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ECE695: Reliability Physics of Nano-Transistors

Lecture 1: Reliability of Nanoelectronic Devices

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Outline of lecture 1

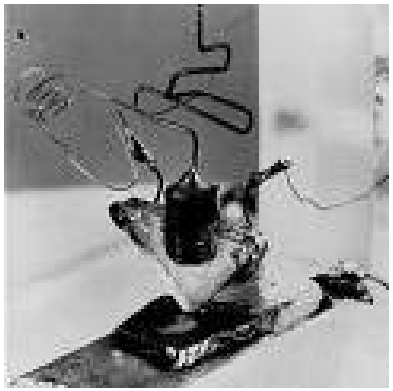
1. Evolving Landscape of Electronics
2. Performance, Variability, and Reliability
3. Classification of Reliability
4. Course Information
5. Conclusions

Technology & transistors in electronics

Vacuum Tubes

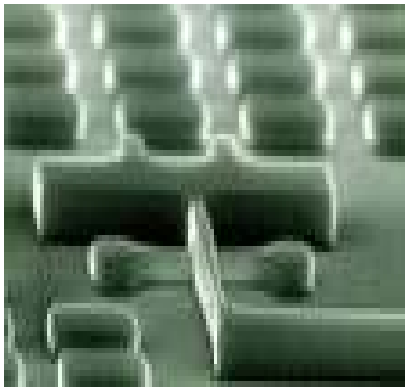
1906-1950s

Bipolar



1947-1980s

MOSFET



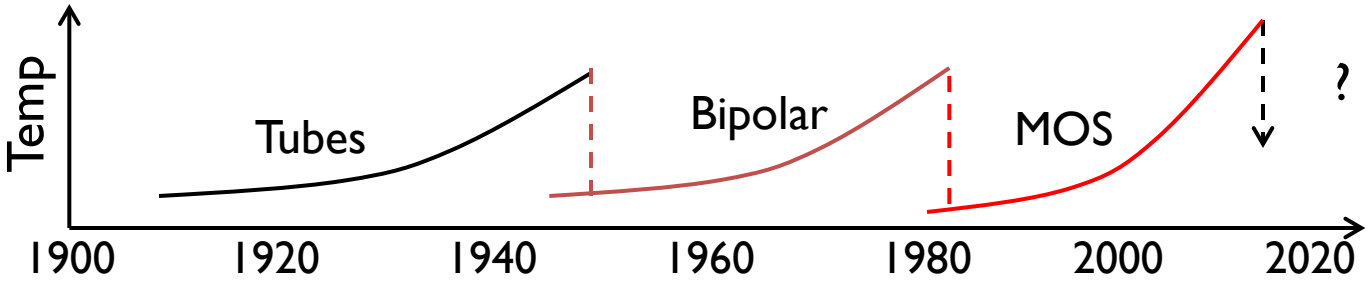
1960-until now

Now ??

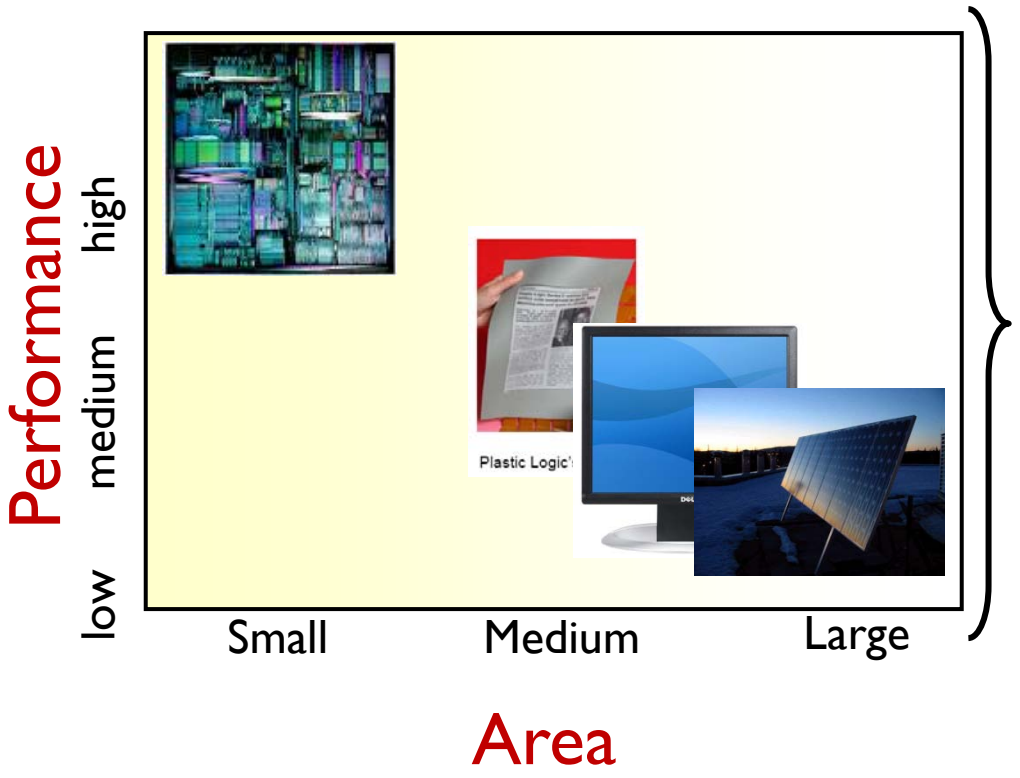
Sub-60 mV/dec Switches

Bio Sensors

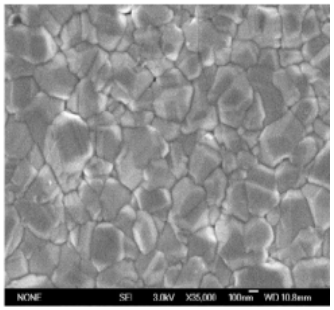
Displays ….



