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ECE695: Reliability Physics of Nano-Transistors

Lecture 26-2: Statistics of soft breakdown (Breakdown Position correlation)

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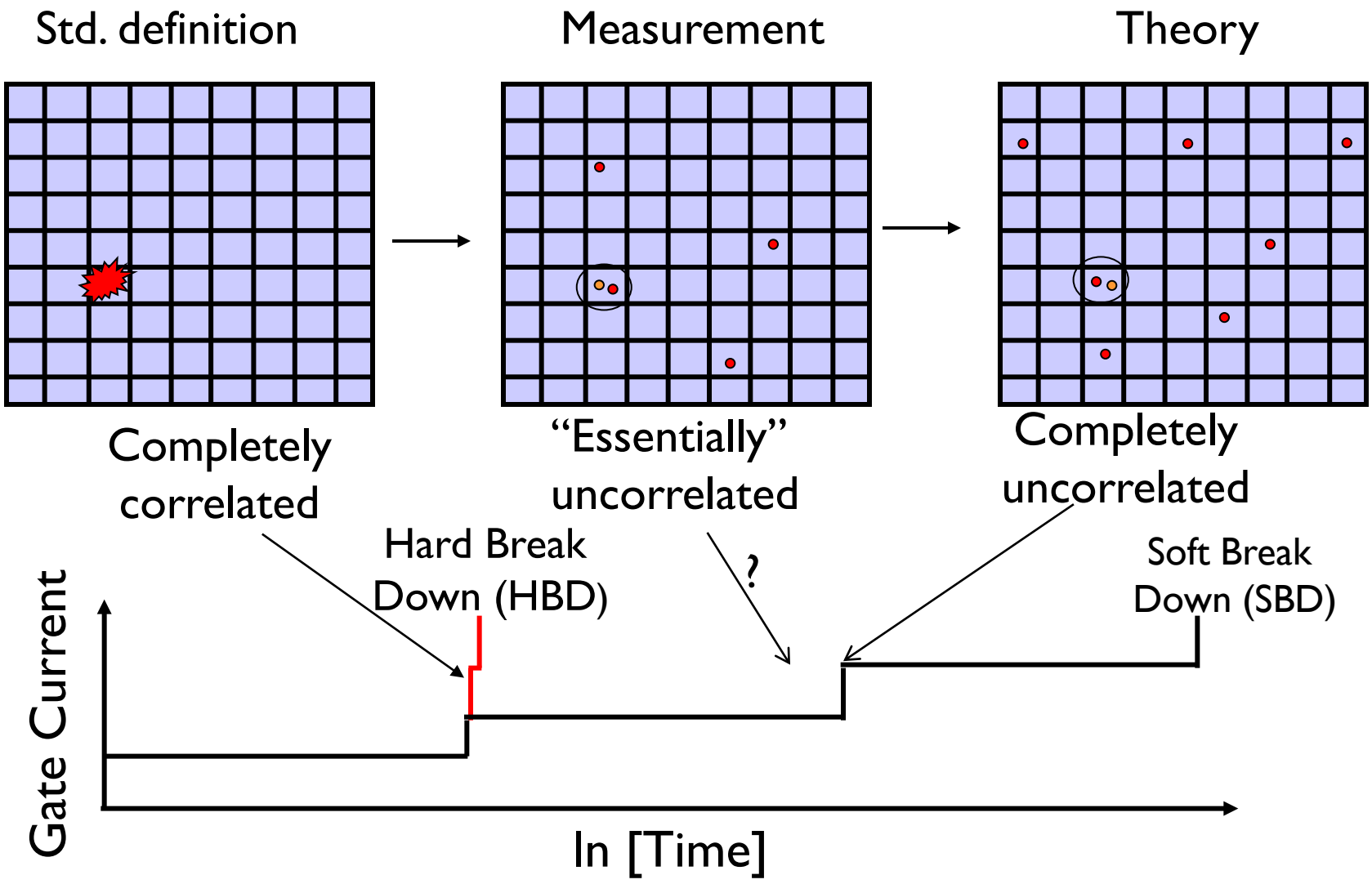
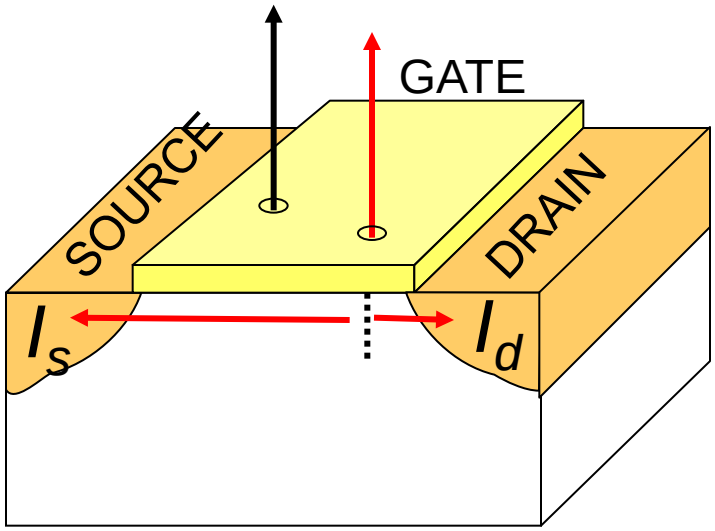
Outline

1. Position and time correlation of BD spot
2. How to determine the position of the BD Spot
3. Position correlation in BD spots
4. Why is localization so weak?
5. Conclusions

