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ECE695: Reliability Physics of Nano-Transistors

Lecture 40: Failure Analysis and Epilogue

Muhammad Ashraful Alam
alam@purdue.edu

Outline

1. Plan experiments, test carefully, and then post-mortem
2. Summary: NBTI, HCI, TDDB, Radiation
3. Summary: Measurement and Data Analysis
4. Summary: Why I work on this field
5. Conclusion

CSI: Failure case studies

1. Field returns of Agere hard disk – the issue of cheap fan.

2. Field returns of IBM Chip – Po contamination during cleaning of bottles

3. Story of liberty ships during second world war – Welding vs. bolting.

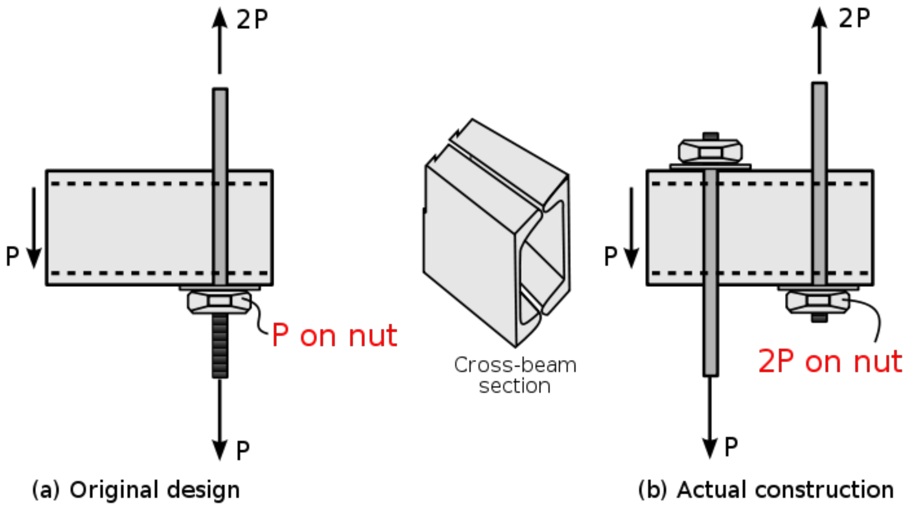
4. Comet explosion in Calcutta on May 02, 1953.
(http://aviation-safety.net/database/record.php?id=19530502-0)

Reliability is a system issue; cascading effects of isolated events

Failure case studies

1. Hyatt Regency walkway collapse , Oct. 14, 1978.

Wikipedia



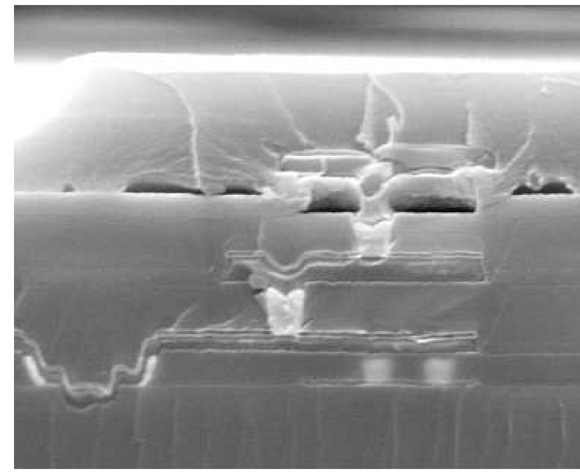
Three days after the disaster, Wayne Lischka, a structural engineer hired by *The Kansas City Star* newspaper, discovered a significant change in the design of the walkways. Coverage of the event later earned the *Star* and its sister publication the *Kansas City Times* a Pulitzer Prize for local news reporting in 1982.