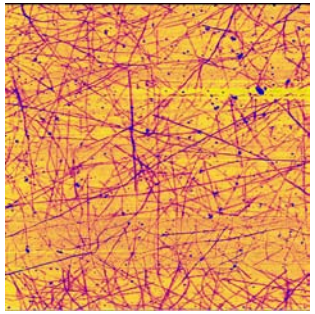
Landscape of electronics in evolving



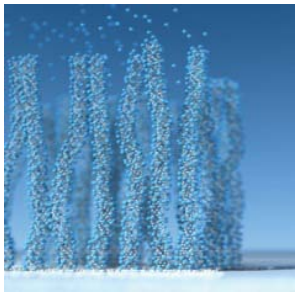
Poly-Si



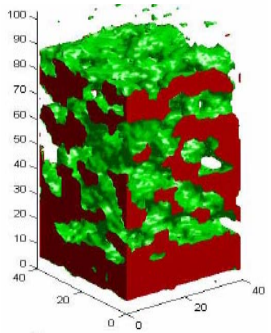
Carbon NanoNet



super-capacitors



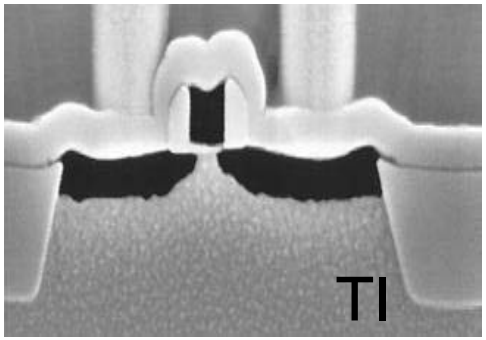
Solar cells



Electronics is a vibrant industry with many new applications

Evolution in microelectronics

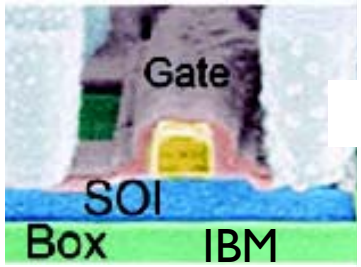
Mobility improvement by new materials (Ion)



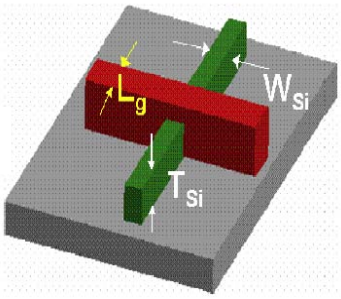
- Strained silicon
- Ge channel
- III-V materials

Electrostatics improvement by new device geometry (Ion/Ioff)

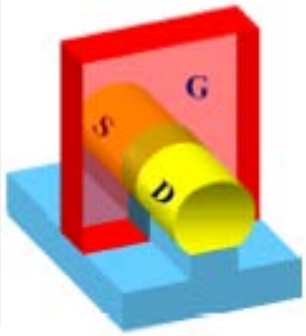
SOI



FINFET



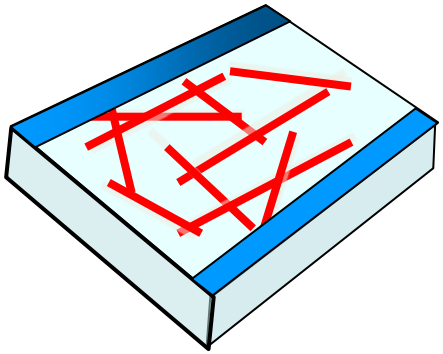
NW



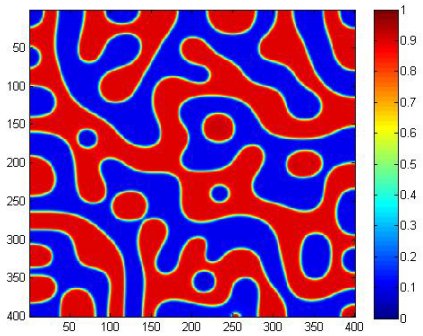
- Silicon on insulator (SOI)
- Tri-gate (e.g. FINFET)
- Surround gate (e.g. NW)

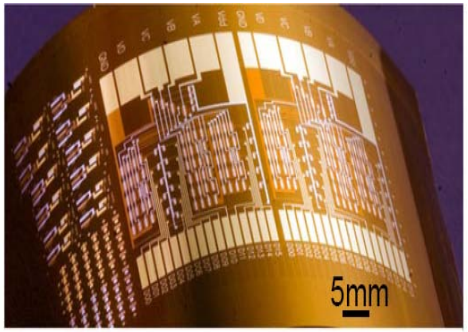
Evolution in large area electronics

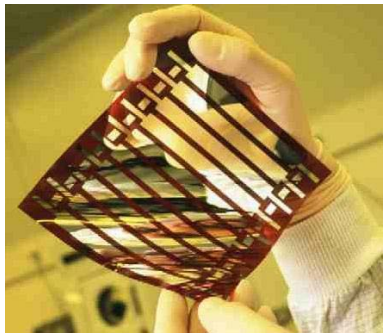
Flexible Electronics



Organic Solar Cells







New materials for novel devices enhance performance, but also accentuate reliability concerns