Soft BD improves Dielectric Lifetime



Drift and Diffusion in a MOSFET

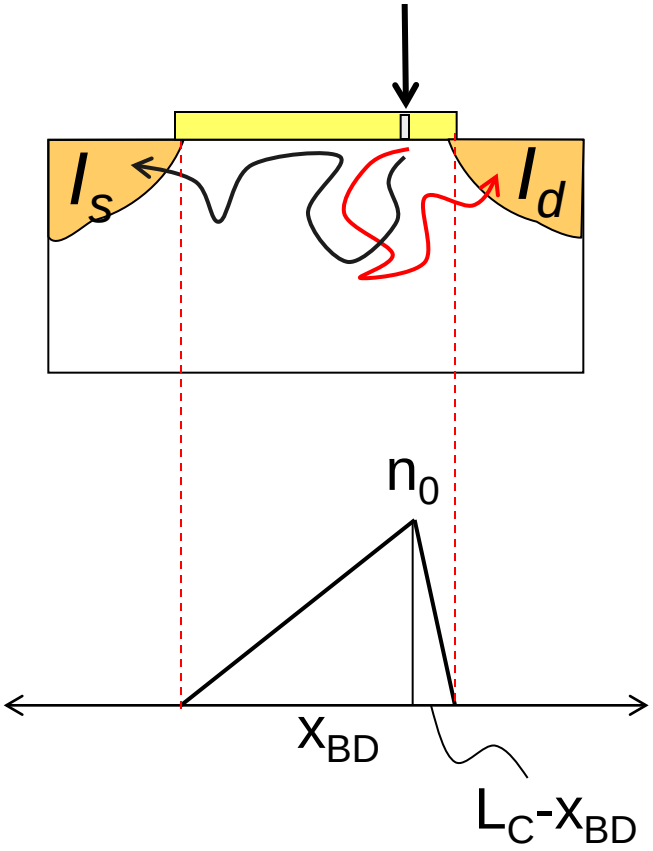


$$J_n = qD\nabla n + qn\mu\nabla\phi$$

$$\nabla \bullet J_n = 0$$

$$D\nabla^2 n + \mu\nabla(n\nabla\phi) = 0$$

A Simple Derivation of Current-Ratio Method



$$D\nabla^2 n + \mu\nabla(n\nabla\phi) = 0$$

$$D\frac{d^2n}{dx^2} = 0$$

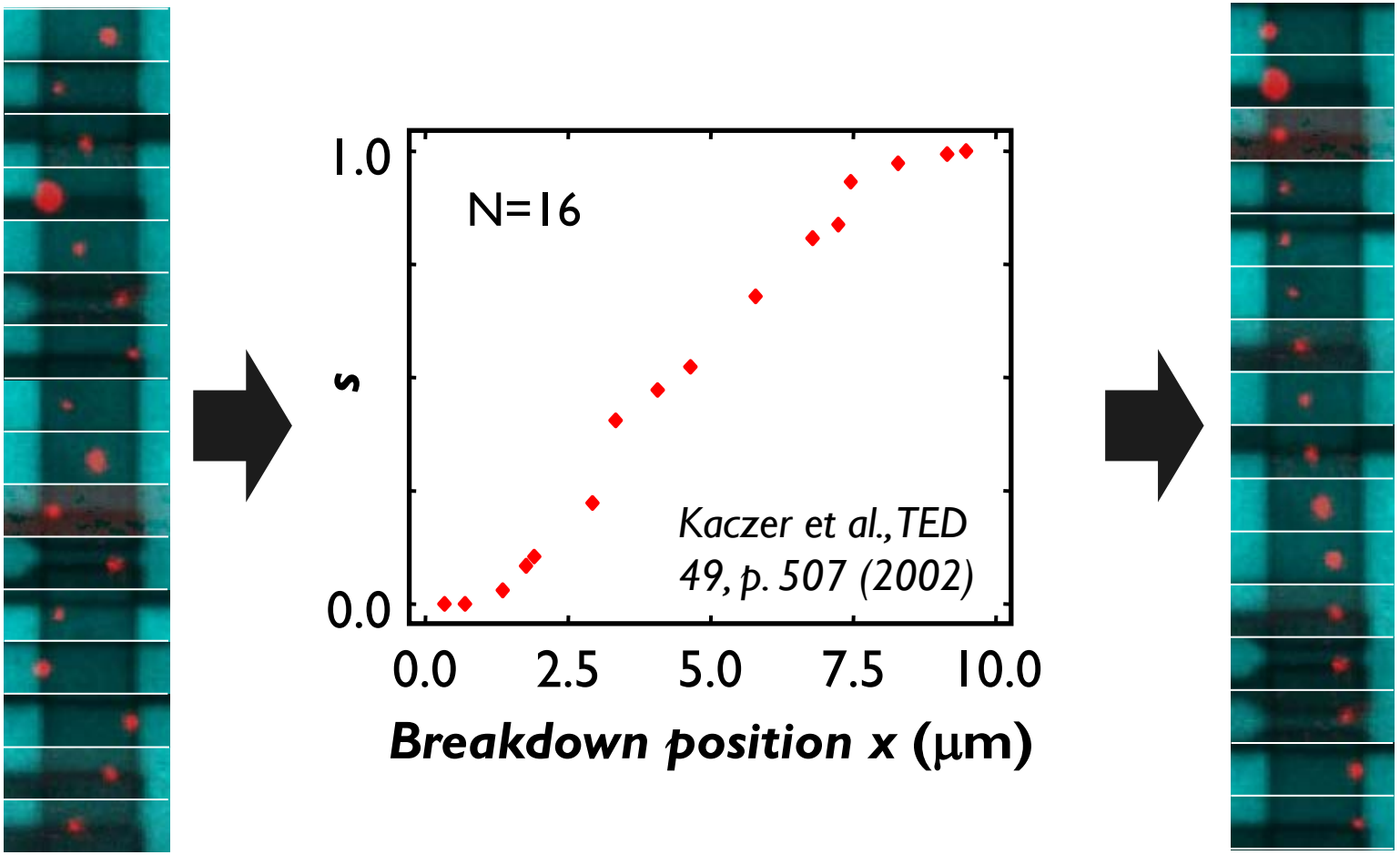
$$n = Ax + B$$

$$I_s = qWD\frac{n_0}{x_{BD}}$$

