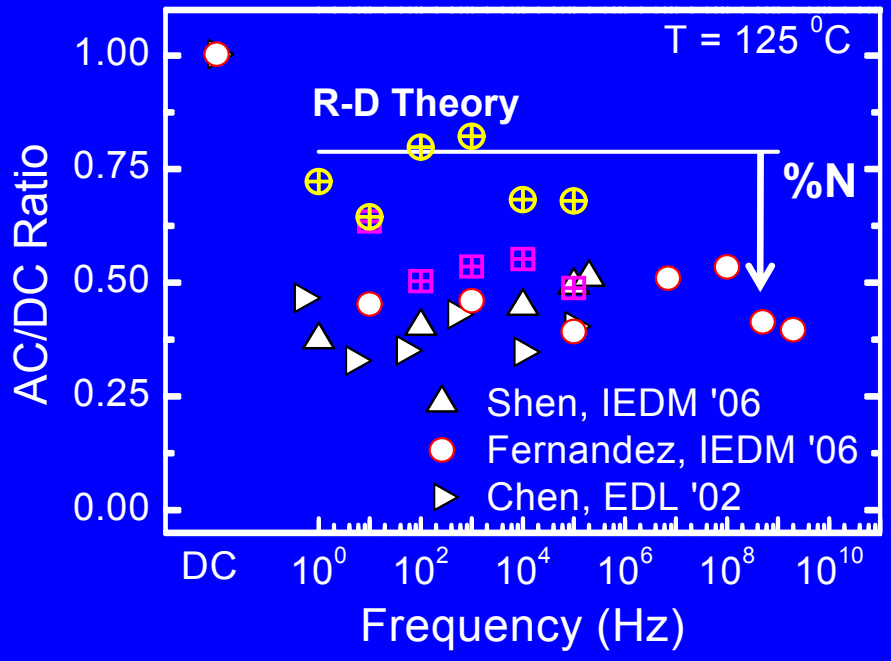


AC/DC Ratio = $\Delta V_{T,AC}/\Delta V_{T,DC}$

NBTI Signatures - 4: AC/DC Ratio

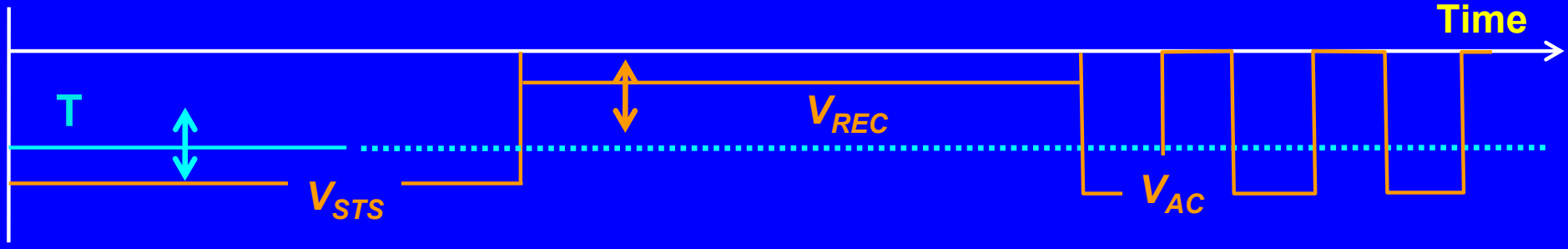


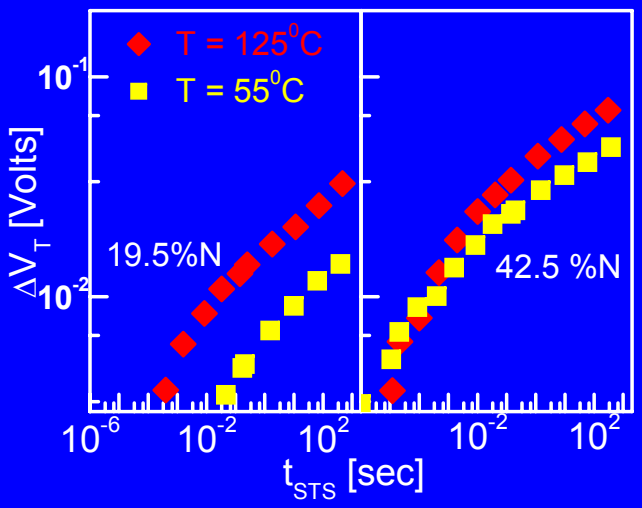


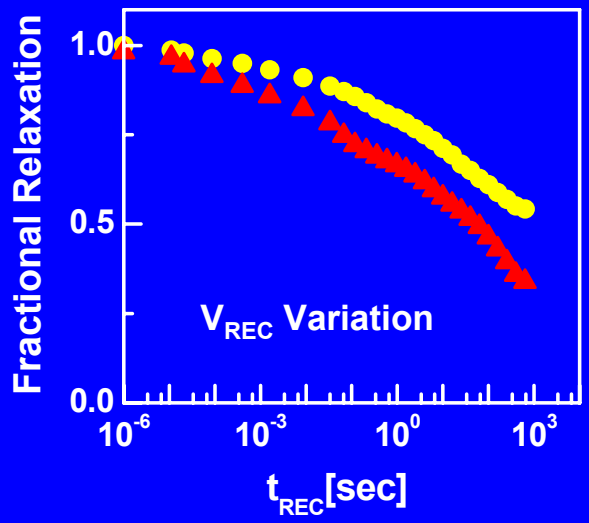


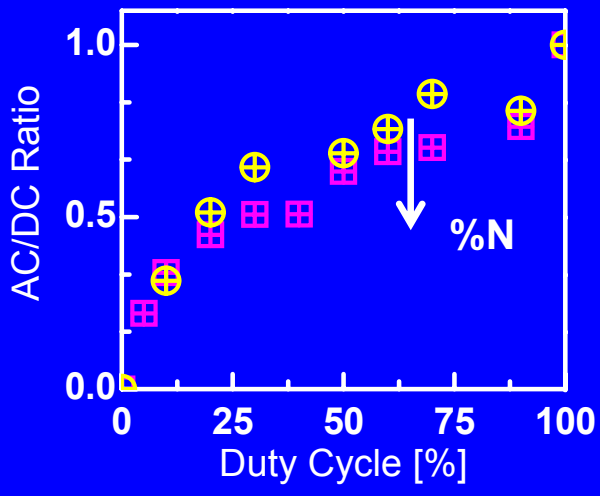
- **Frequency independent for all %N**
- **Non-universal duty dependence**