Outline

1. Landscape of Electronics: Performance
2. Performance, Variability, and Reliability
3. Classification of Reliability
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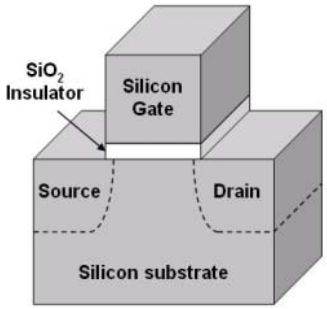
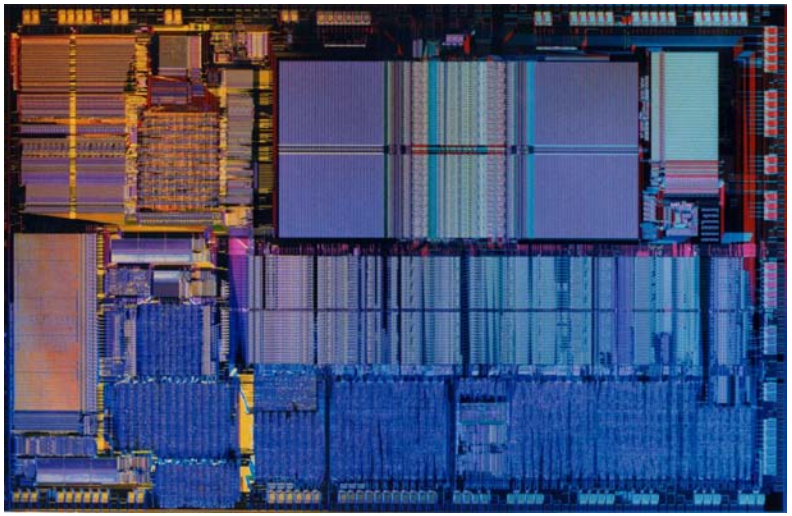
Uniformity of Components in Systems

Maudslay (1800),
Whitworth (1841),
Sellers (1864)

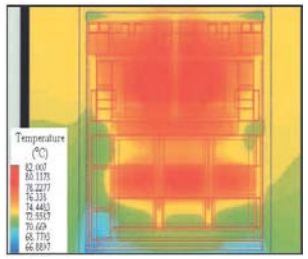


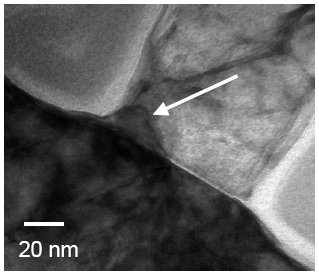


Building large systems presumes uniformity of components ....