$$\frac{x_{BD}}{L_C} = \frac{I_d}{I_s + I_d}$$

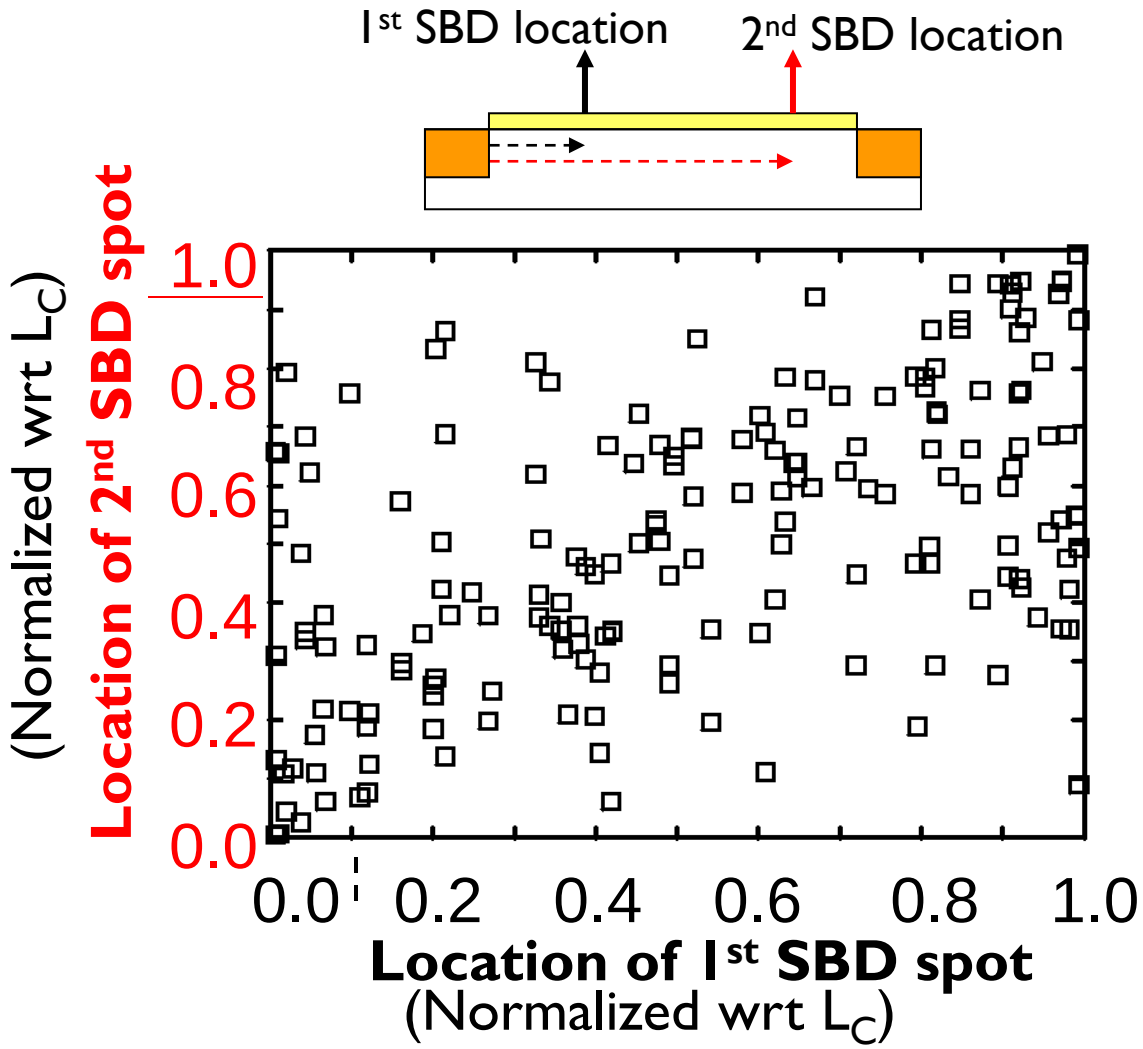
Works in accumulation, because diffusion is dominant !

BD Position randomly distributed over channel



Emission microscopy on L=10 μm nFETs confirms the BD position determination method.

Spatial correlation: measurements



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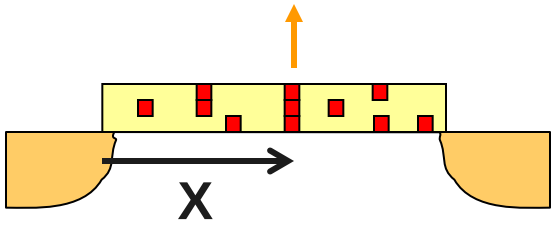
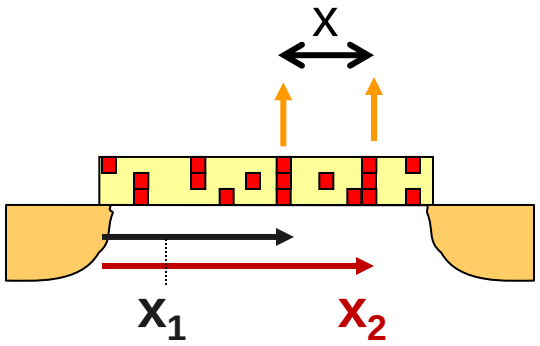
Spatial correlation: Theory