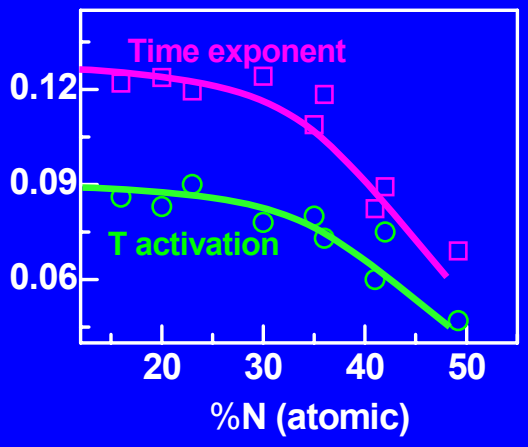
NBTI Signatures: Summary

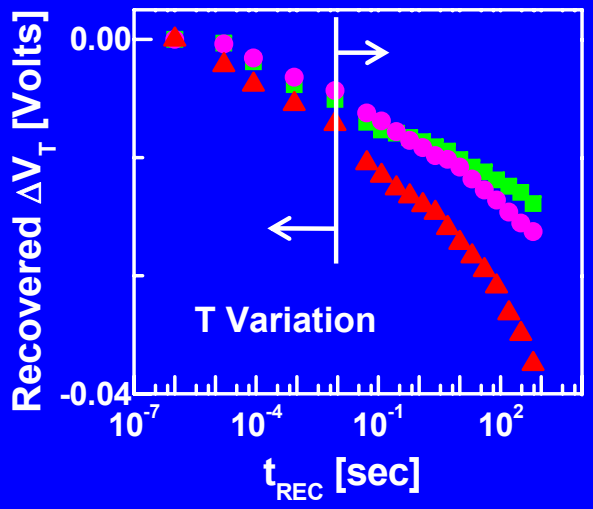


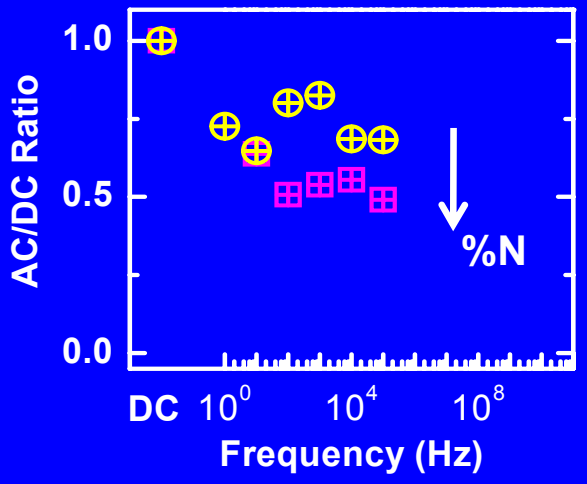












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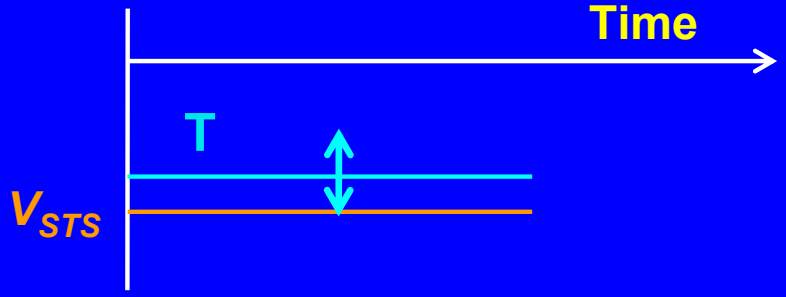
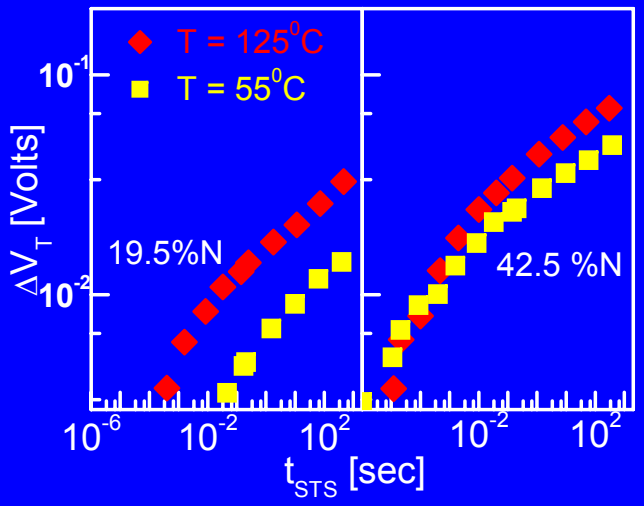
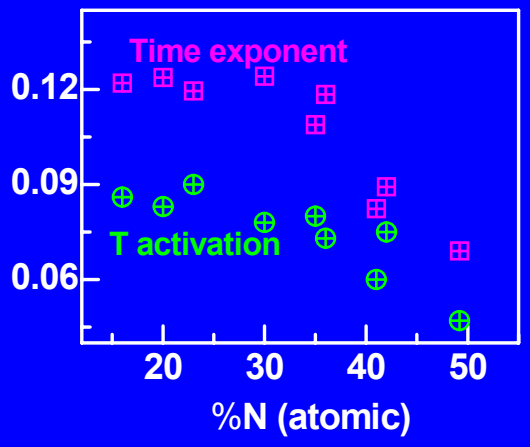
Developing Hypothesis