Process, reliability, and design

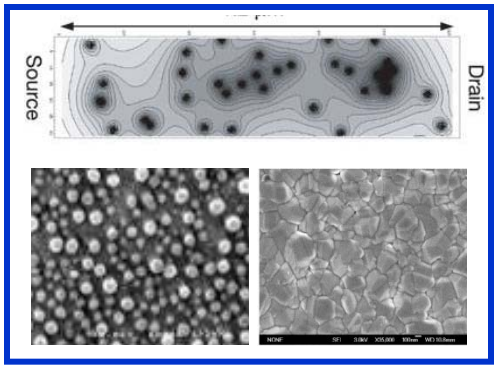
Reliability

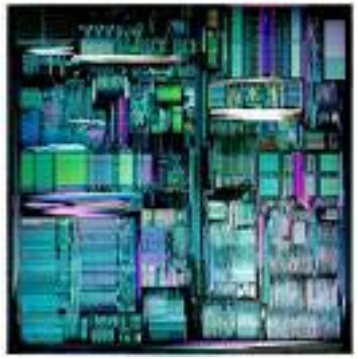


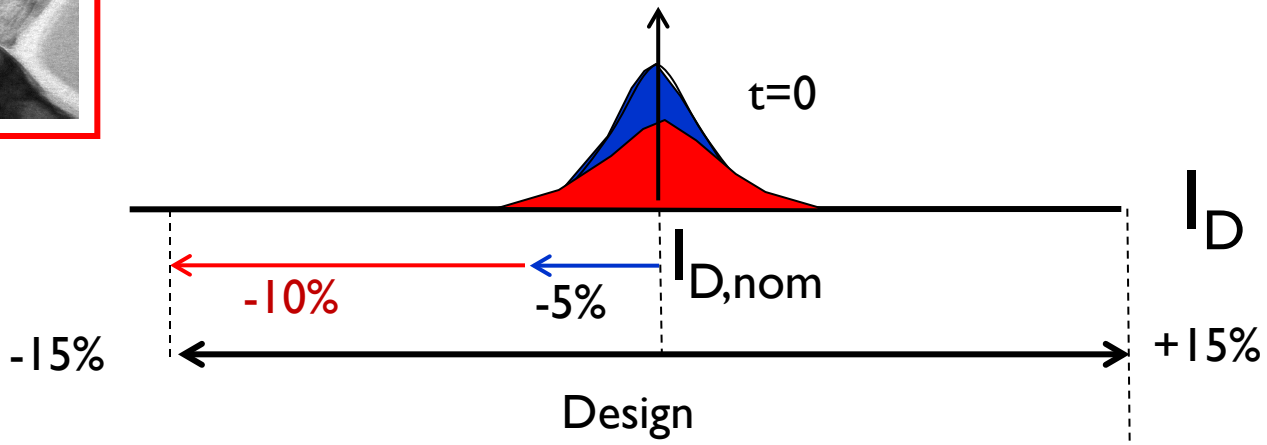


plus

Process



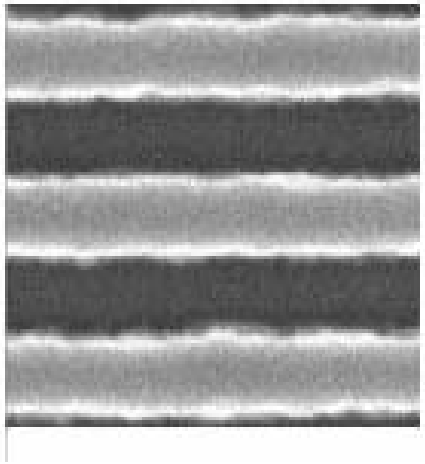




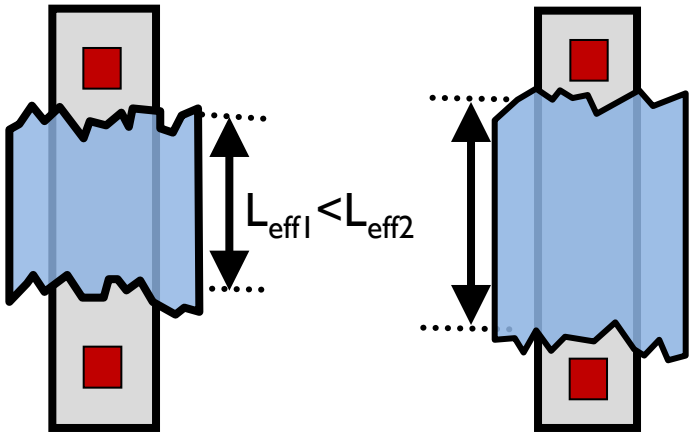
We do not have too much margin

Process variations in scaled transistors

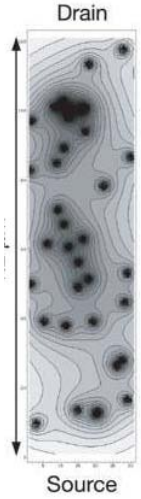
1) Line Edge Roughness

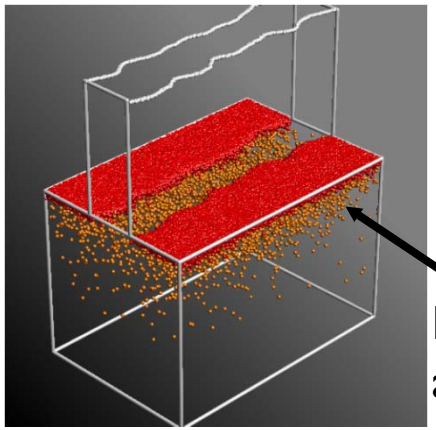


A. Asenov, TED03



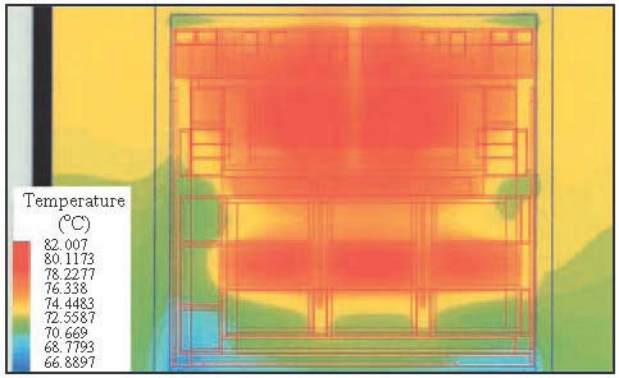
2) Random Dopant Fluctuations



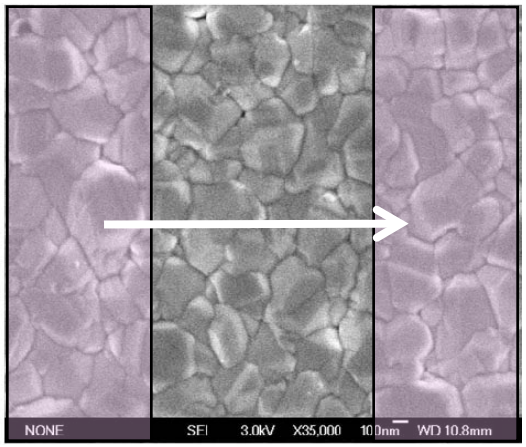


M. Hane, et. al., SISPAD 2003

3) Non-uniform Temperature



Solar cells and display electronics



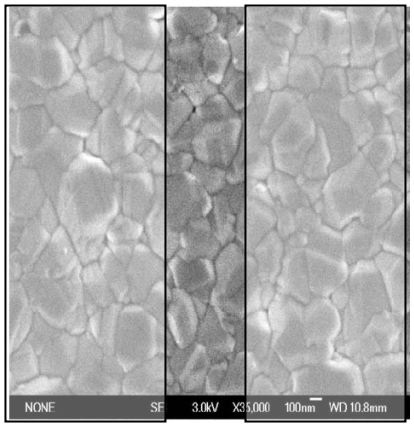
Key issues:

Transport through barriers created by grain boundaries

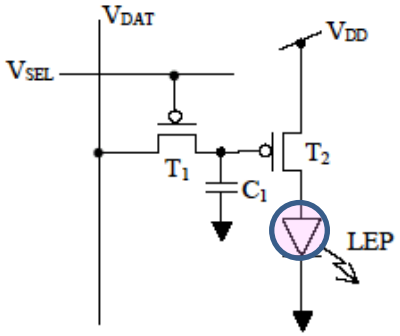
Device/device fluctuation

Process variation: thin film transistors

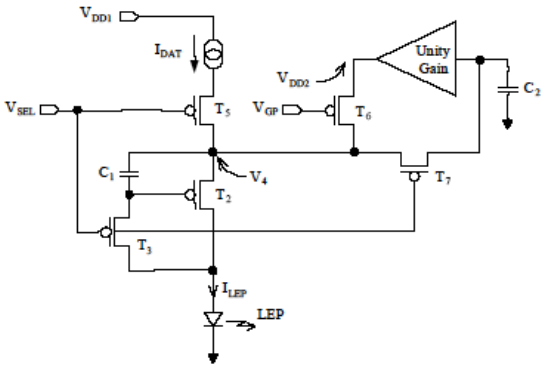
Modern poly TFT is reaching dimensions of a single grain