$$P(x_1 < x) = x$$

Uncorrelated trap generation

→ random loc. for 1st BD

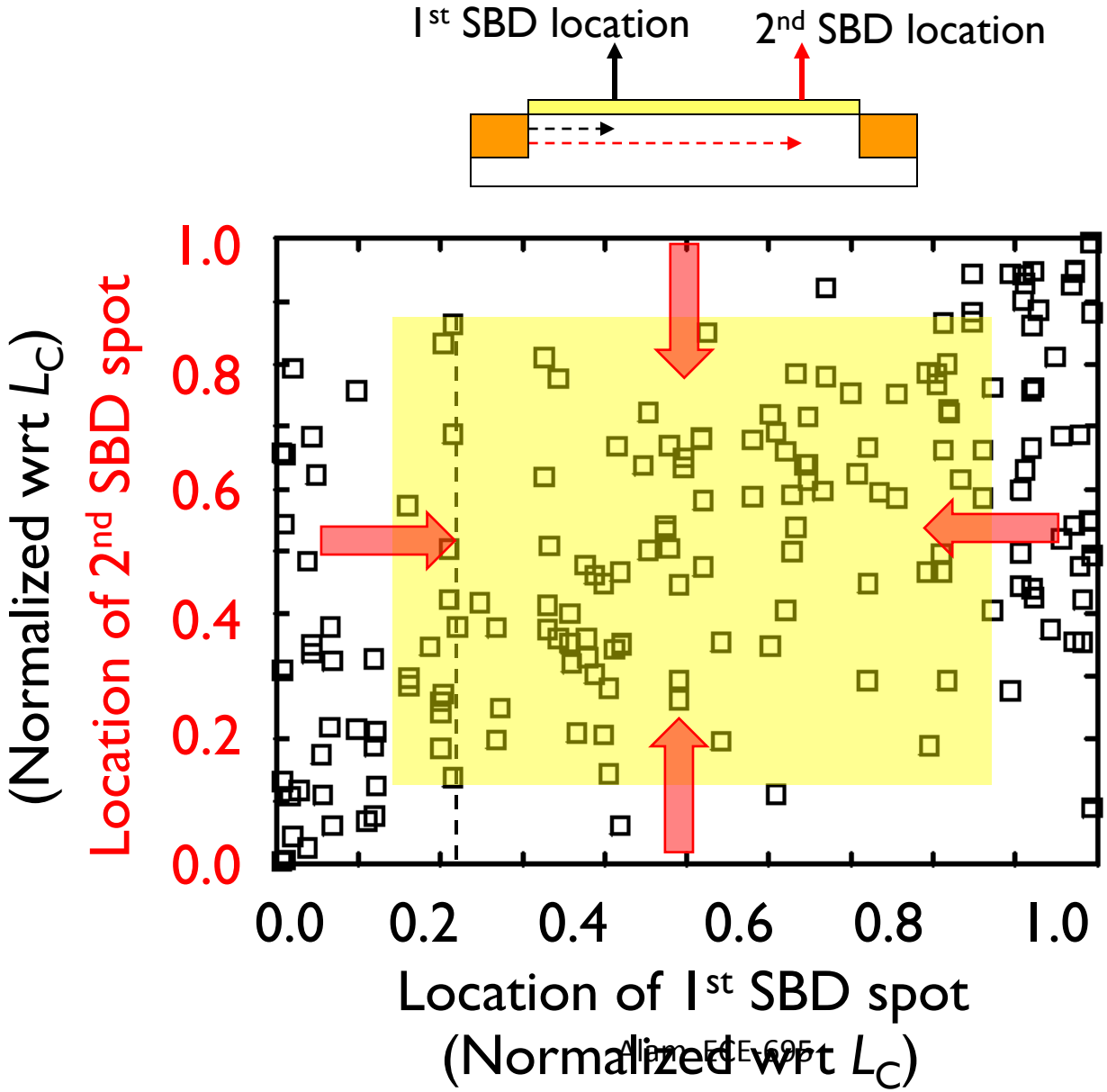


$$P_2(|x_1 - x_2| < x) = 2x - x^2$$

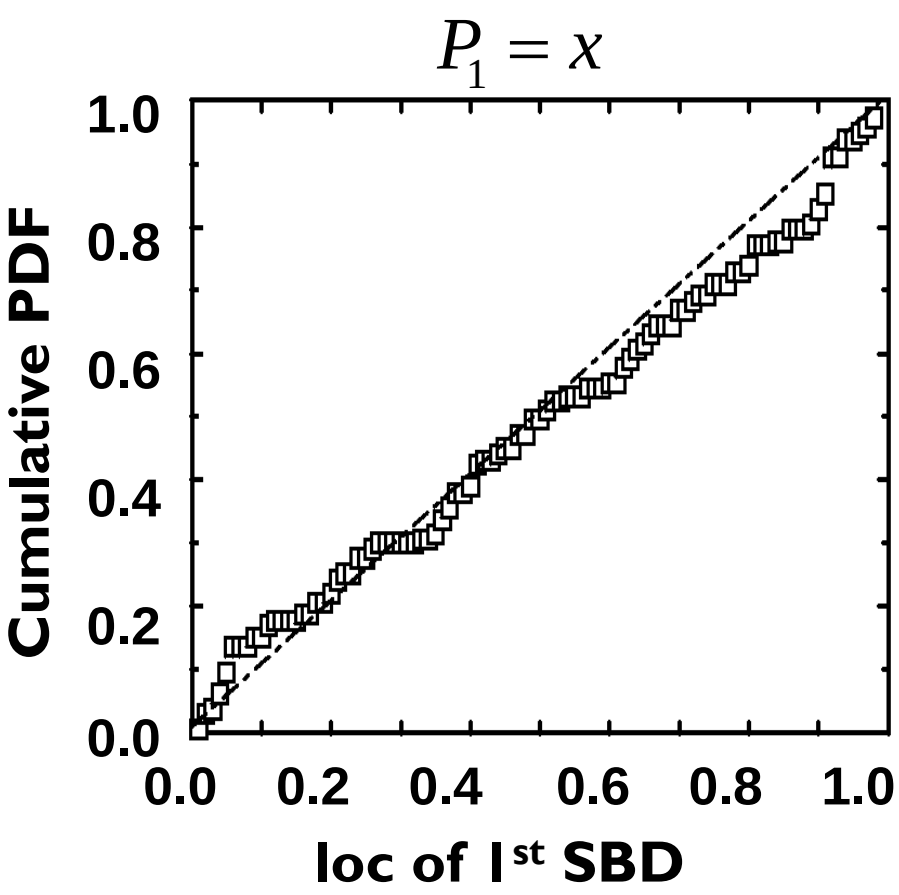
Uncorrelated trap generation

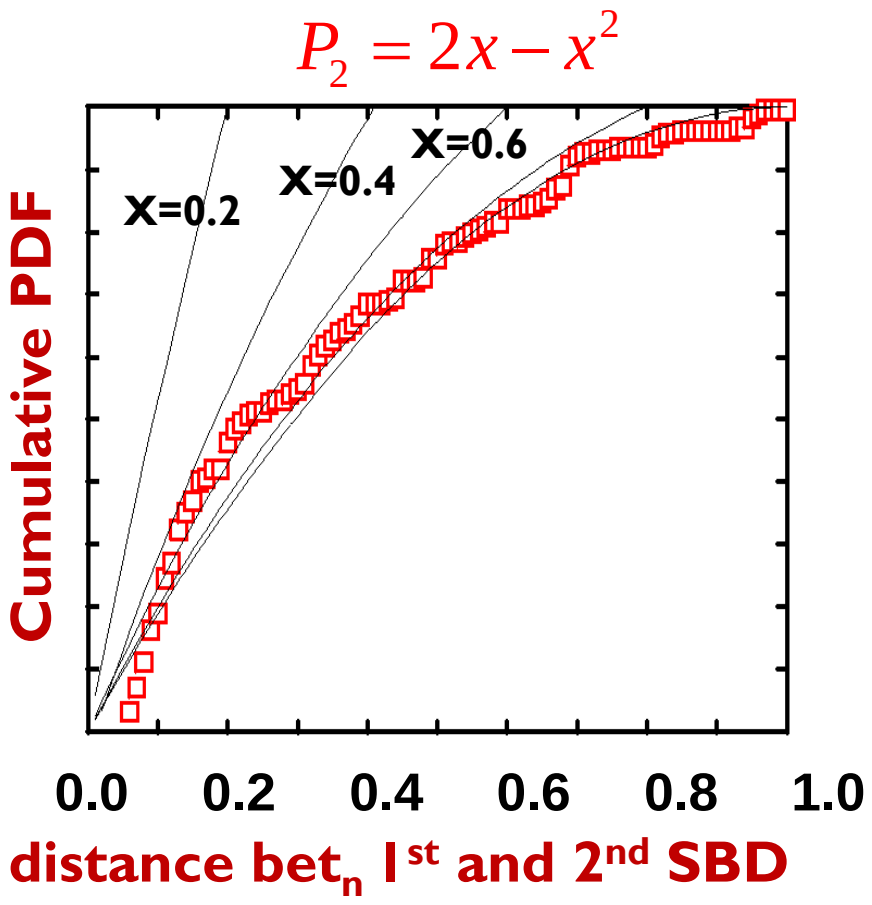
→ random loc. for 1st and 2nd BD

Rationale for S/D region exclusion



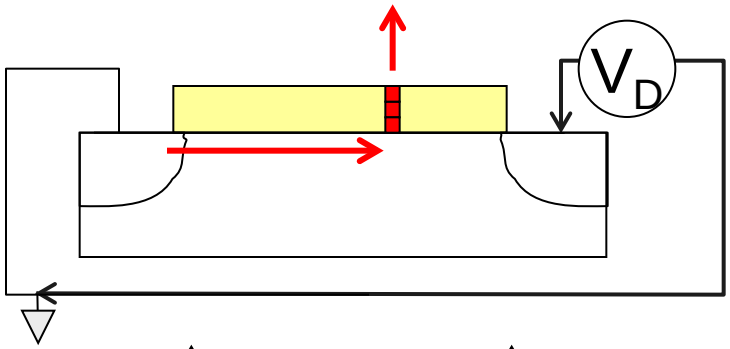
Spatial correlation: analysis

