ECE695: Reliability Physics of Nano-Transistors
Lecture 26-2: Statistics of soft breakdown
(Breakdown Position correlation)

Muhammad Ashraful Alam
alam@purdue.edu
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

- **Std. definition**
  - Completely correlated

- **Measurement**
  - “Essentially” uncorrelated

- **Theory**
  - Completely uncorrelated

- **Graph**
  - Gate Current vs. In [Time]
  - Hard Break Down (HBD)
  - Soft Break Down (SBD)

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Drift and Diffusion in a MOSFET

\[ J_n = qD\nabla n + qn\mu\nabla \phi \]
\[ \nabla \cdot J_n = 0 \]
\[ D\nabla^2 n + \mu \nabla (n\nabla \phi) = 0 \]
A Simple Derivation of Current-Ratio Method

Works in accumulation, because diffusion is dominant!

\[ D \nabla^2 n + \mu \nabla (n \nabla \phi) = 0 \]
\[ D \frac{d^2 n}{dx^2} = 0 \]
\[ n = Ax + B \]
\[ I_s = qWD \frac{n_0}{x_{BD}} \]
\[ \frac{x_{BD}}{L_C} = \frac{I_d}{I_s + I_d} \]
Emission microscopy on $L=10 \, \mu m$ nFETs confirms the BD position determination method.

BD Position randomly distributed over channel

$N=16$

$s$

$0.0 \quad 2.5 \quad 5.0 \quad 7.5 \quad 10.0$

Breakdown position $x$ (\(\mu m\))


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Spatial correlation: measurements

I\textsuperscript{st} SBD location

2\textsuperscript{nd} SBD location

Location of I\textsuperscript{st} SBD spot

Location of 2\textsuperscript{nd} SBD spot

(Normalized wrt \( L_c \))

(Normalized wrt \( L_c \))

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Spatial correlation: Theory

Uncorrelated trap generation
→ random loc. for 1st BD

\[ P(x_1 < x) = x \]

Uncorrelated trap generation
→ random loc. for 1st and 2nd BD

\[ P_2(\left|x_1 - x_2\right| < x) = 2x - x^2 \]
Rationale for S/D region exclusion

1st SBD location    2nd SBD location

<table>
<thead>
<tr>
<th>Location of 1st SBD spot</th>
<th>Location of 2nd SBD spot</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>0.2</td>
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<tr>
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</tr>
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</table>

(Location of SBD spot normalized wrt $L_C$)
Spatial correlation: analysis

Trapping generation is spatially uncorrelated (essentially)!

\[ P_1 = x \]

\[ P_2 = 2x - x^2 \]
Measurement in Inversion ? Voltage-Ratio Method

\[ \nabla \cdot J = 0 \quad \Rightarrow \quad \mu \frac{d^2V}{dx^2} = 0 \]

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

\[ \frac{x}{L} = \frac{V_D I_D}{V_S I_S + V_D I_D} \]
Voltage-Ratio and Current-Ratio methods compared

For all gate biases

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 …

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Recall: Understanding the Hole Fluxes

![Graph showing hole fluxes vs. gate voltage]

\[
\log \left( \frac{J_h}{J_e} \right) \quad \text{vs.} \quad V_G \quad [\text{volts}]
\]

- **SILC**: stress-induced-leakage-current
- **C. Hu, JAP, 1985**
- **Kamakura, JAP, 2001**

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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

Electron current after oxide SBD in the channel

Hole injection before oxide trap generation in the channel

Hole injection after oxide SBD in the channel

Significant increase in current

Marginal increase in hole generation

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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


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?