Instrumentation needed: Microscopes

Microscopes (e.g.
Optical microscope ,
Scanning acoustic microscope (SAM)
Scanning Acoustic Tomography (SCAT),
Atomic Force Microscope (AFM)
X-ray microscope, Scanning SQUID microscope

Scanning Electron Microscopy
Scanning electron microscope (SEM)
- Electron beam induced current (EBIC) in SEM
- Charge Induced Voltage Alteration (CIVA) in SEM
- Voltage contrast in SEM
- Electron backscatter diffraction (EBSD) in SEM
- Energy Dispersive X-ray Spectroscopy (EDS) in SEM

Transmission electron microscope (TEM)



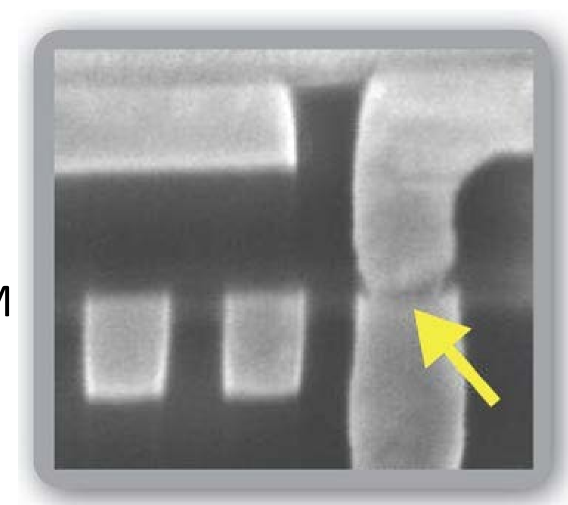


Figure 3: This image depicts a defective layer-2 via.1

Instrumentation needed

Sample Preparation
Jet-etcher, Plasma etcher, Back Side Thinning Tools , Focused ion beam etching (FIB)

Spectroscopic Analysis
Transmission line pulse spectroscopy (TLPS), Auger electron spectroscopy
Deep Level Transient Spectroscopy (DLTS)

Laser Signal Injection Microscopy (LSIM)
Photo carrier stimulation
- Static
  - Optical beam induced current (OBIC)
  - Light Induced Voltage Alteration (LIVA)
- Dynamic
  - Laser Assisted Device Alteration (LADA)

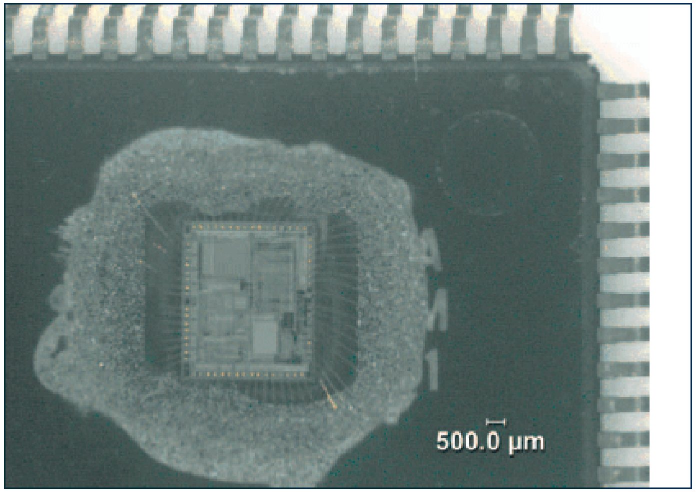
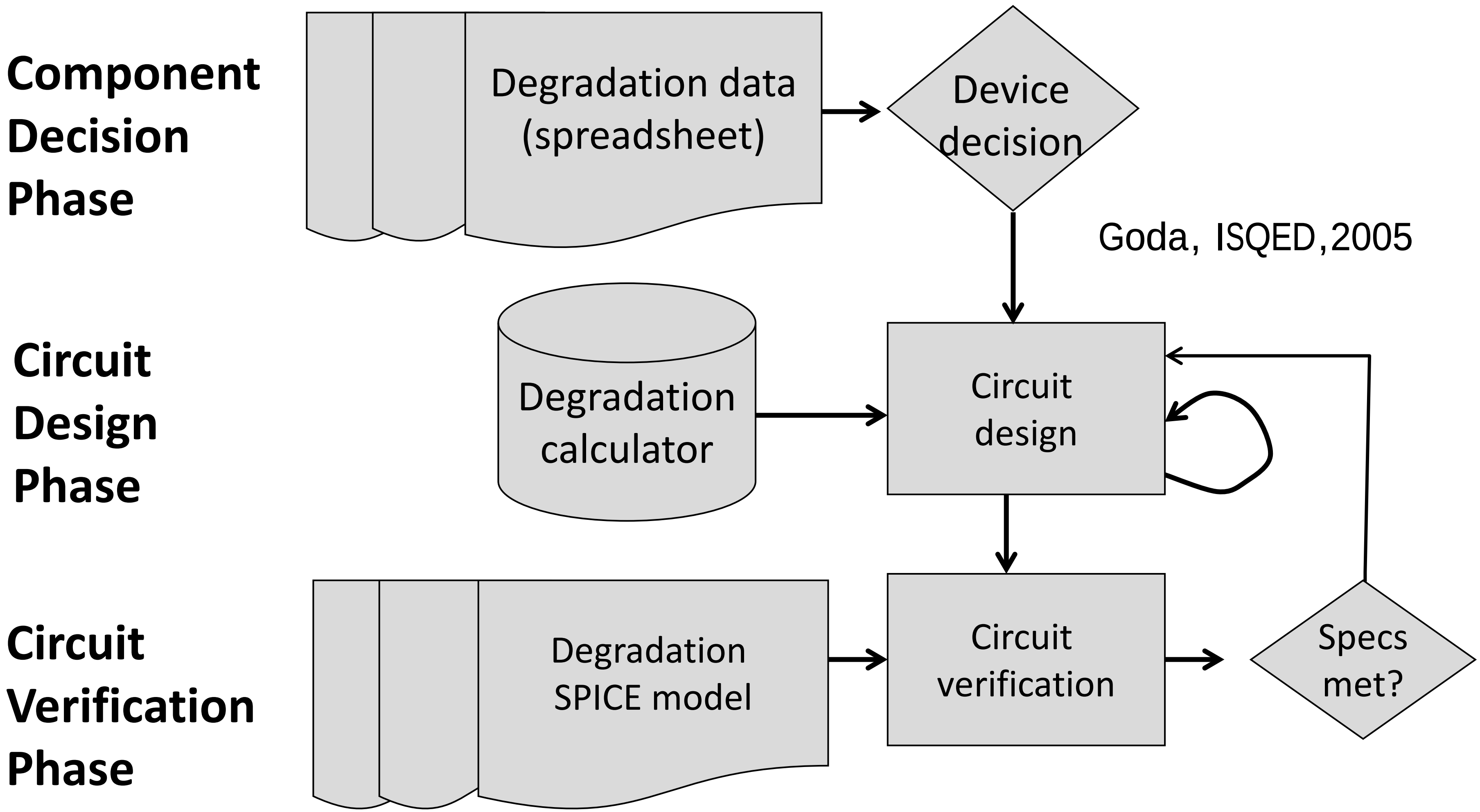