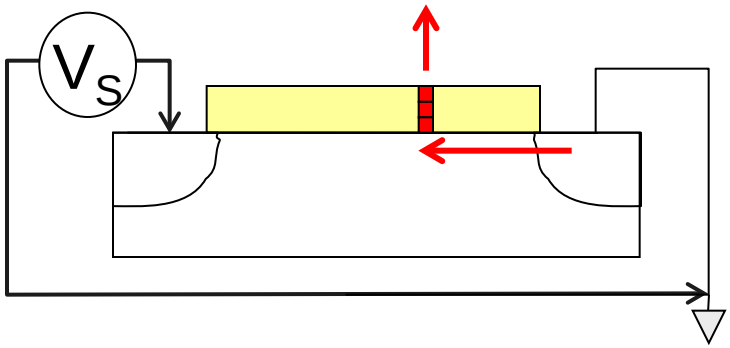


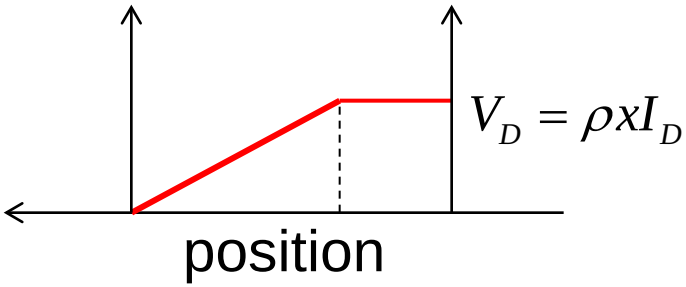


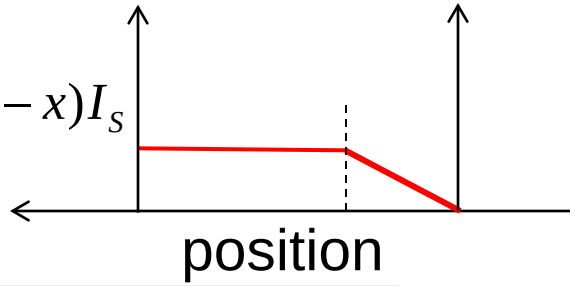
Trap generation is spatially uncorrelated (essentially)!

Measurement in Inversion ? Voltage-Ratio Method









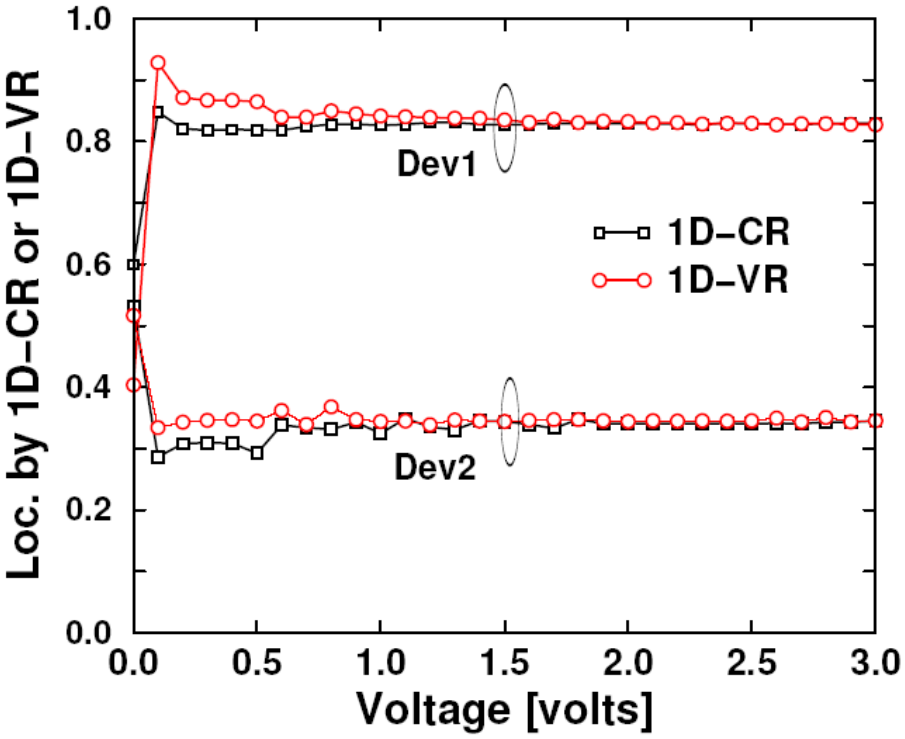
$$J = D\frac{dn}{dx} + ne\mu E \quad \nabla \bullet J = 0 \quad \Rightarrow \mu\frac{d^2V}{dx^2} = 0$$