..... makes pixel design increasingly complicated



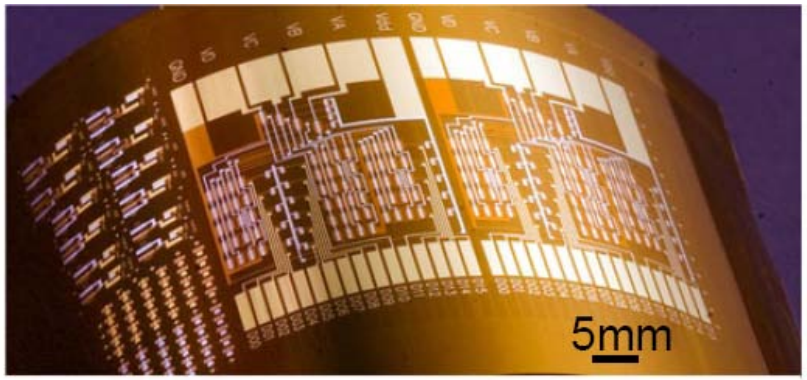
Old pixel



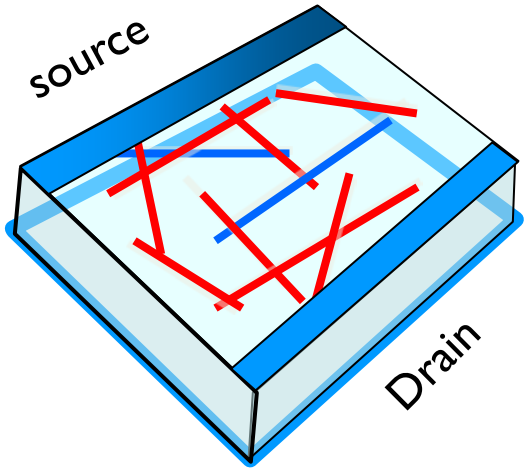
Modern pixel

Simon Tam, IEDM, 2002

Flexible nanonet electronics

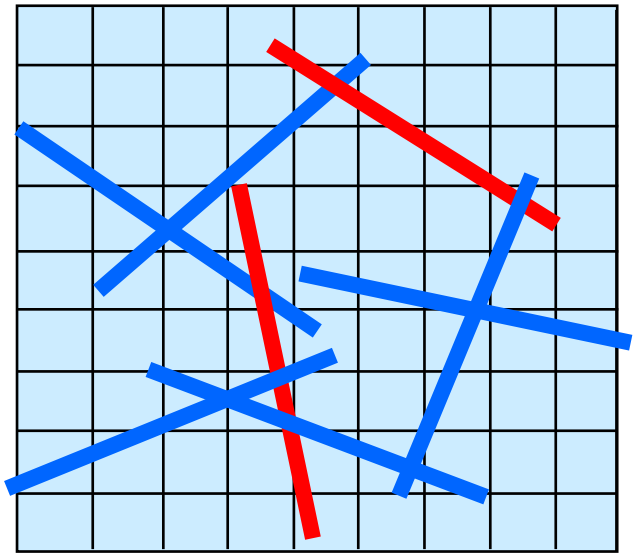


Cao, Nature, 2008

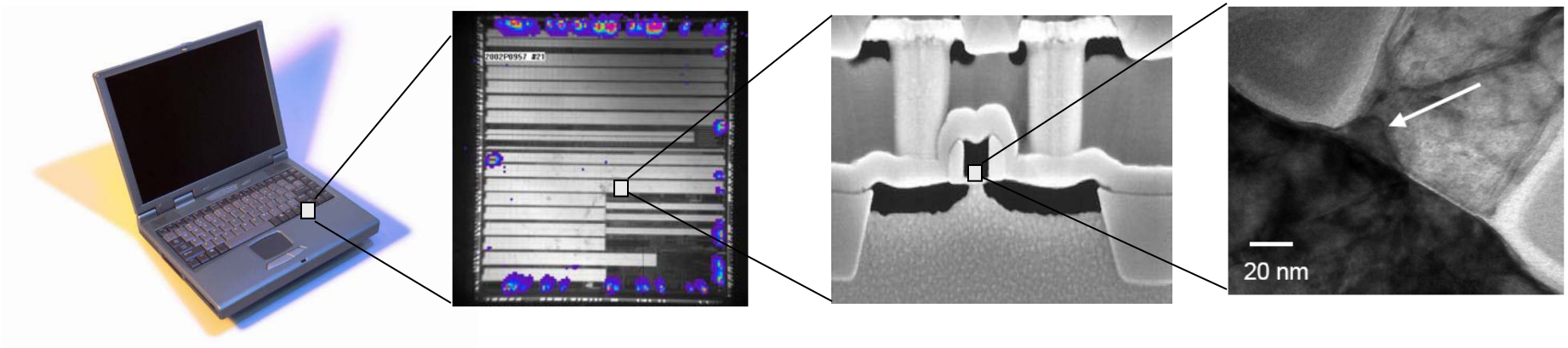


Metallic and semiconducting tubes

Heterogeneous percolation



Reliability: time dependent degradation



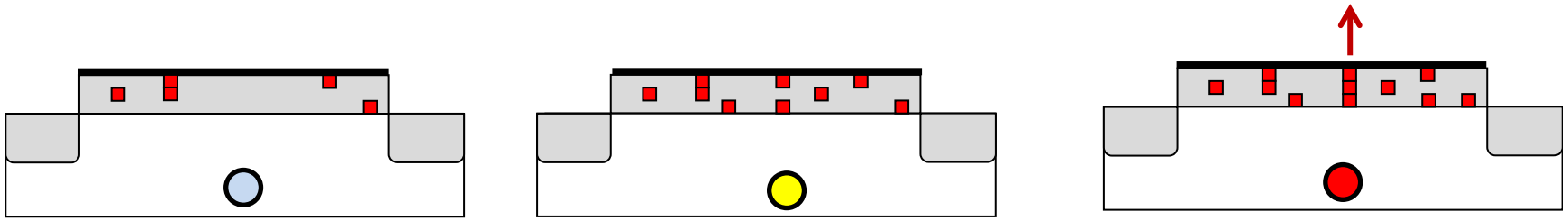
A manufacturer bets the company of the physics of reliability …..