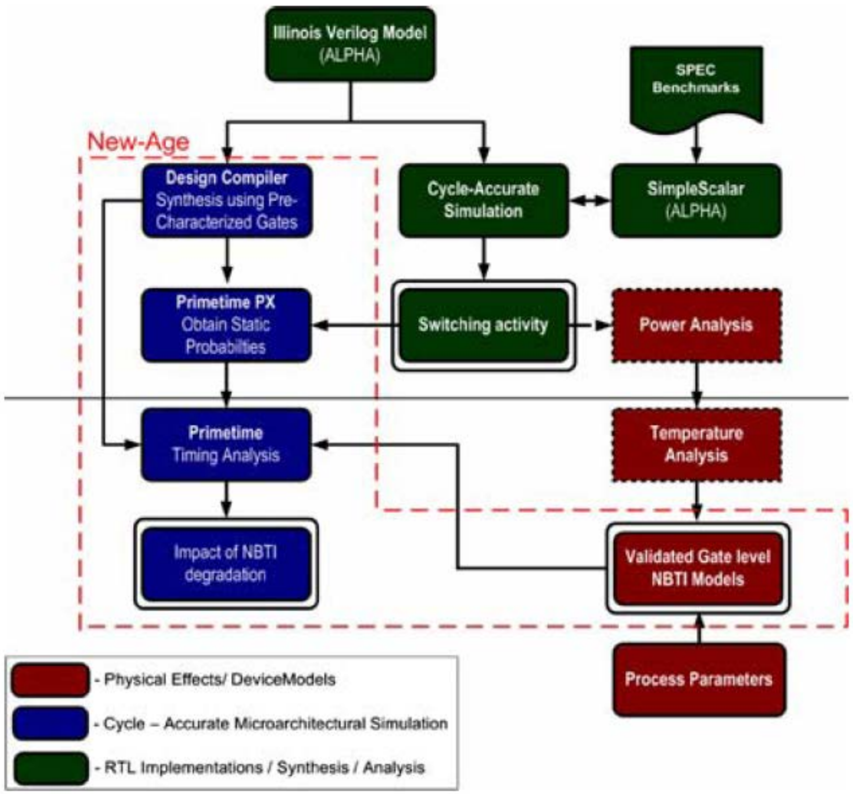
Figure 4-3: De-capped IC.