$$V_D = \rho x I_D \quad \& \quad V_S = \rho(L-x)I_S$$

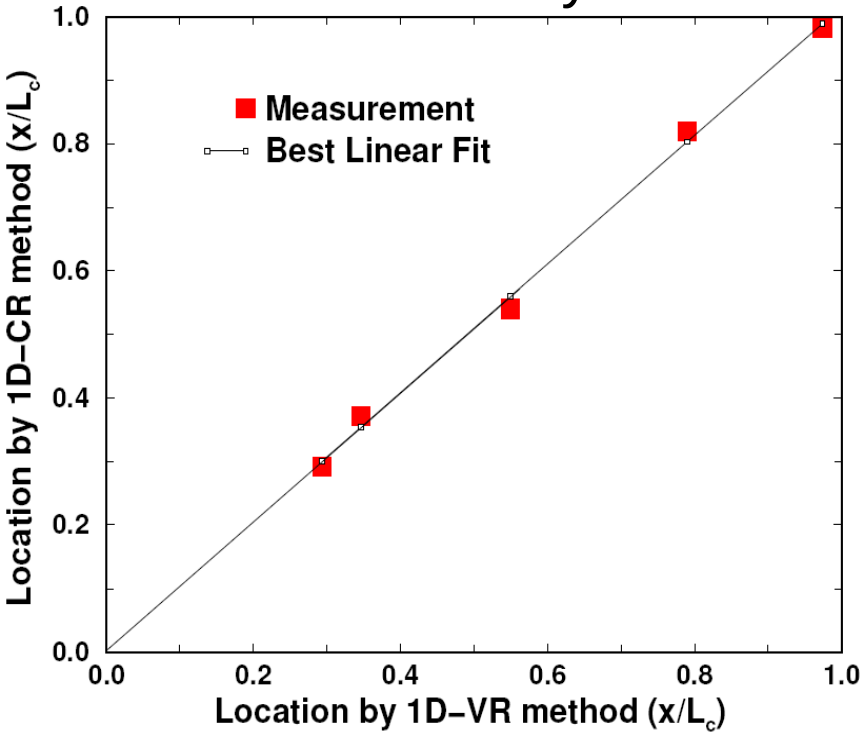
$$\frac{x}{L} = \frac{V_D I_D}{V_S I_S + V_D I_D}$$

Voltage-Ratio and Current-Ratio methods compared

For all gate biases



…. and for many devices

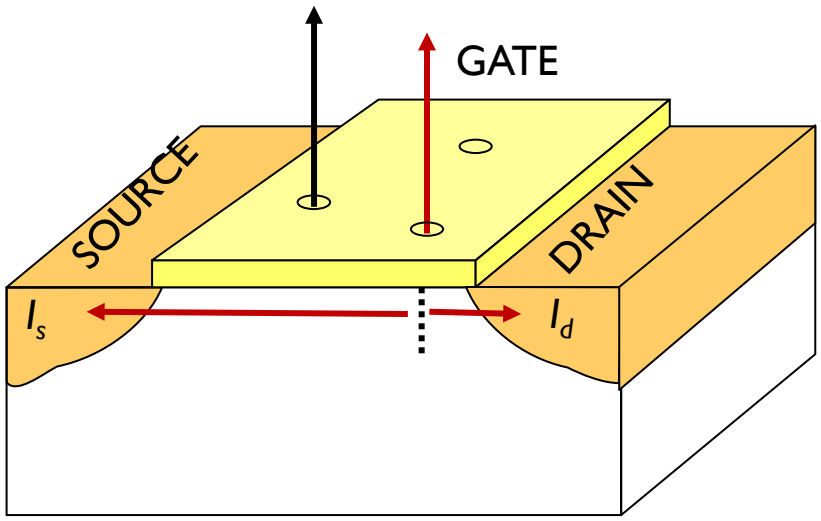


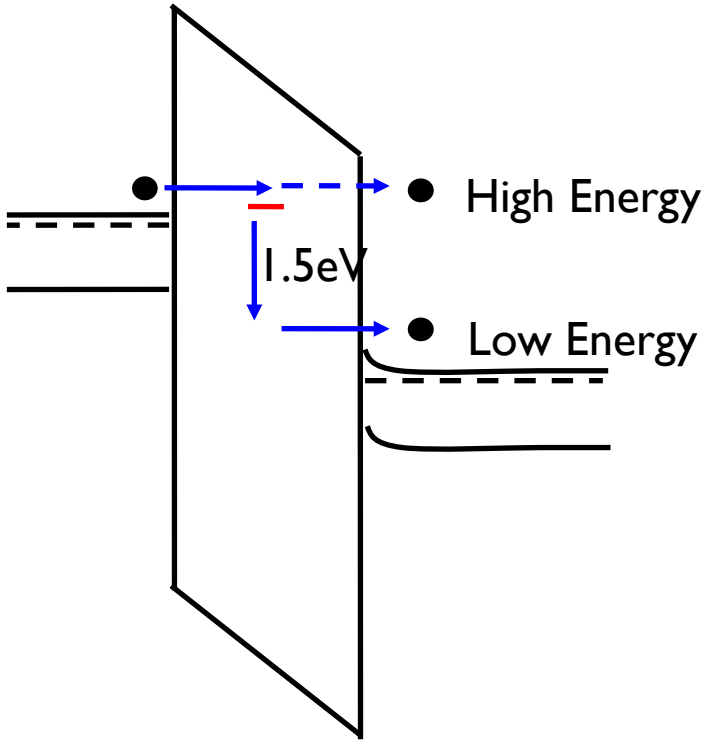
Theory is robust, suitable for generalization to 2D.

Outline

1. Theory of correlated Dielectric Breakdown
2. Excess leakage as a signature of correlated BD
3. How to determine the position of the BD Spot
4. Why is localization so weak?
5. Conclusions