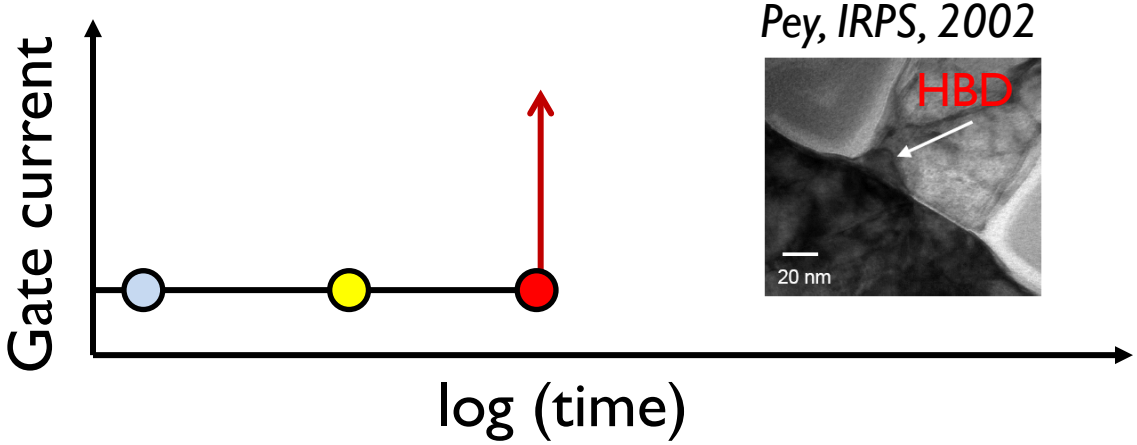
… because the ICs operate in incredibly harsh conditions, turning on and off trillions of time during its lifetime ….

… because the lines can open, the source/drain can be shorted, the gate oxide can break ….

Design for reliability

Time dependent dielectric breakdown



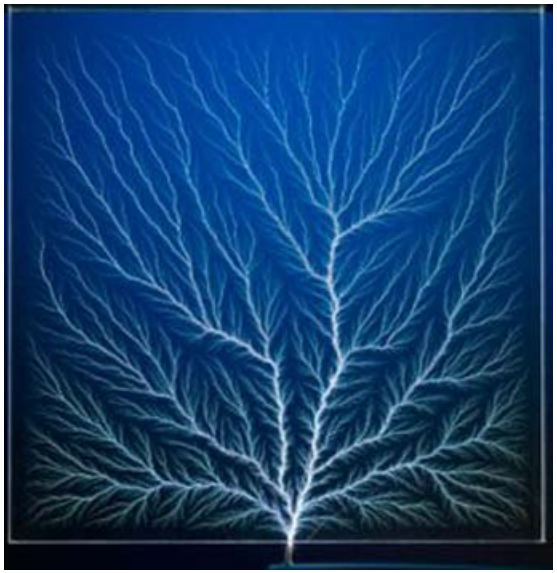


Pey, IRPS, 2002

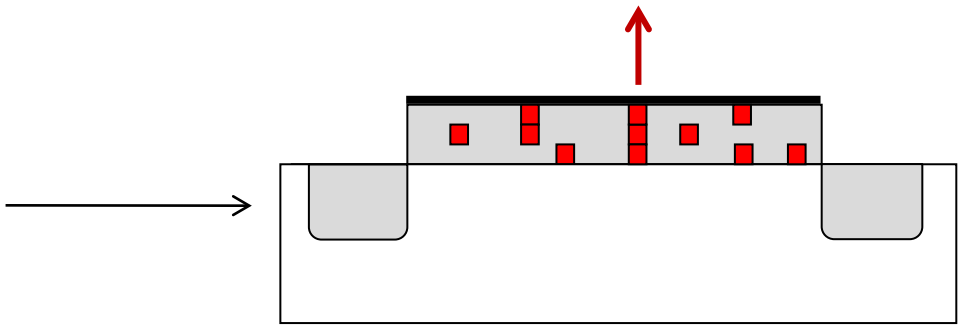
Reliability: a *stochastic* process terminated by a *threshold*

Reliability: correlation, power-laws, contacts

Correlated breakdown
in thick Insulators



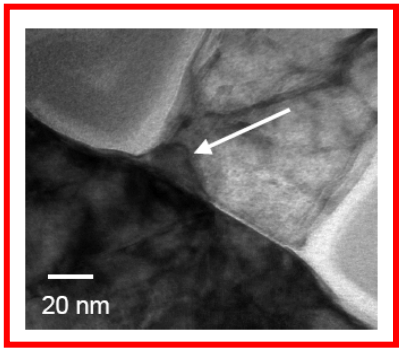
Uncorrelated breakdown
In thin insulators



Theory of partially correlated breakdown
is important and contacts define everything.

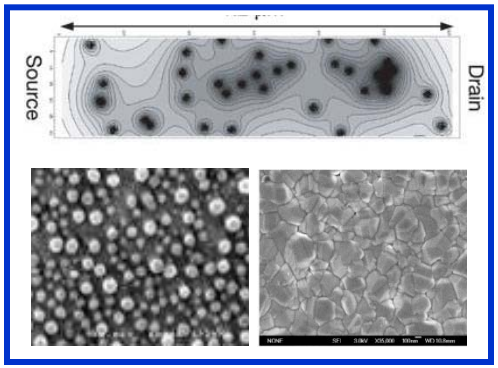
Equivalence between variability & reliability