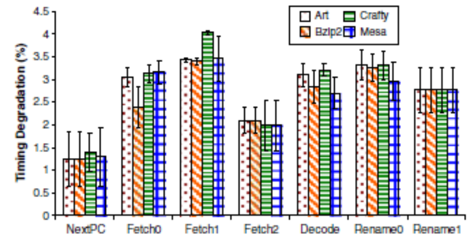
Software Based Fault Location Techniques
CAD Navigation
Automatic Test Pattern Generation (ATPG)

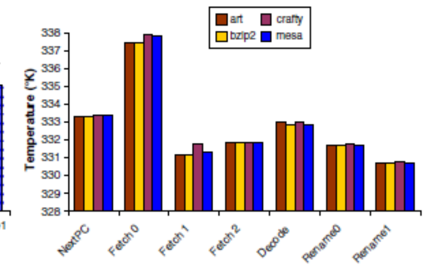
CAD Tool: An Example from Texas Instruments

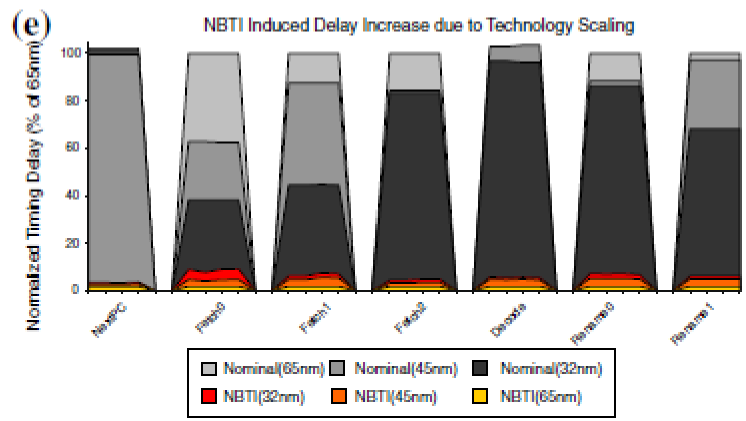


CAD Tool: New-Age from Arizona State









M. DeBole, Int. J. Parallel Prog. 2009.

Stagenet from GSRC manages Floorplanning for smooth stressing.