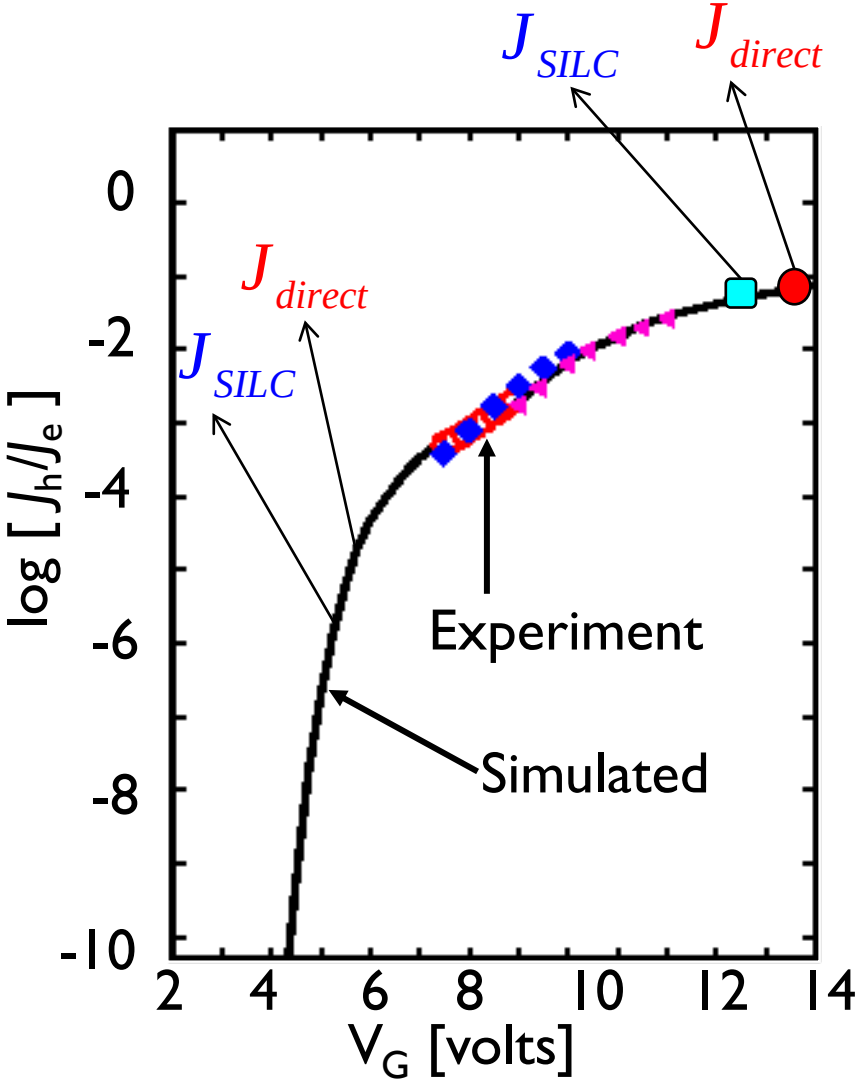
Recall: Quantum Yield (QY) Measurement





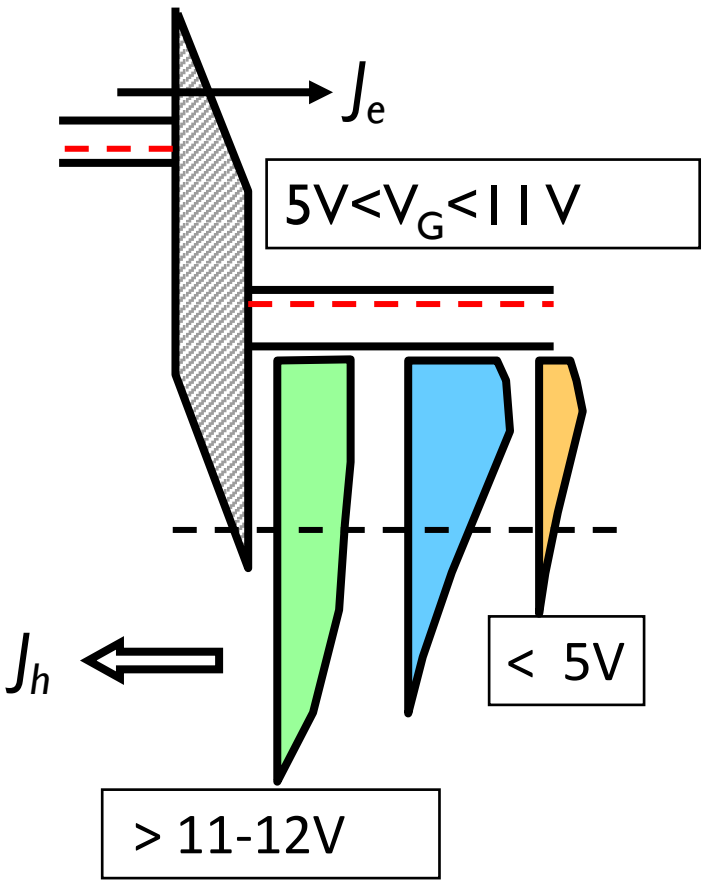
Apparently there is a structural relaxation for oxide defects …