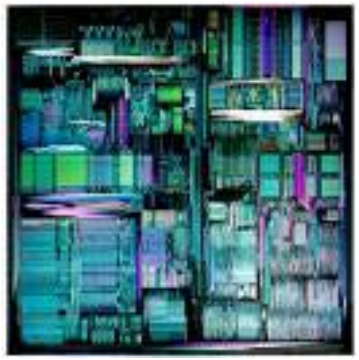
Reliability



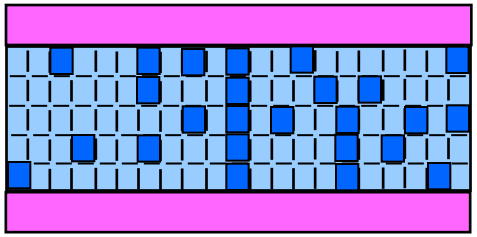
plus

Variability

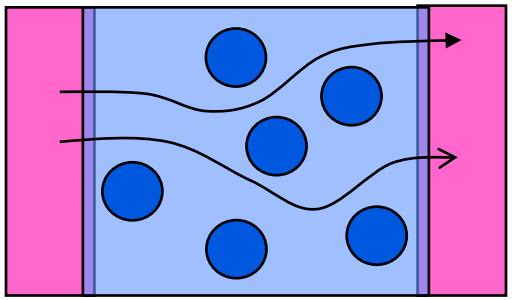




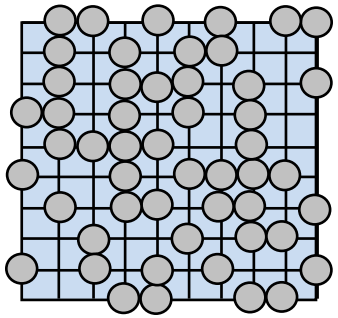
Side view (TDDB)



top view (RDF)



model



Spatial and temporal fluctuation should be considered with same framework …

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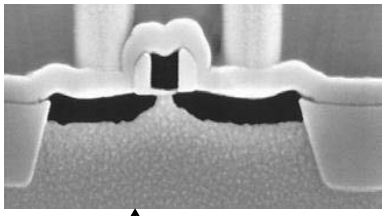
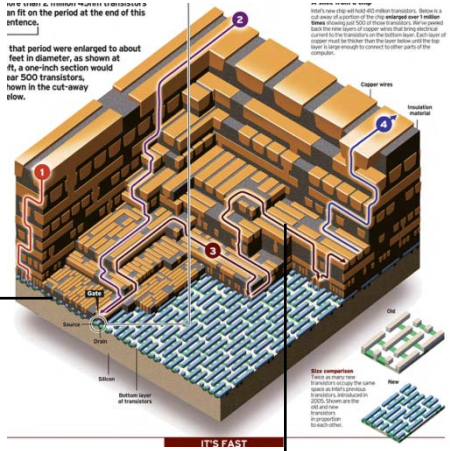
Reliability of nanotransistors



The Oregonian, 2008

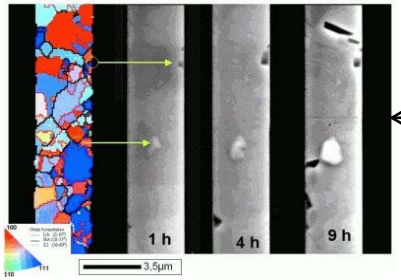


Transistor Reliability

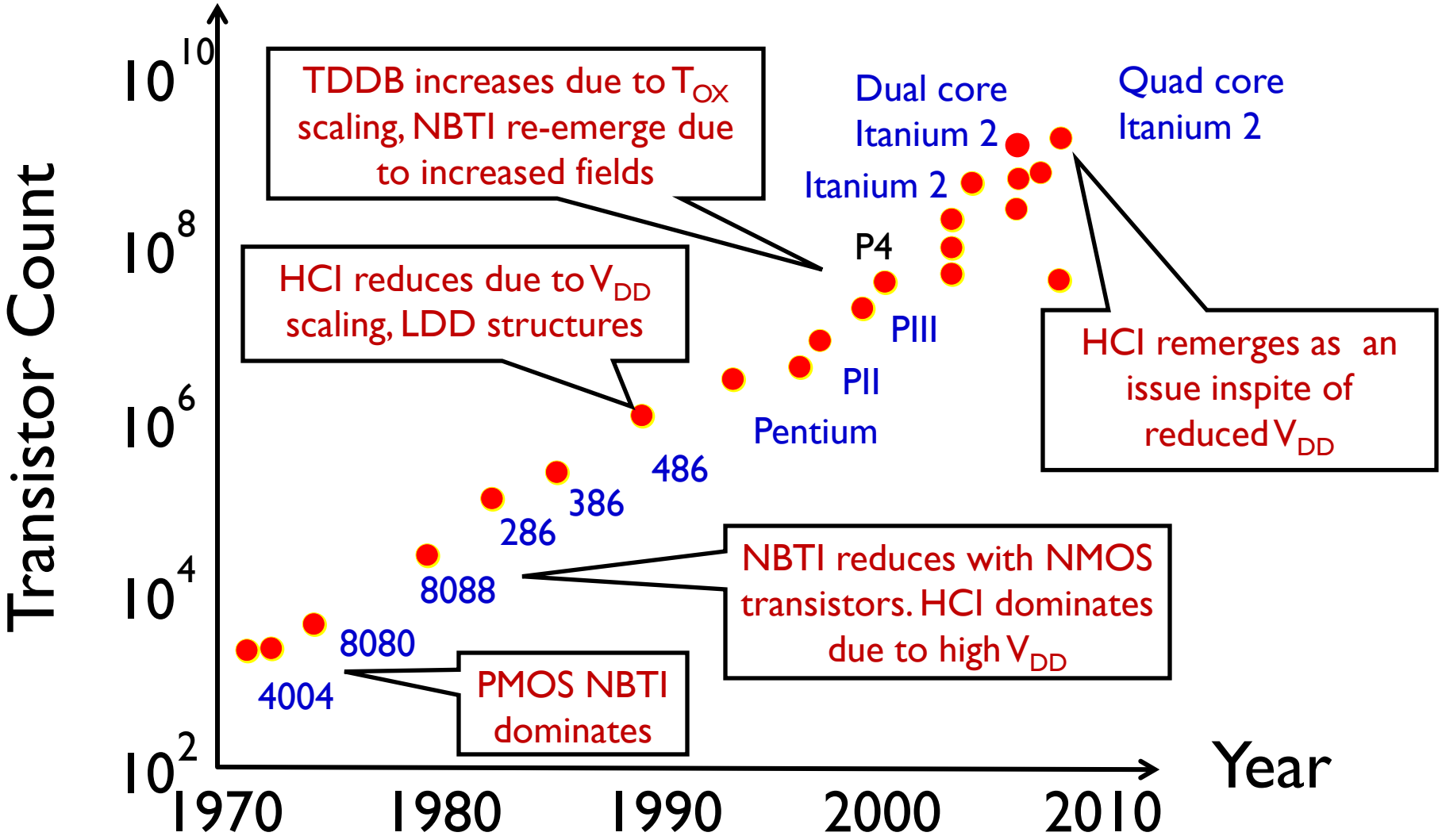
- Gate Dielectric Breakdown
- Negative Bias Temperature Instability
- Hot Carrier Degradation
- Radiation Induced damage