Outline

1. Plan experiments, test carefully, and then post-mortem

2. **Summary: NBTI, HCI, TDDB, Radiation**

3. Summary: Measurement and Data Analysis

4. Summary: Solutions by Statistical design by Circuits and Systems

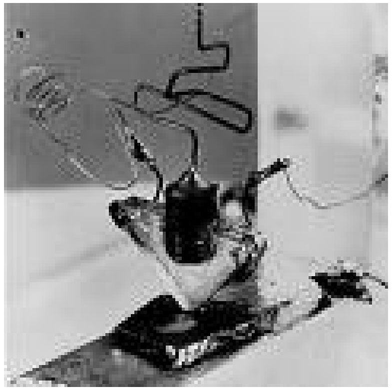
5. Conclusion

Technology & transistors in electronics

Vacuum Tubes

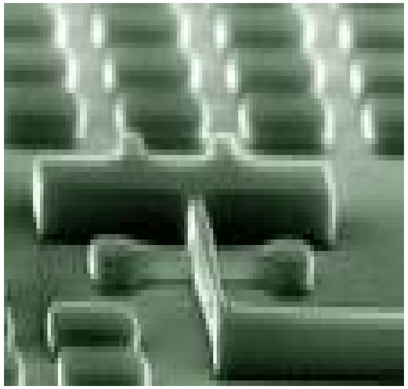
1906-1950s

Bipolar

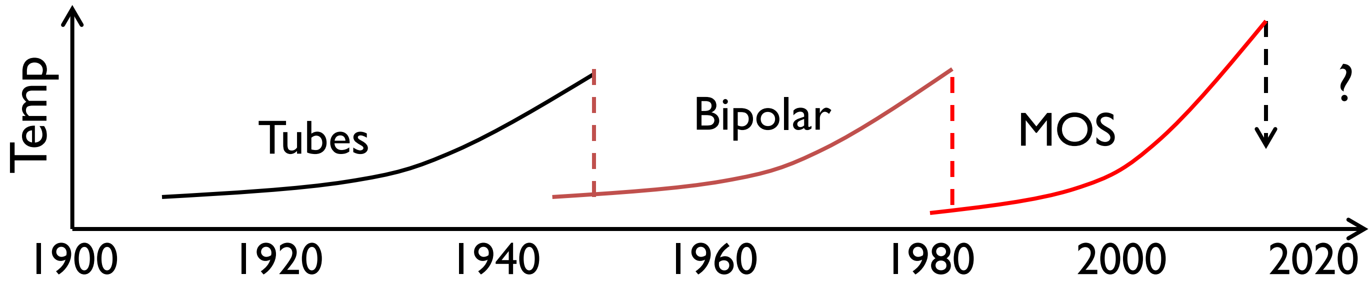


1947-1980s

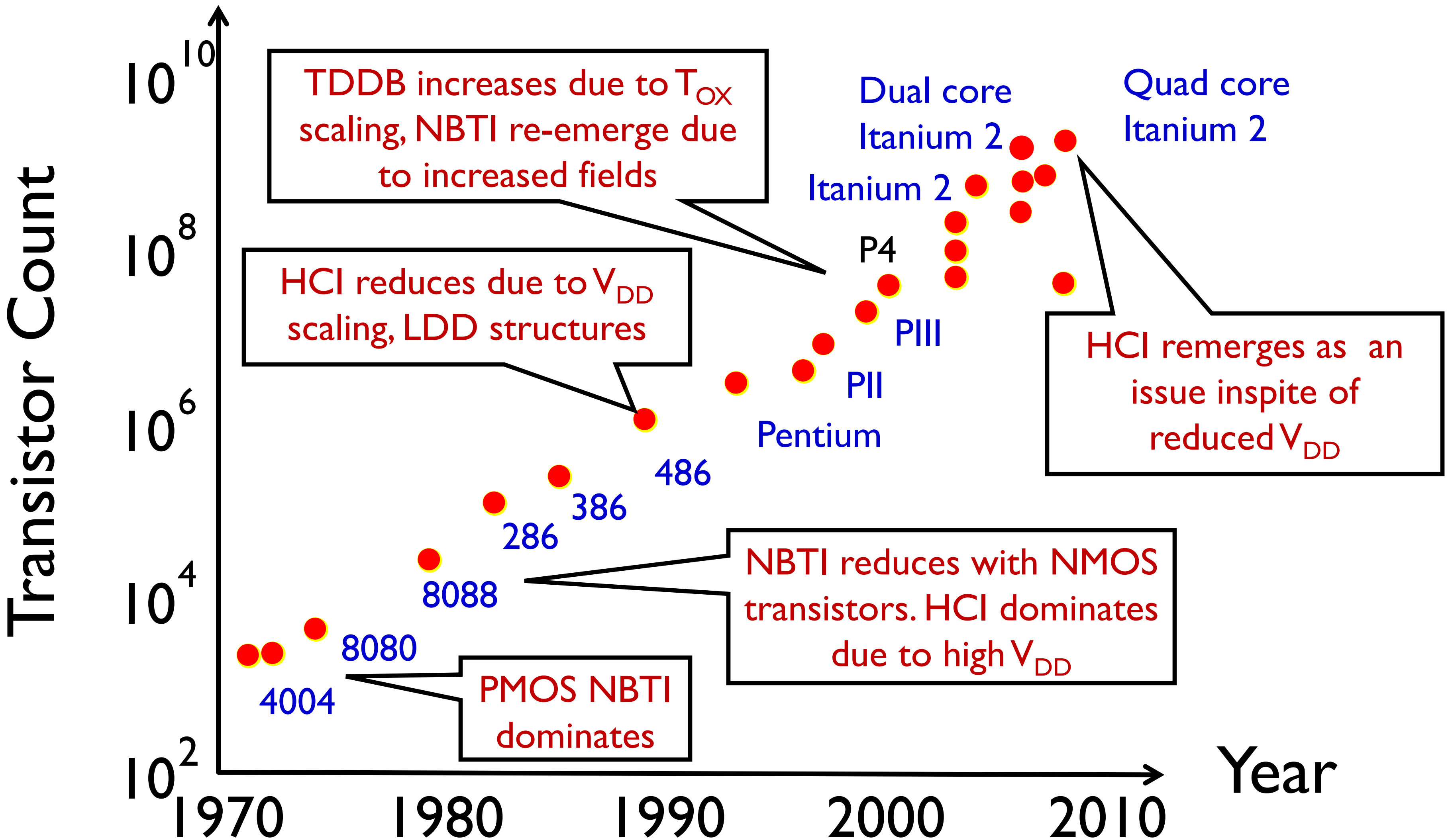
MOSFET



1960-until now



Scaling and reliability: A short history



Defects and Coordination

1. Crystalline, poly-crystalline, and a-materials all have a broad range of applications in IC industry. They appear very different initially.

2. We learned that a-material is not really random and it is easy to calculate the size-distribution from elementary theory.

3. Recall Euler and Maxwell relationships in understanding coordination and defect formation. An amorphous material need not be defective. A-Si has fewer types of defects, but more of them.

NBTI degradation

1. PMOS specific degradation

2. Degradation described by power-laws arising from Reaction-Diffusion model. Frequency independent; S-shaped duty cycle dependence

3. Complex field acceleration based on polarization

4. Non-Arrhenius temperature activation

5. Circuits techniques are often needed to address NBTI problems.

HCI degradation

1. Both NMOS/PMOS may be affected. Still a concern even with voltages close to 1V

2. Time-Universality if a key feature.

3. Hot carrier driven voltage acceleration; can be obtained from scaling theory.