Power-law time exponent

Temperature activation

Uncorrelated mechanism at short and long t_{STS}

Interface Trap: Reaction-Diffusion Model

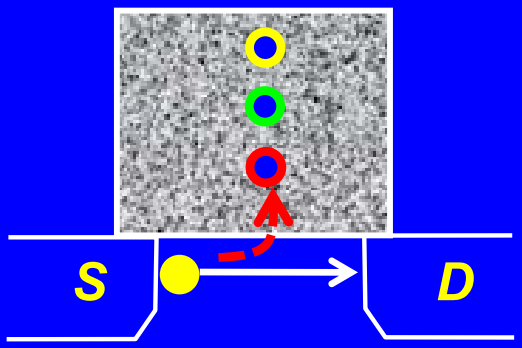
Hole trapping: Shockley-Read-Hall

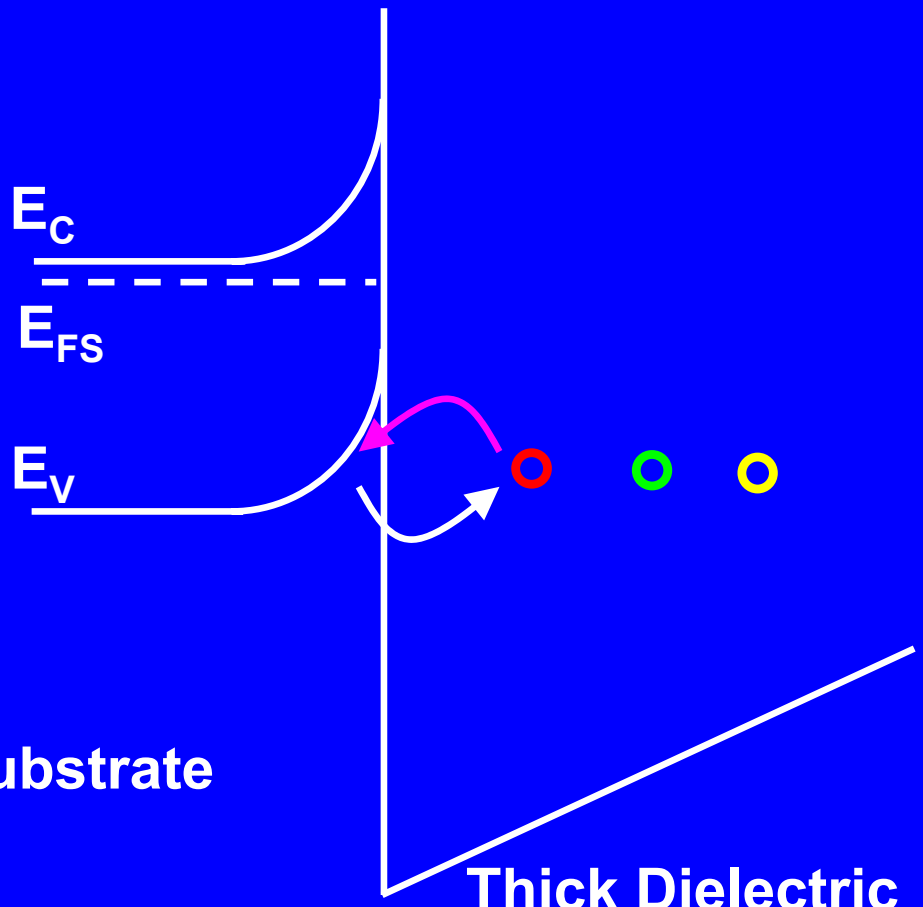
NBTI Relaxation

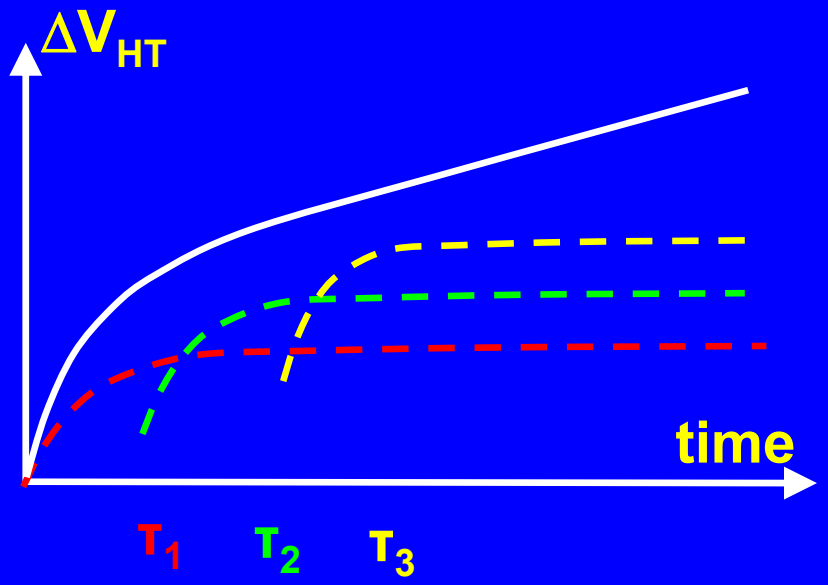
AC/DC Ratio

Hole Trapping into Oxide Defects N_{OT}

$$\frac{df_T}{dt} = \sigma v_{th}\left[p_h T_1 (1 - f_T) - n_S T_1 f_T\right]$$



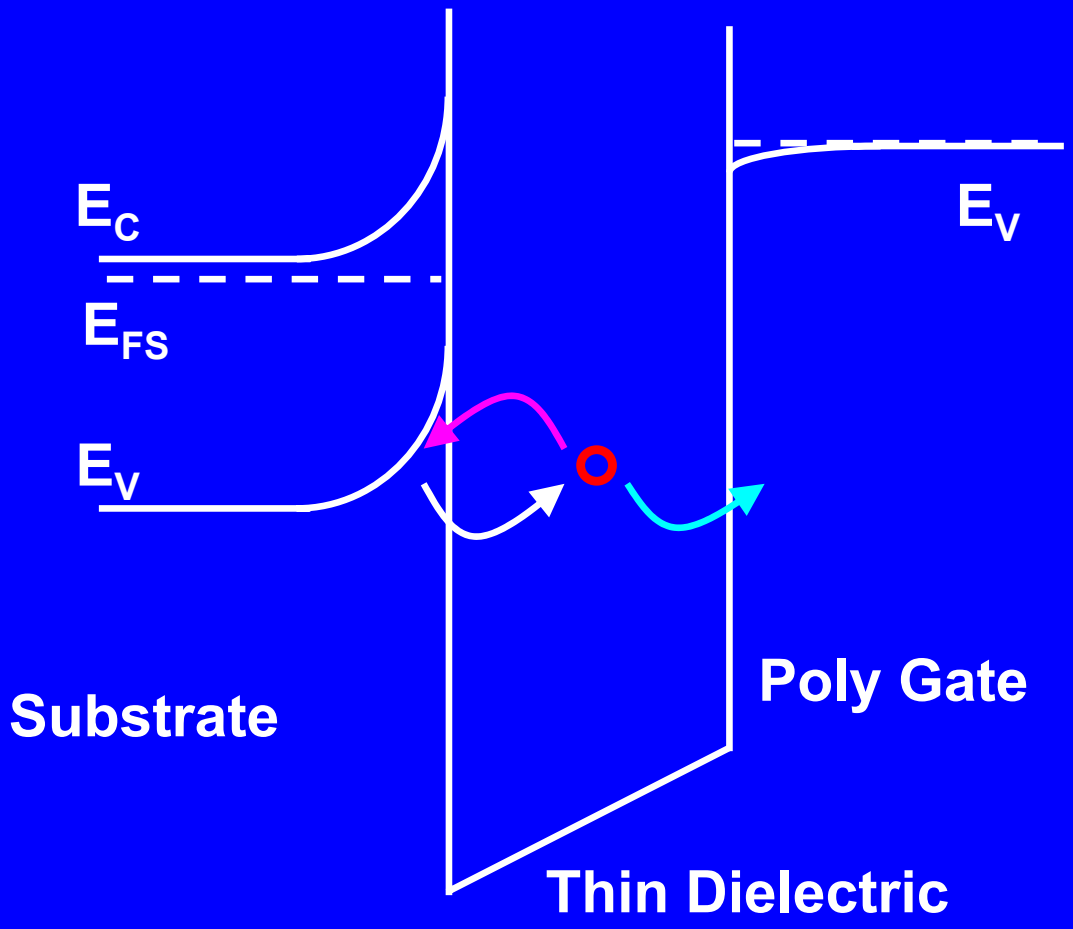


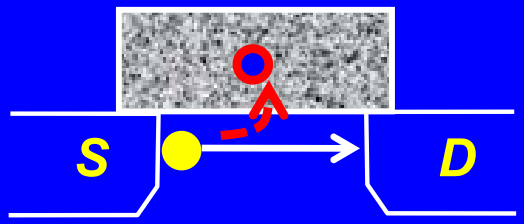


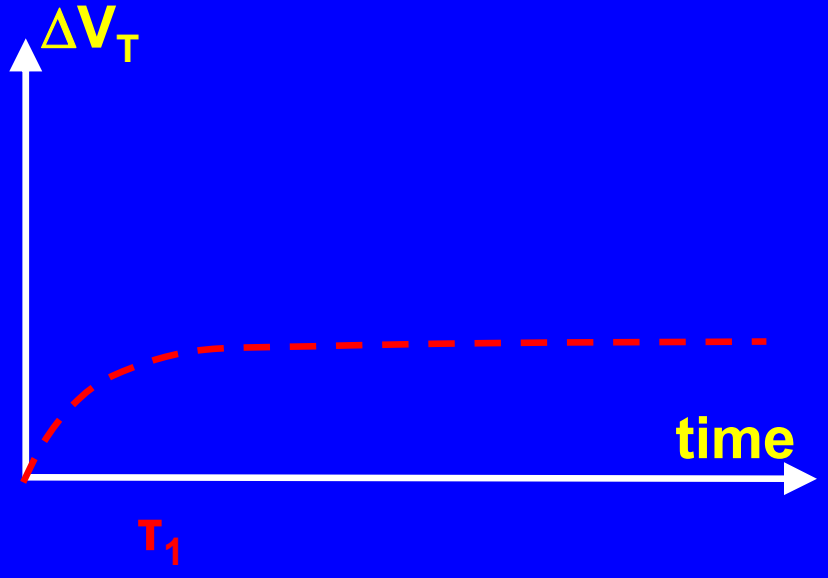
Thick dielectric: Large time constant
Temperature independent: Tunneling

Hole Trapping into Oxide Defects N_{OT} …

$$\frac{df_T}{dt} = \sigma v_{th}\left[p_h T_1 (1 - f_T) - n_S T_1 f_T - n_G T_2 f_T\right]$$

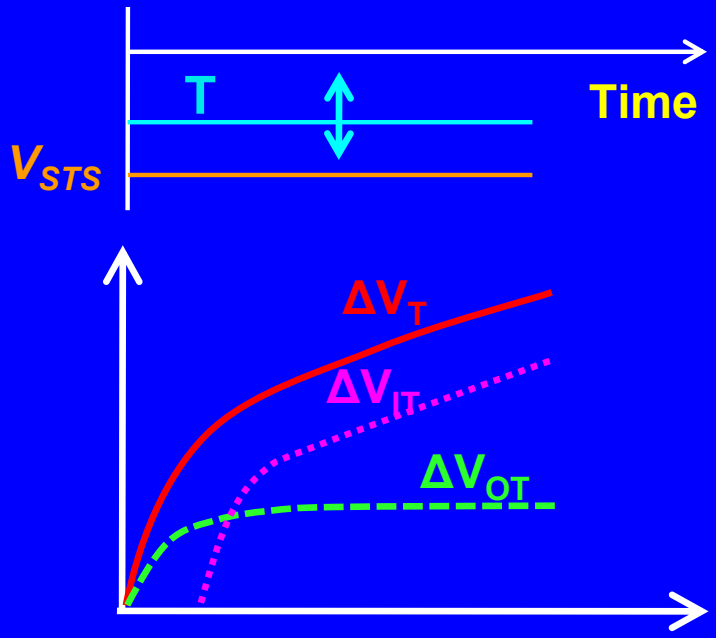


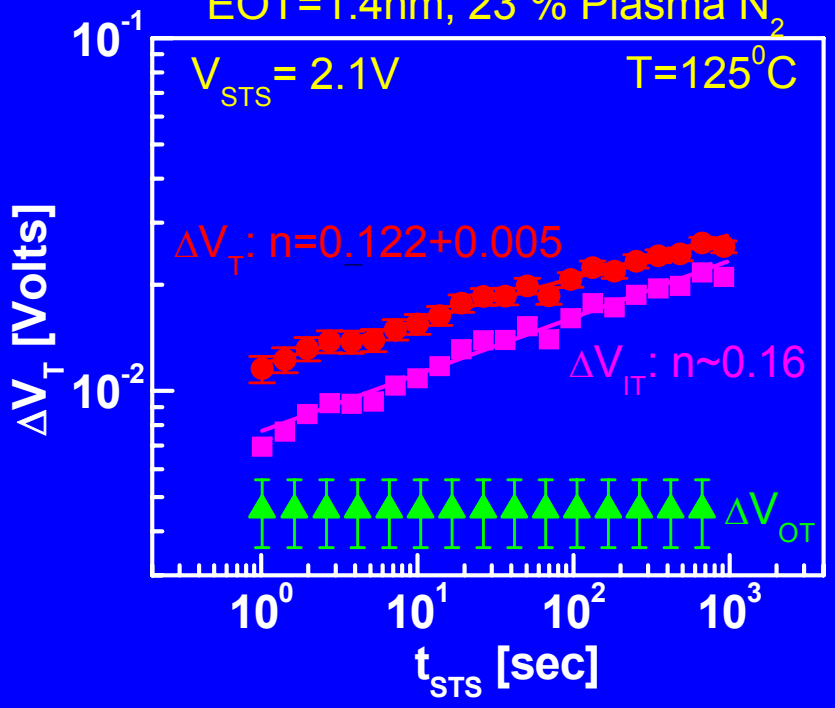


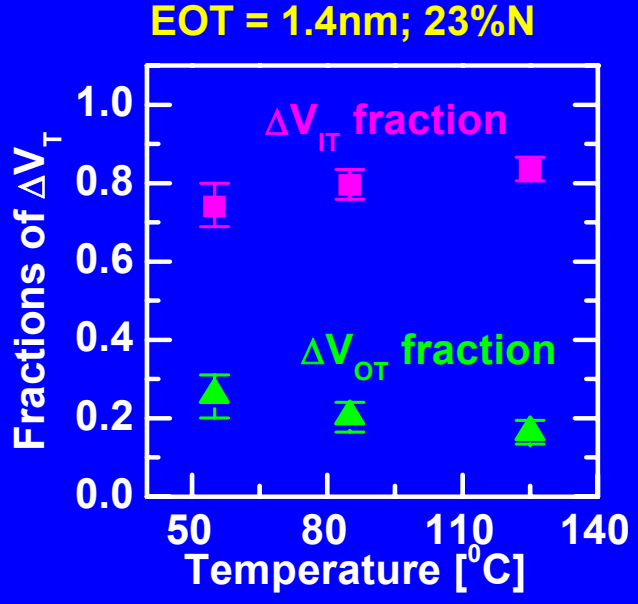


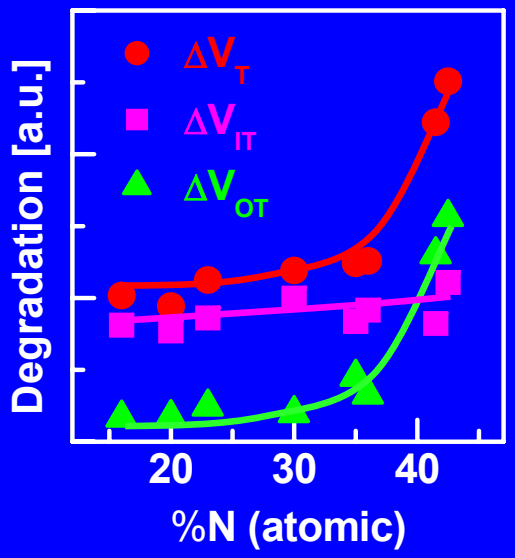
Thin dielectric: Small time constant
Temperature independent: Tunneling