Interconnect Reliability

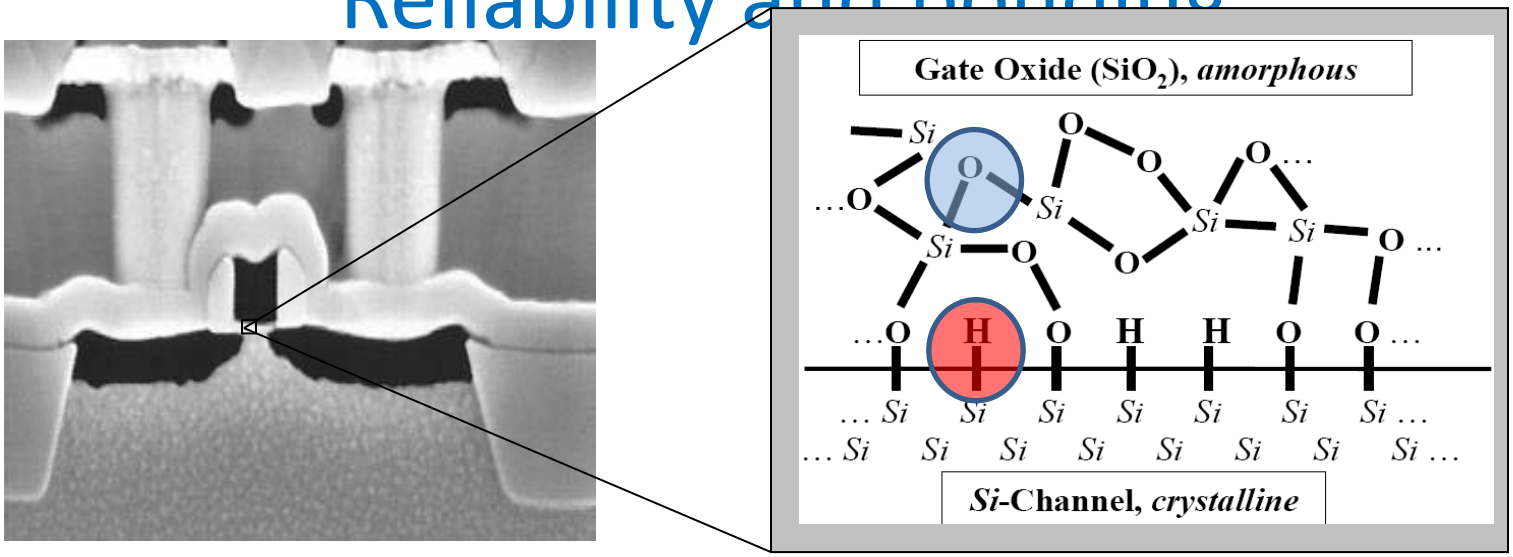
- Electro-migration/Stress-migration.
- Inter-level dielectric breakdown



Scaling and reliability: A short history



Reliability and bonding



Broken Si-H bonds

Negative Bias Temperature Instability (NBTI)

Hot carrier degradation (HCI)

Broken Si-O bonds

Gate dielectric Breakdown (TDDB)

Electrostatic Discharge (ESD)

Radiation induced Gate Rupture (RBD)

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Course Information

- Introduction to Reliability (3 Lectures)
- Physics of Defects (3 Lectures)
- Negative Bias Temperature Instability (6 lectures)
- Hot Carrier Degradation (4 lectures)
- Characterization Techniques (4 lectures)
- Gate Dielectric Breakdown (9 Lectures)
- Radiation Damage (5 lectures)
- Statistics and Backend Reliability (5 lectures)

Reference books

Fundamentals of Modern VLSI Devices

Taur and Ning, Cambridge University, 1998.

Advanced Semiconductor Fundamentals, 2nd Ed.

Pierret, Prentice Hall

Semiconductor Material and Device Characterization

D. Schroeder, John Wiley and Sons.

Lecture Notes and Review Papers

Class participation (10%), Homework (25%), Two exams (40%), and a Final report (15%)

A Word about references

Some references are included in the slides; for others, please refer to a comprehensive list of references included in the review papers posted at the website.

I have used a few figures from Google Images. The links are available in the reference pages. Let me know of any copyright issues.

A set of lecture notes on reliability are available at http://cobweb.ecn.purdue.edu/~ee650/handouts.htm

The 2009 Summer School notes posted at https://nanohub.org/resources/7168 could be useful.

A number of programs that were used to obtain the results of this tutorial are available from www.nanohub.org

Conclusions

- Modern electronics is developing rapidly with many new applications.

- Variability and reliability are two distinct and fundamental concerns of modern electronic devices.

- Reliability is fundamentally about a stochastic process terminated by a threshold. The process may be correlated or uncorrelated, and the evolution depends on boundary conditions.

- We will focus on reliability of nano-transistors. The theoretical and mathematical approaches are easily adapted to other electronic and nano-electronic components.