4. Anomalous temperature acceleration.

5. Device design (LDD) and circuit solutions are effective.

TDDB breakdown

1. Historically a NMOS issue, now predominately PMOS failure mode

2. The exact mechanism of time dynamics is still under investigation.

3. Voltage acceleration well described by Anode Hole Injection theory.

4. Soft breakdown allows significant improvement in lifetime. Breakdown becomes correlated for thick oxides.

Radiation damage

1. A challenging problem that has gotten worse with scaling.

2. The error modes associated with older technologies have been replaced with new issues for modern systems. Understanding the new modes are essential in combating radiation concerns.

3. Circuit solutions like ECC and system redundancy and multi-cycle computing has been particularly effective.

Measurement

1. Learning to do characterization and failure analysis and understanding the fundamentals of measurement theory essential for reliability physics.

2. Developing characterization techniques and theory behind them is as important as developing reliability theory itself.

3. Differentiate between on-the-fly and stress-measure-stress experiments. Often give very different results.

Data Analysis

1. Distribution is physical, therefore try deriving the distribution from physical principles.

2. Data plotting is key – Median-based analysis, Hazen, Kaplan formula allows unbiased plotting.

3. Fitting the nonlinear data by MLE is most effective. Always get error bounds by bootstrap and use as few parameters as possible (AIC).