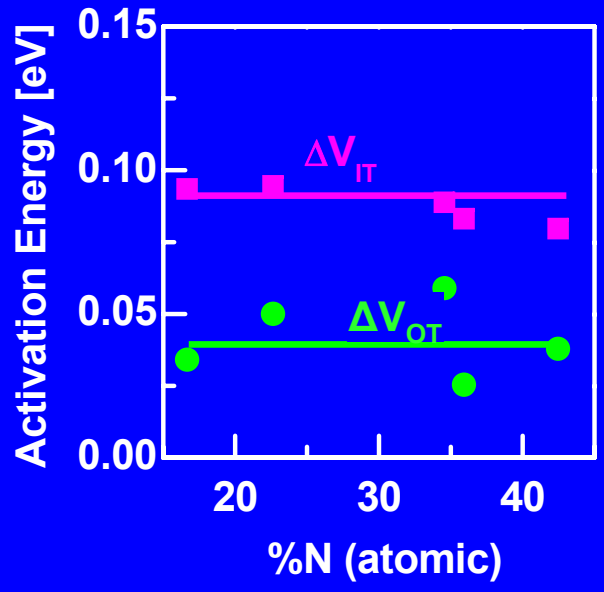
N_{IT}/N_{OT} Decomposition: Stress



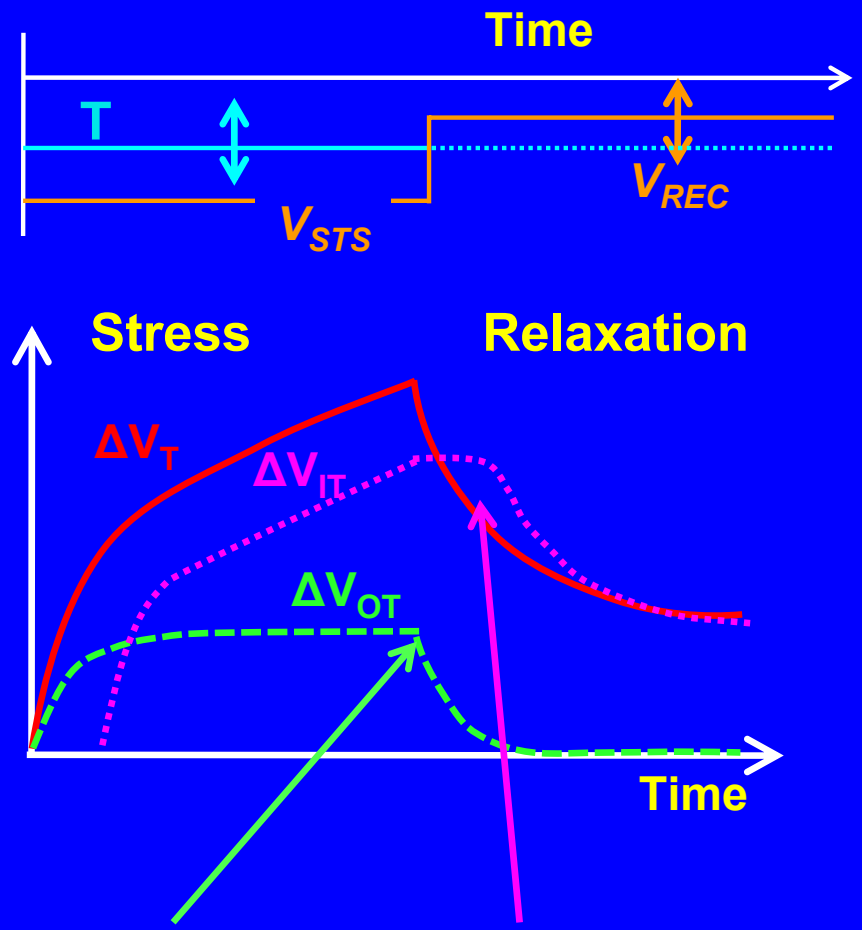


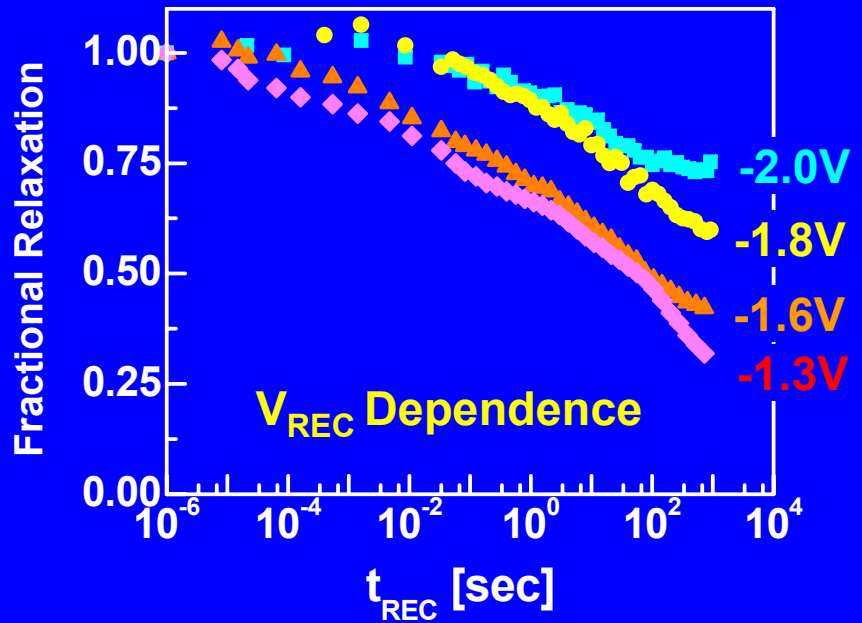


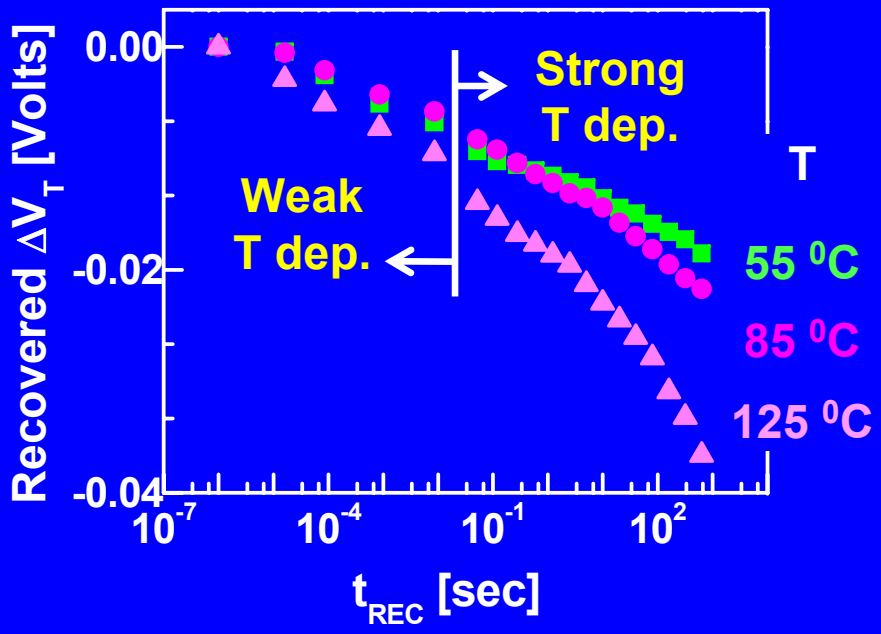




N_{IT}/N_{OT} Decomposition: Relaxation







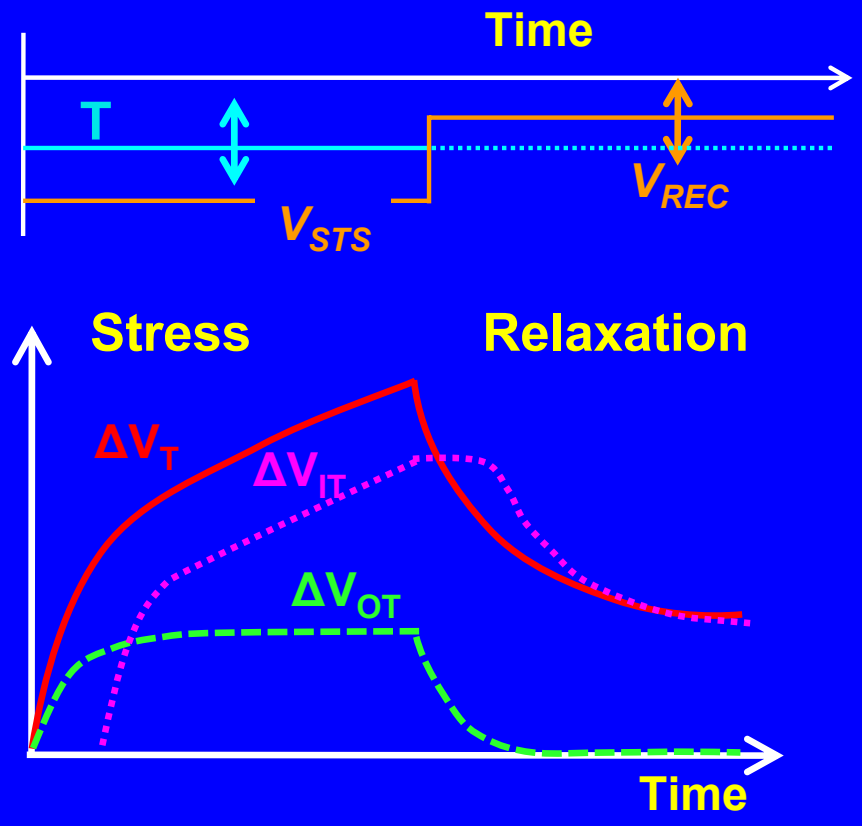
Hole Detrapping:

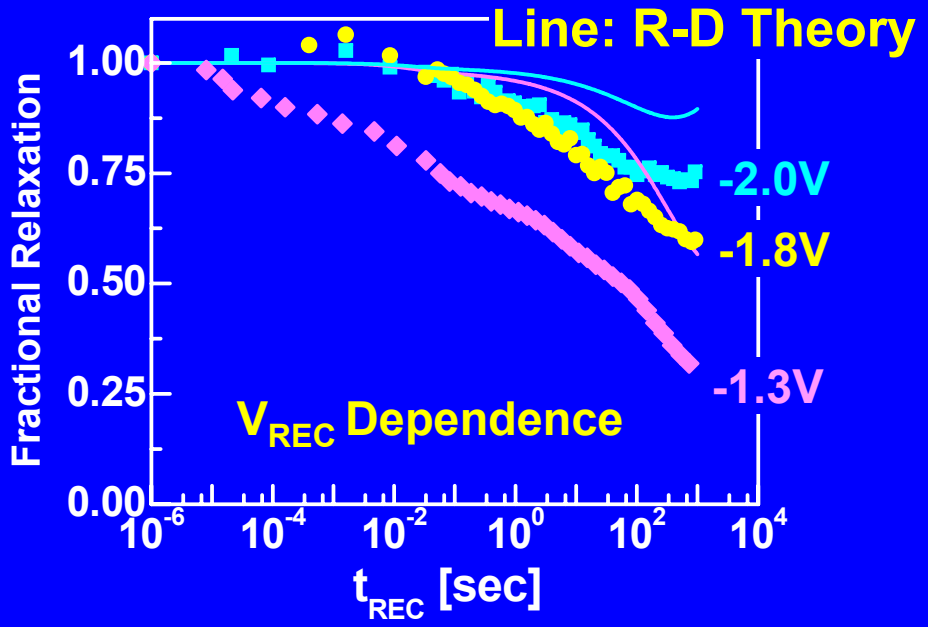
- T independent
- For V_{REC}~ -1.6V

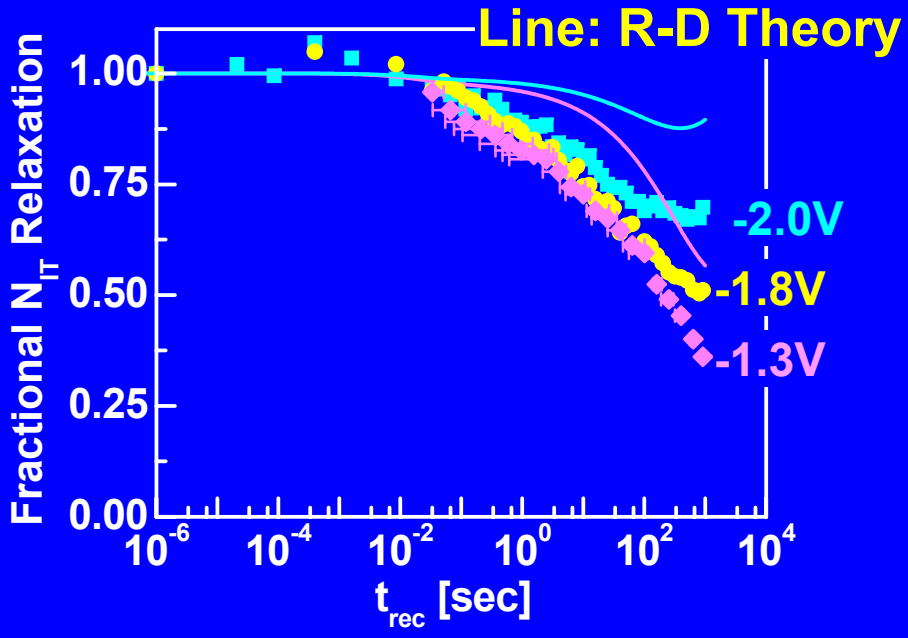
N_{IT} Relaxation:

- After t_{REC} ~10ms
- At any V_{REC}

N_{IT}/N_{OT} Decomposition: Relaxation …

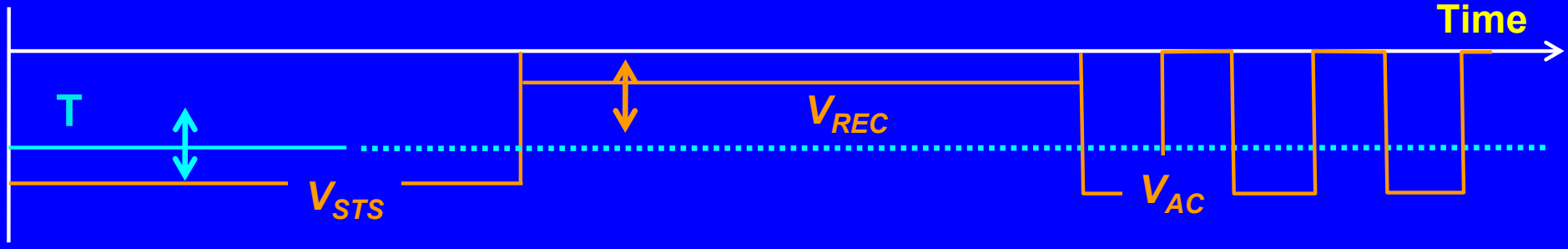




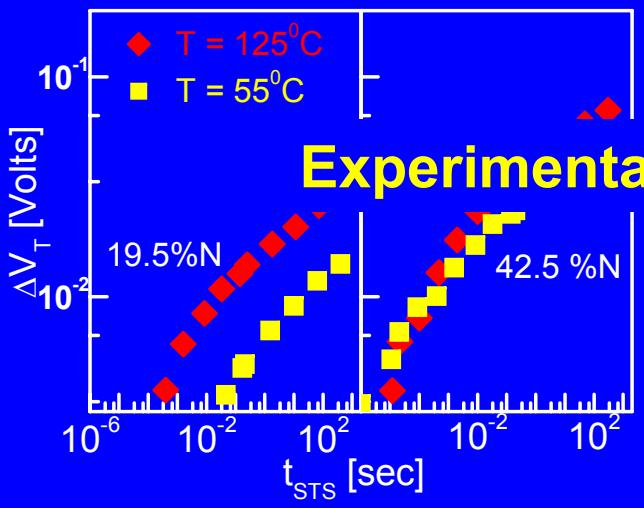


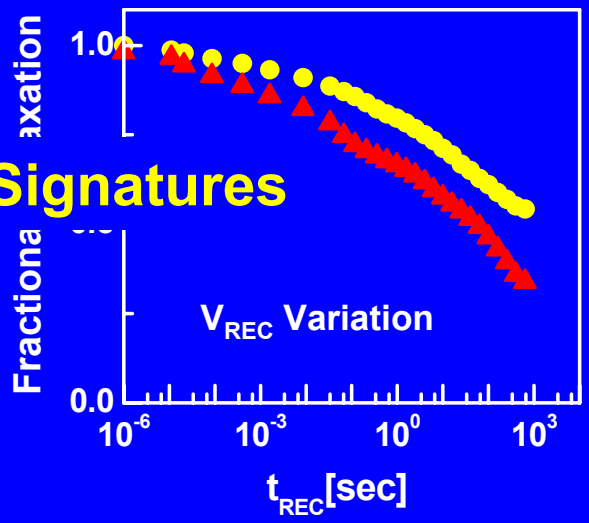
- Decomposition → Reduces gap
- Small oxide trap generation reduces the gap further