Recall: Understanding the Hole Fluxes



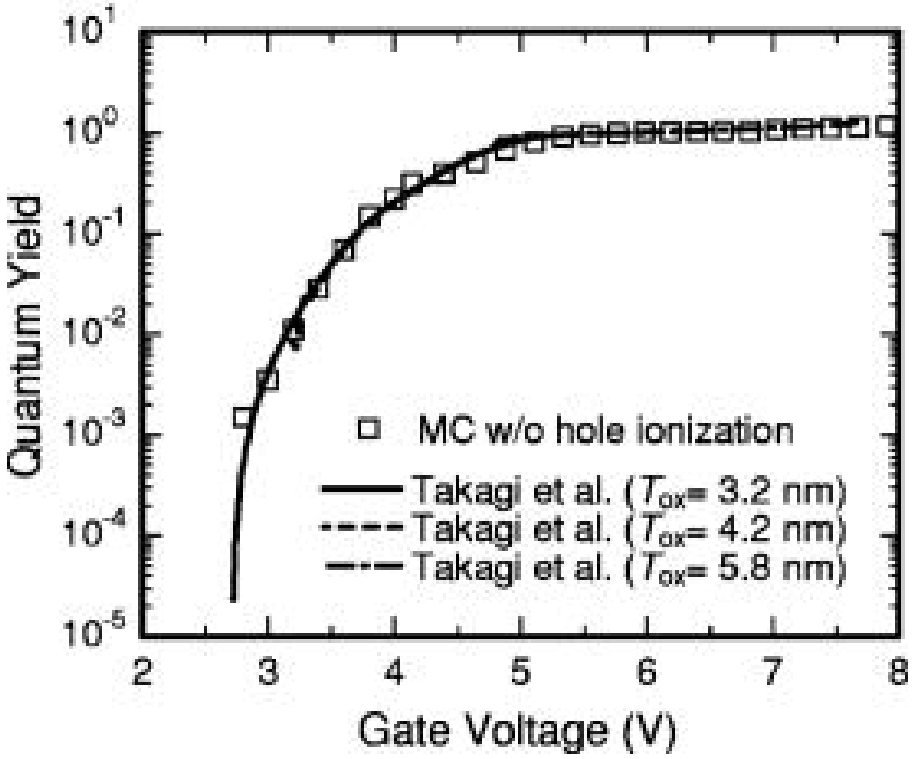
SILC: stress-induced-leakage-current

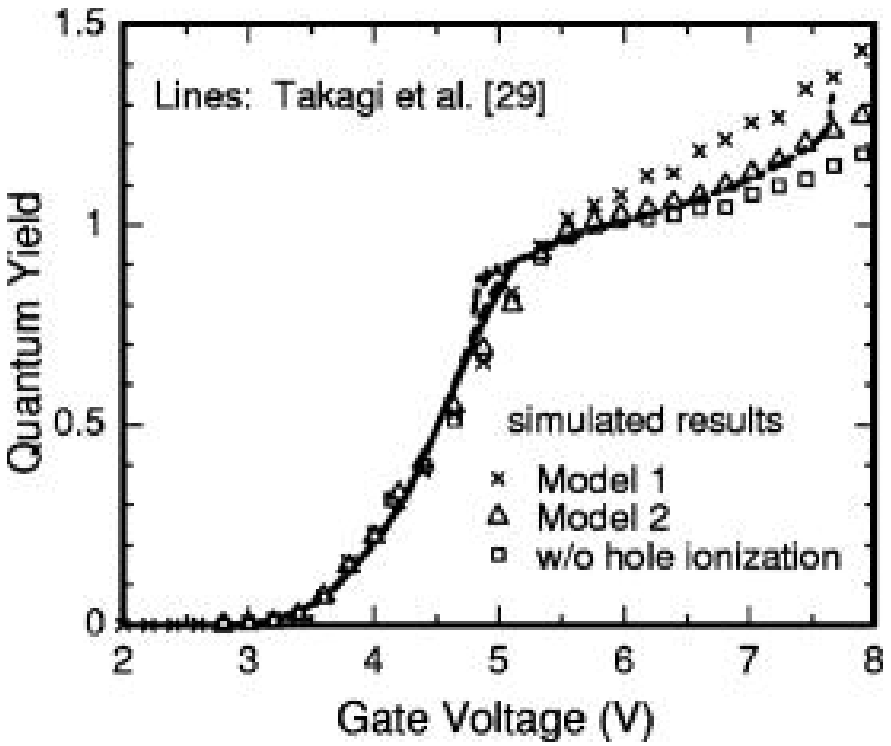
C. Hu, JAP, 1985



Kamakura, JAP, 2001

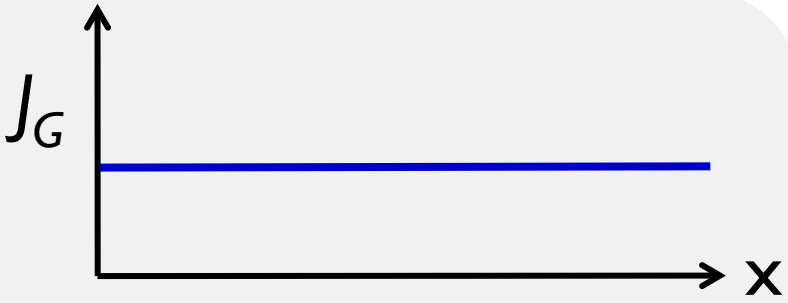
Dependency of QY on gate voltage



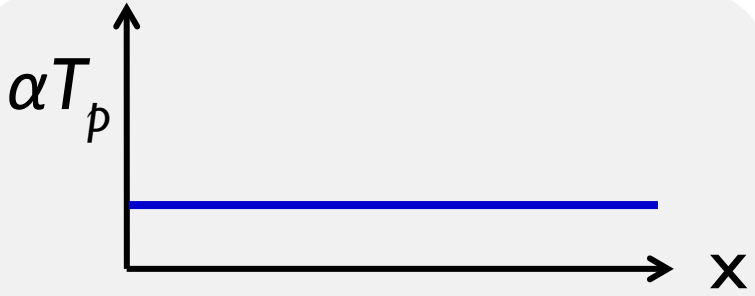


Efficiency of hole generation is reduced dramatically at low voltage

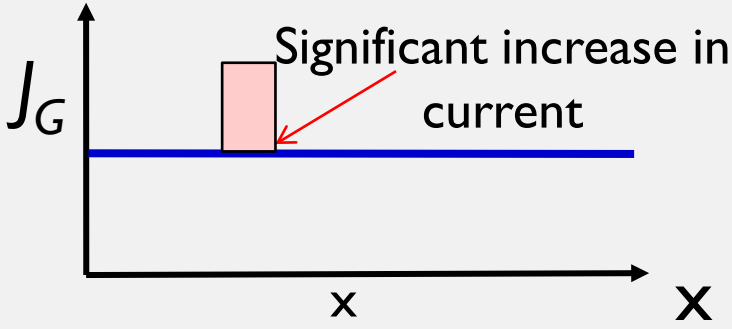
Review of localization (Weak Localization)



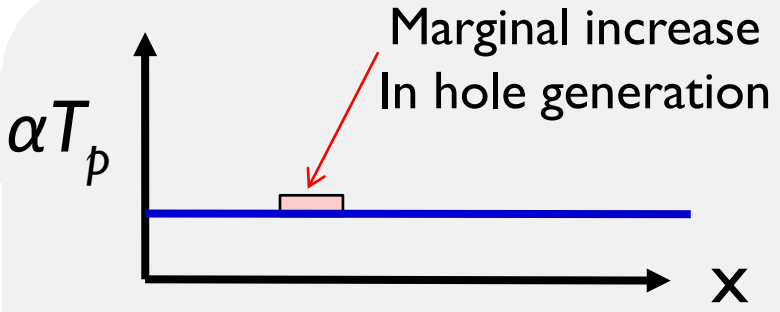
Electron current before oxide trap generation in the channel



Hole injection before oxide trap generation in the channel



Electron current after oxide SBD in the channel



Hole injection after oxide SBD in the channel

Conclusions

- An algorithm of determining both in time and position correlations is discussed. We find that in classical MOSFET, the correlation is weak.

- Leakage current provides a methodology of determining Weibull factor, voltage acceleration, and correlation factors just by using few devices at very low voltages.

- Energy relaxation during tunneling through the defects is an important part of the puzzle for dielectric breakdown. Without such relaxation, defect generation will be localized. In thick oxides, such localization does occur, but fortunately, not so for thin oxides.

References

- The position correlation and the theory of BD spots are discussed in "Theory of Current-Ratio Method for Oxide Reliability: Proposal and Validation of a New Class of Two-Dimensional Breakdown-Spot Characterization Techniques," M. Alam, D. Monroe, B. Weir, and P. Silverman, Proceedings of International Electron Device Meeting, 2005.

- 2D BD-position also discussed in detail in "Exploratory analysis of the breakdown spots spatial distribution in metal gate/high-K/III–V stacks using functional summary statistics" by E. Miranda, E. O'Connor, P.K. Hurley. Microelectronics Reliability, 50, 1294, 2010.

- Time correlation are discussed by Alam and Smith, "A Phenomenological theory of multiple correlated SBD events", Proc. IRPS, 2003.
- A wonderful historical context of the Markov Chain theory is discussed by B. Hayes in American Scientist, First links in Markov Chain, 2013. http://www.americanscientist.org/libraries/documents/201321152149545-2013-03Hayes.pdf

Review Questions

1. Why do we care about correlation in defect generation?
2. What is the difference between time-correlation vs. spatial correlation?
3. Do you expect Weibull slope to change if the defect generation is correlated?
4. Can you explain physically how leakage in a single device can be used to calculate the Weibull slope ? Which method does this remind you of regarding HCI degradation?
5. The position of the BD spot was analyzed by 1D diffusion equation. What is wrong with the analysis?
6. What does the phrase Iddq refer to? Where were it first used?
7. How do Iddq change NBTI, HCI, and TDDB degradation?