4. Important to participate in DOE for most effective analysis. Output can not exceed input.

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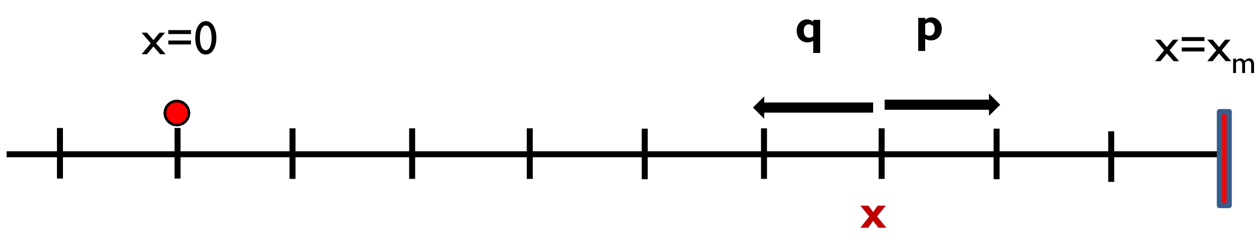
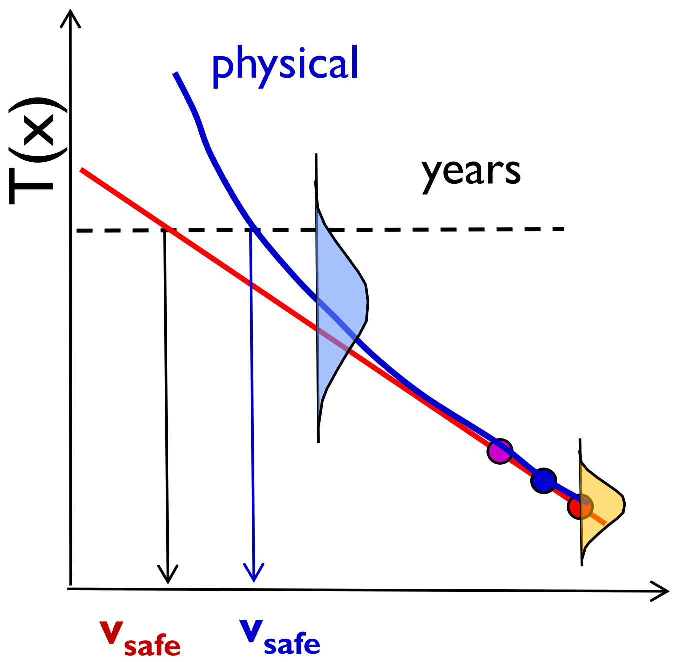
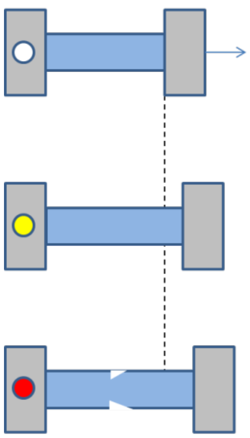
Reliability as an extreme non-equilibrium problem with a threshold

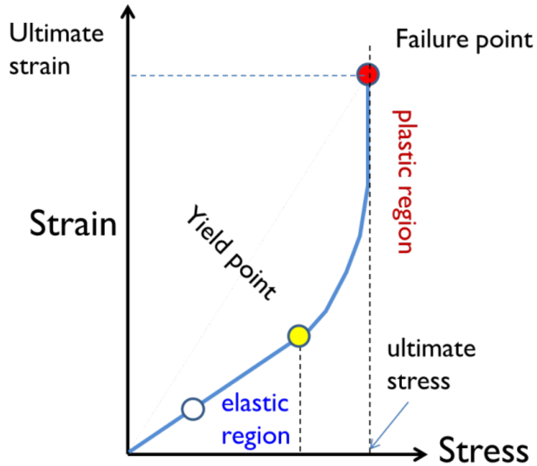


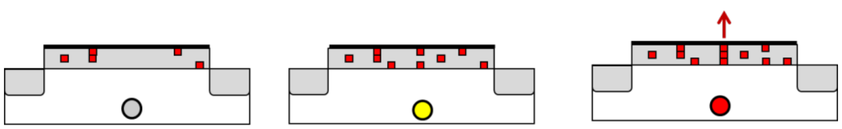


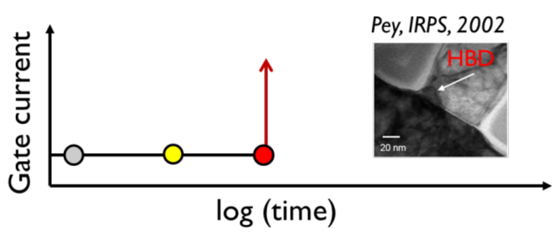
Epilogue: How do we understand so much

Because the world falls apart at $t = 0^+$, it behaves completely normally upto that point ($t = 0^-$).









Epilogue: A contentious field … because theory matters

Like many field in natural sciences, the theory enables long term projection. If theory is wrong, the whole company will be bankrupt – if the theory is overly conservative, the whole company will also be bankrupt. Therefore, data is vetted carefully over and over again to ensure validity of model projection.