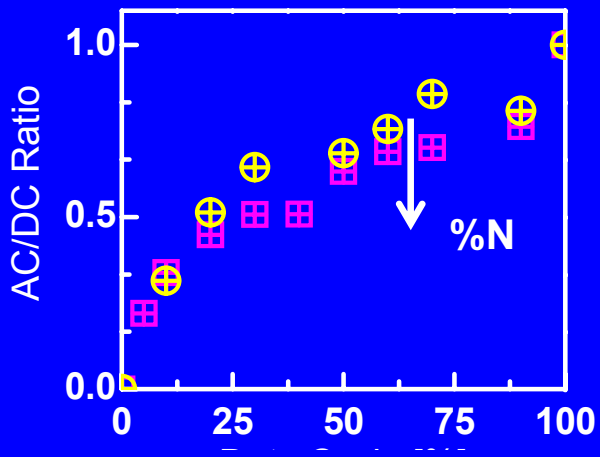
NBTI Signatures: Summary



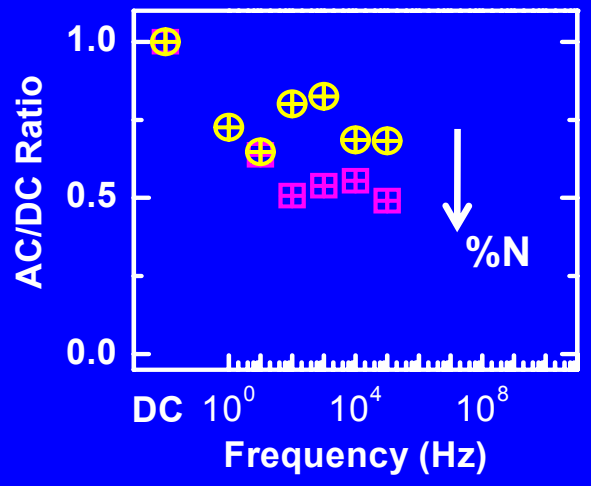
Experimental Signatures



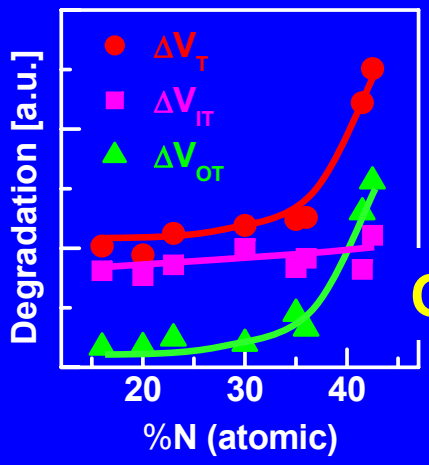


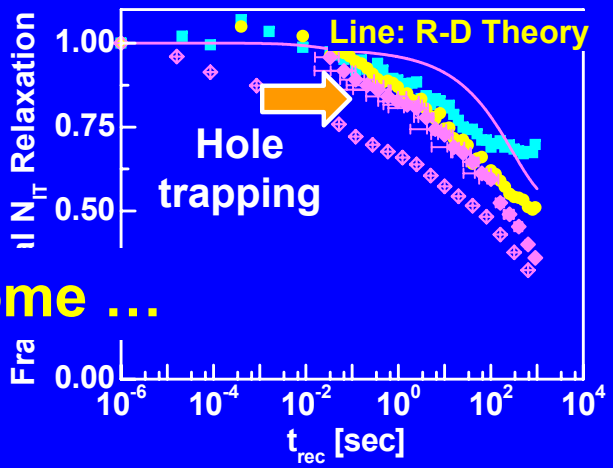


Implication ?

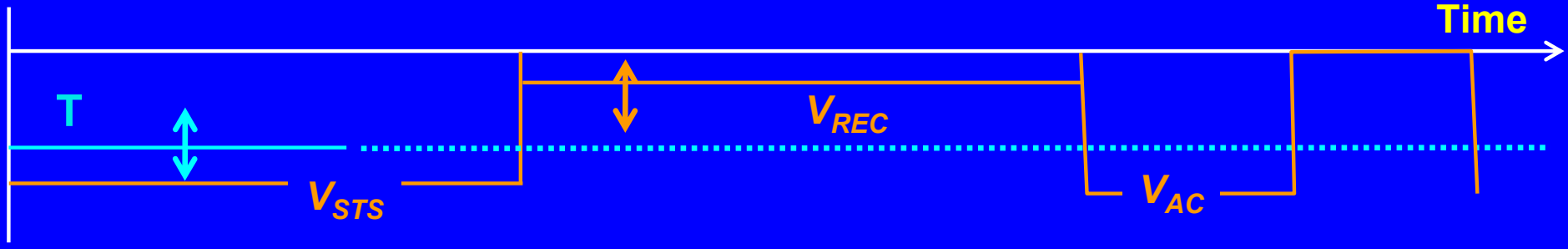


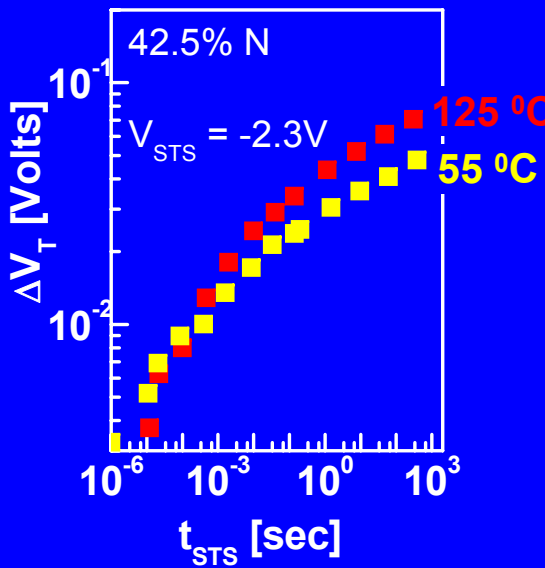
Outcome …

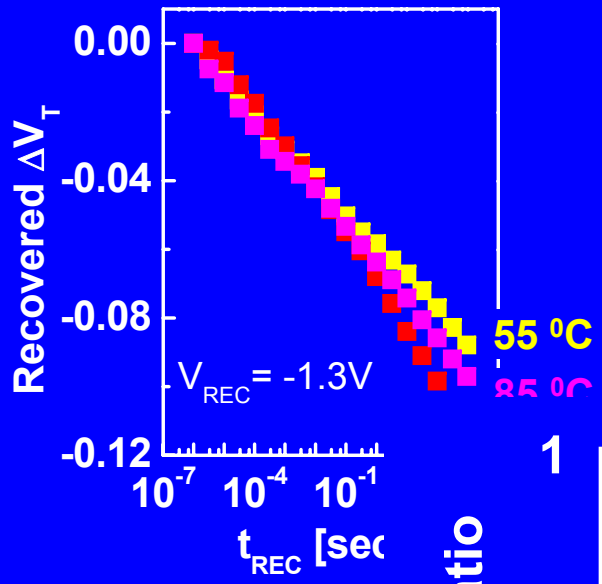


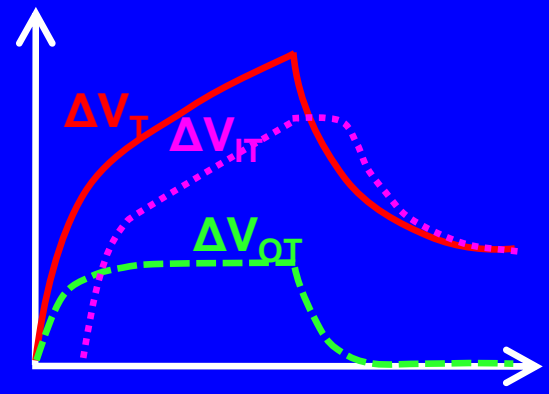


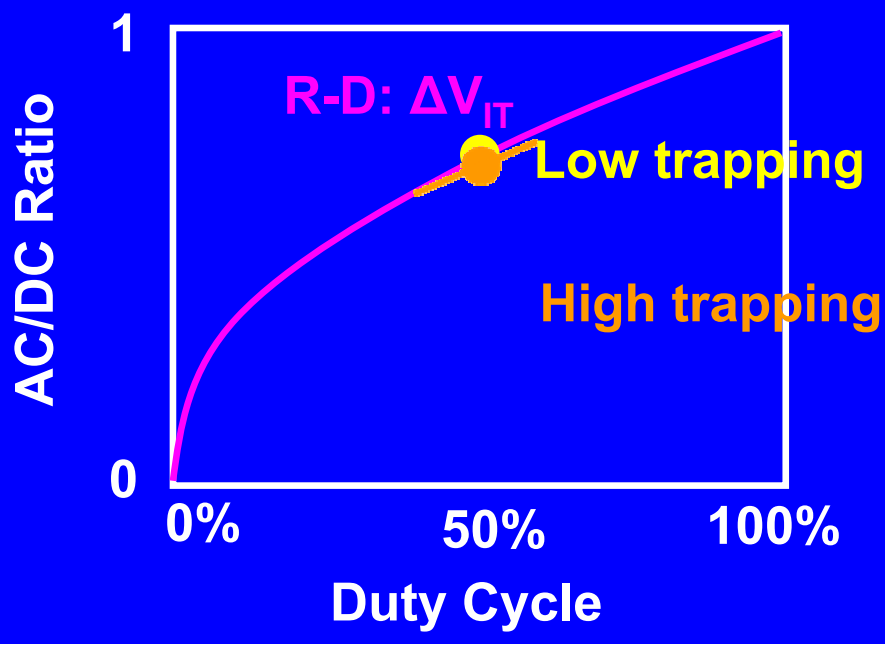
Implication in AC Analysis









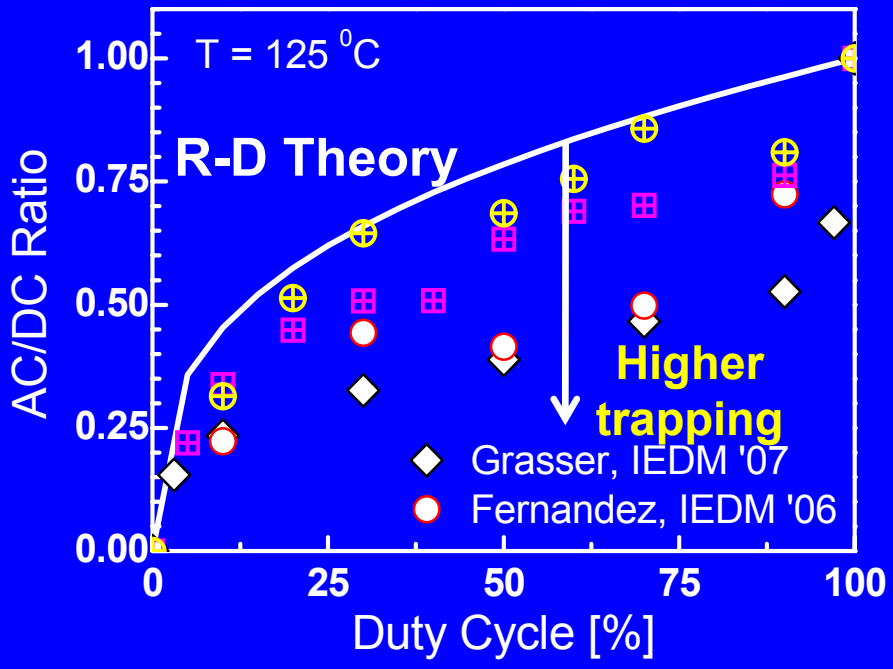


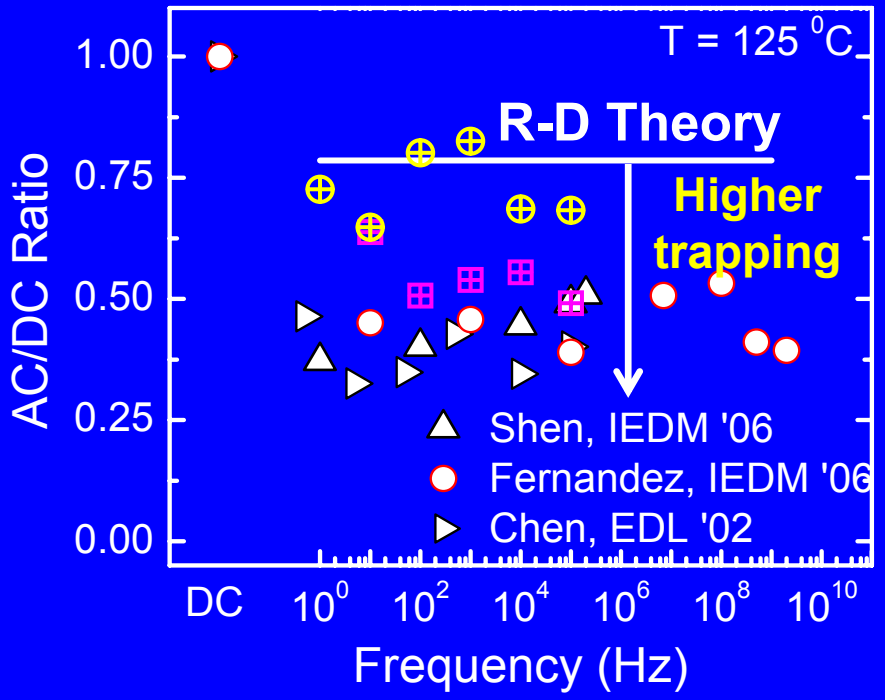
For 50% Duty Cycle:

AC NBTI: $\Delta V_{IT(AC)}$

DC NBTI: $\Delta V_{IT(DC)} + \Delta V_{OT(DC)}$

Implication in AC Analysis …

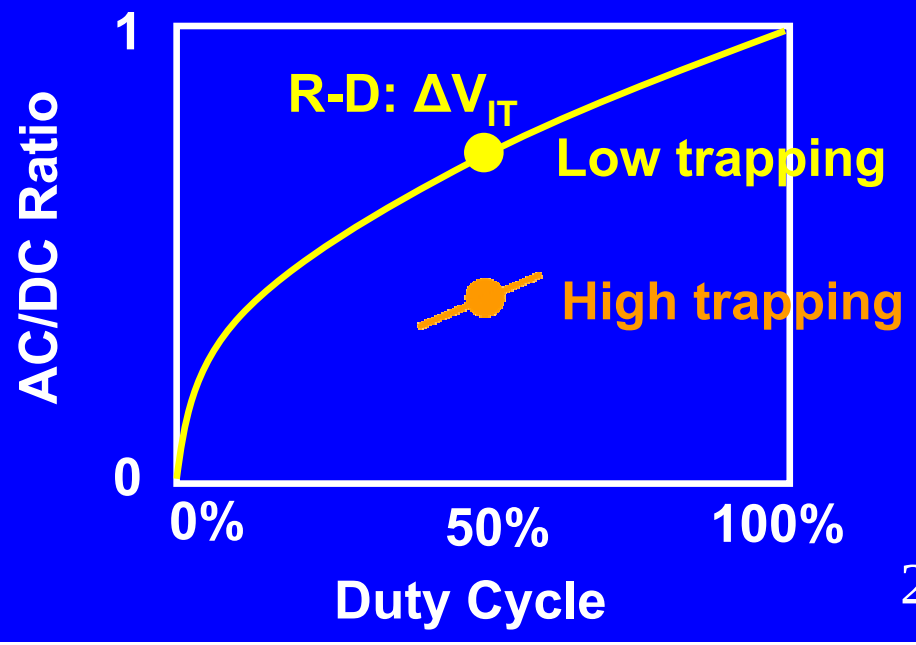




For 50% Duty Cycle:

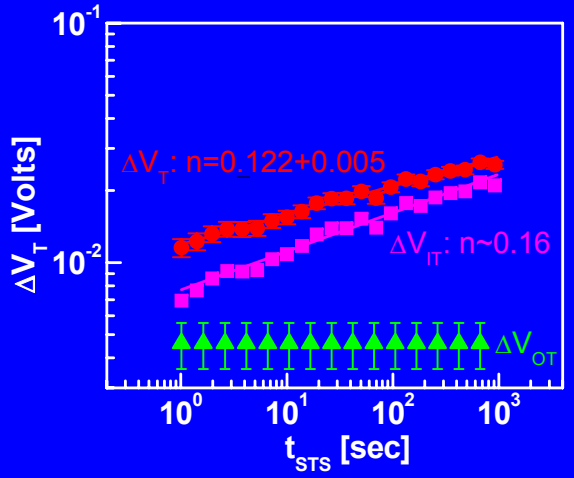
AC NBTI: $\Delta V_{IT(AC)}$

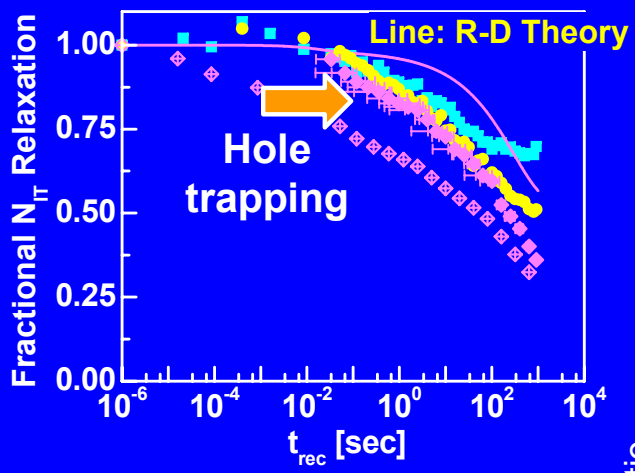
DC NBTI: $\Delta V_{IT(DC)} + \Delta V_{OT(DC)}$



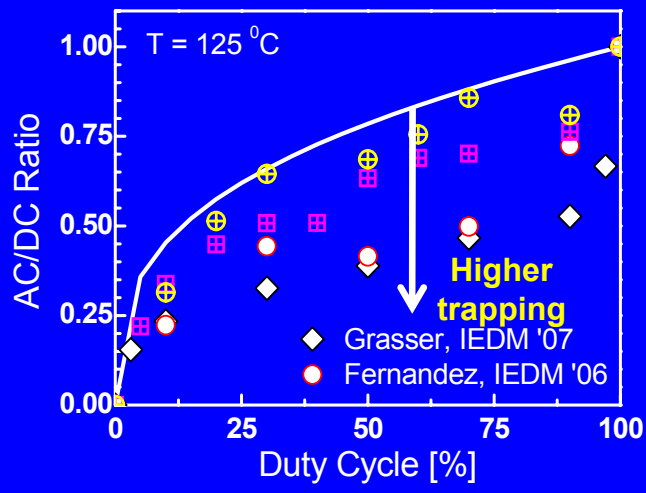
Conclusion

- NBTI is due to N_{IT} and %N-dependent N_{OT}
- Consistent N_{HT}/N_{IT} decomposition





- N_{IT} relaxation is slow and consistent with R-D theory
- Non-universal AC/DC ratio for nitrided transistors