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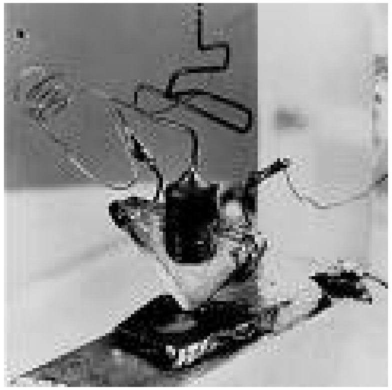
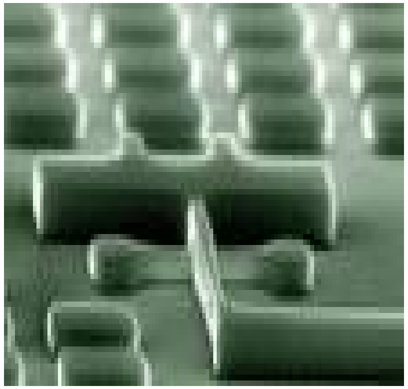
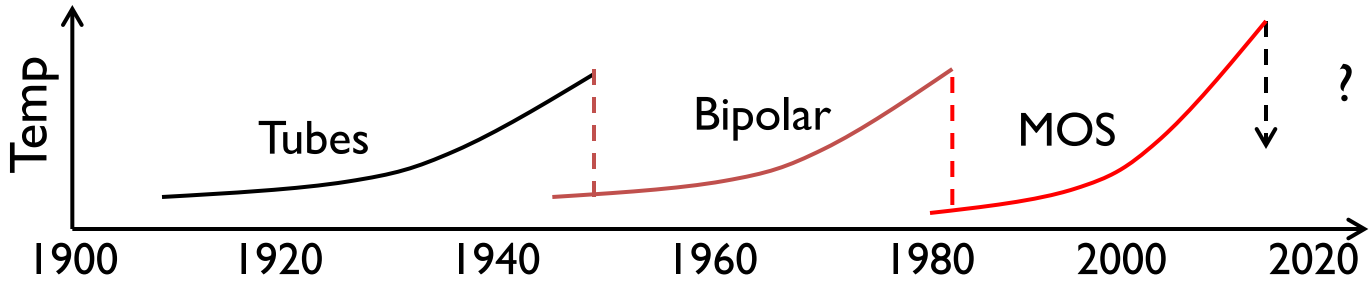
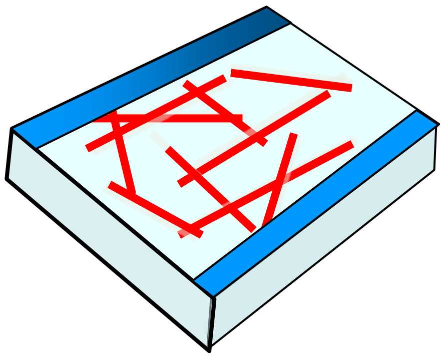
Technology & transistors in electronics

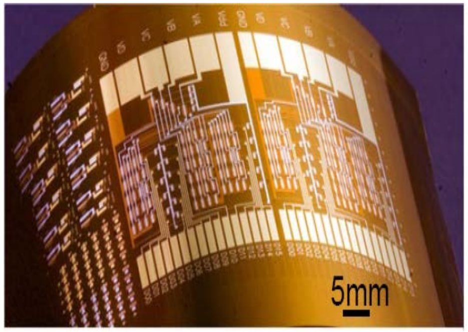
Vacuum Tubes	Bipolar	MOSFET	Now ??
			Sub-60 mV/dec Switches Bio Sensors Displays ….
1906-1950s	1947-1980s	1960-until now	



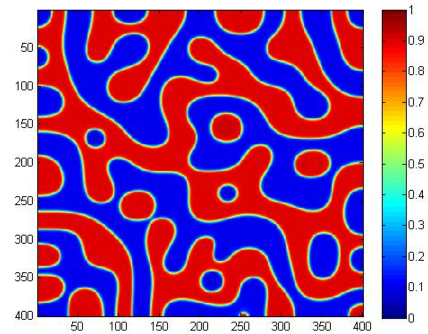
Evolution in large area electronics

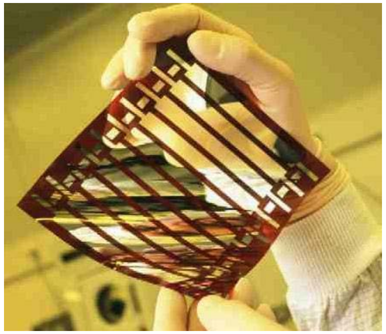
Flexible Electronics





Organic Solar Cells





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

Conclusions

We developed a theory of physical reliability to complement the work on Statistical and Empirical reliability already present.

Our hope is the make the topic as scientific and as broadly accepted as 'Fracture Mechanics' .

Hopefully, you have learned something about extreme non-equilibrium statistical mechanics that you will be able to use in wide variety of situations.