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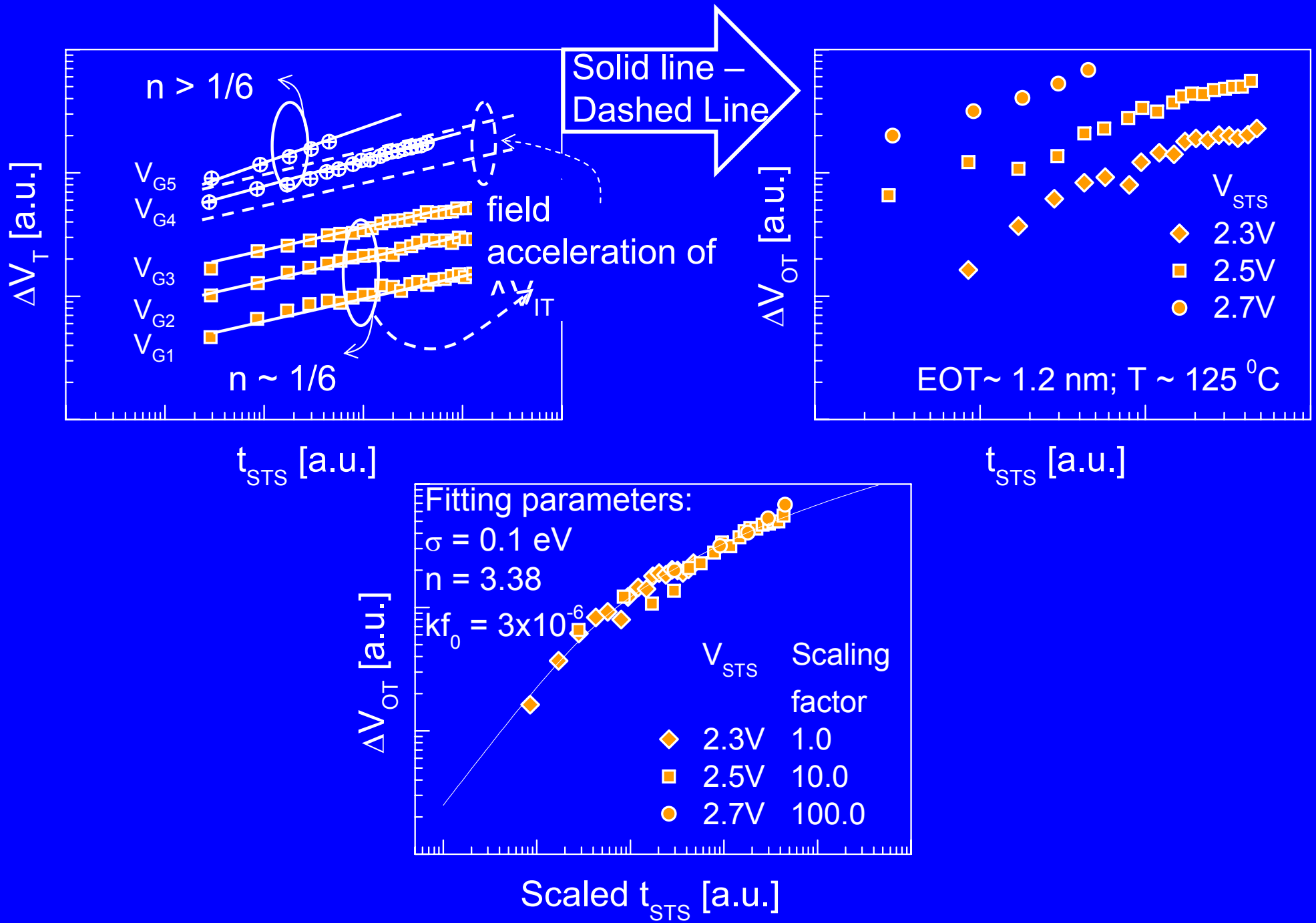
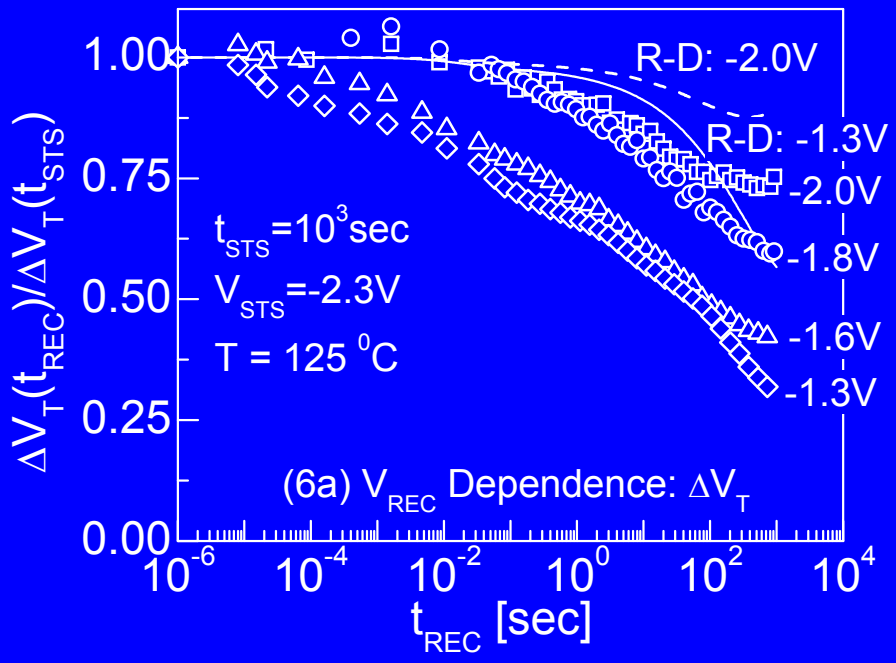
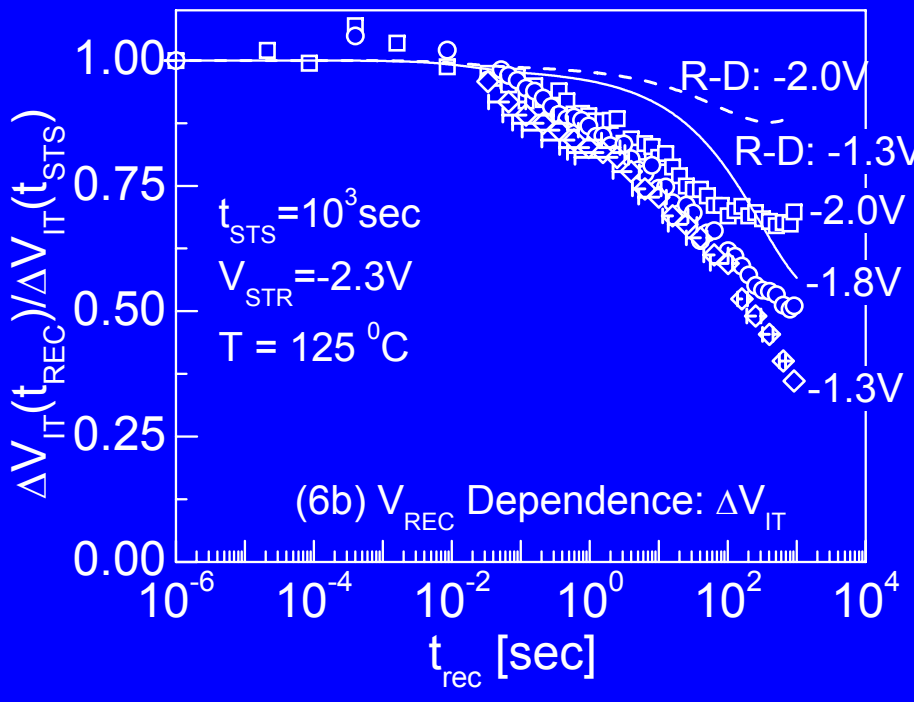
Back Up Slides ……

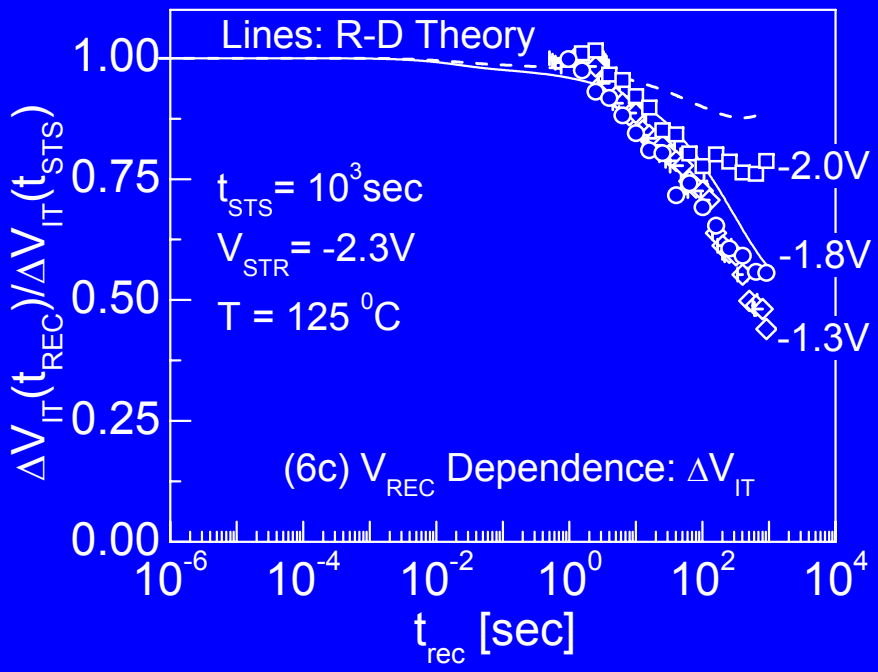
Universality in Oxide Defect Generation



Hole Detrapping: Generated Defect







Hole Detrapping Sites