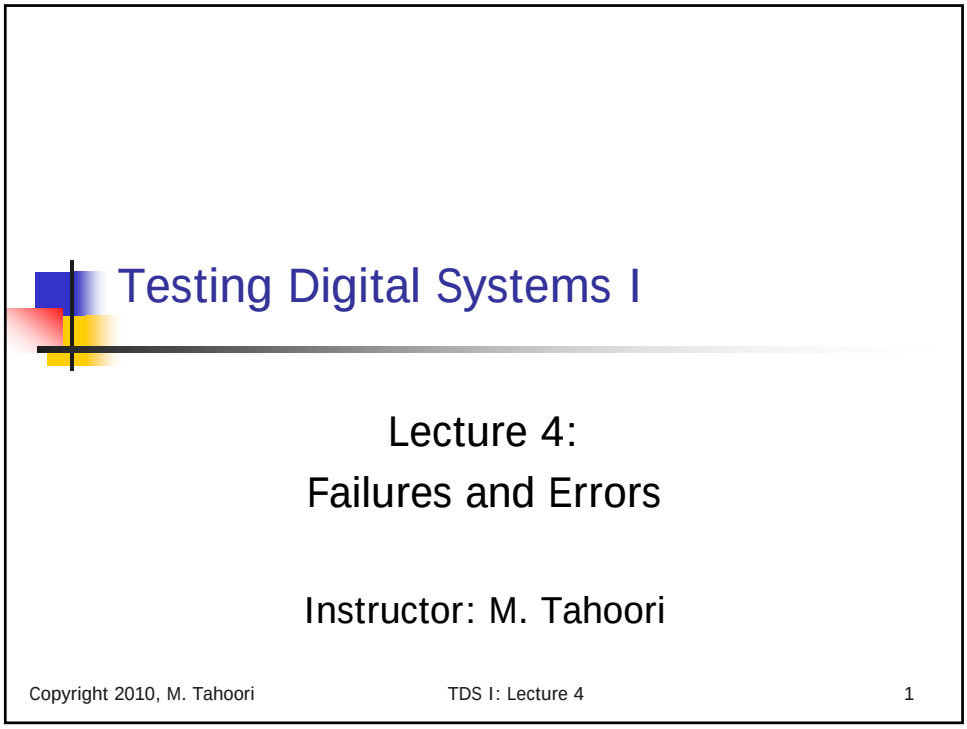
Testing Digital Systems I
Lecture 4:
Failures and Errors
Instructor: M. Tahoori
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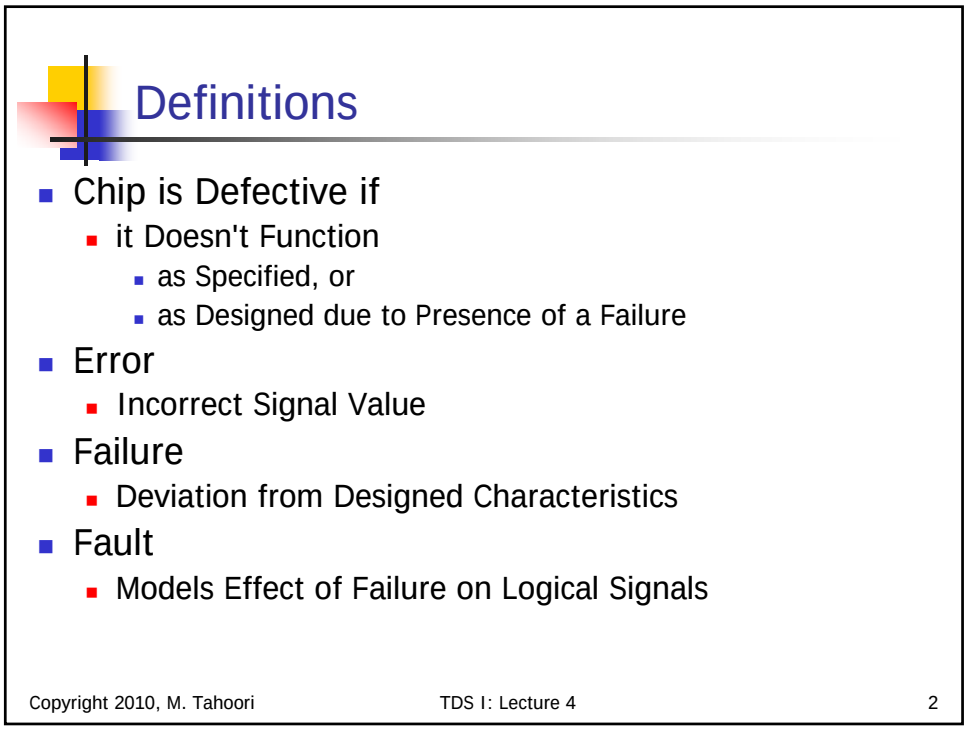
Definitions
Chip is Defective if
it Doesn't Function
as Specified, or
as Designed due to Presence of a Failure
Error
Incorrect Signal Value
Failure
Deviation from Designed Characteristics
Fault
Models Effect of Failure on Logical Signals
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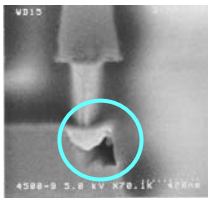
Error

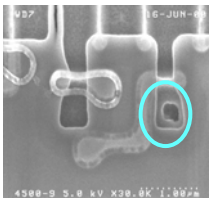
- Incorrect Signal Value
  - Caused by Failure or Coupled Disturbance
  - Effect of failure
- Transient Error - Coupled Disturbance
  - Conductive Coupling:
    - Power Supply, Ground Bounce
  - Capacitive Coupling
    - Adjacent Conductors
  - Electromagnetic Coupling
    - EMI
  - Radiation
    - α-Particles, cosmic rays

Evidence of Manufacturing Defects

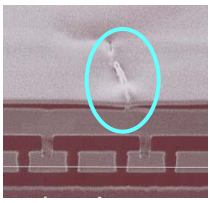
Void under anchor



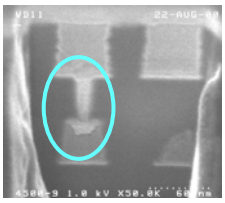
Silicon damage



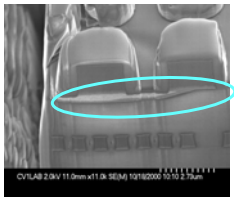
Metal2 extrusion/ ILD2 crack



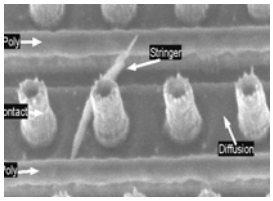
Metal 1 Shelving



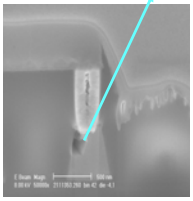
M4-M4 Short

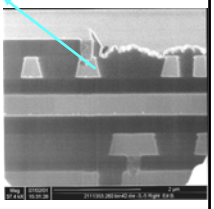


Poly stringer



M4 Void Formations





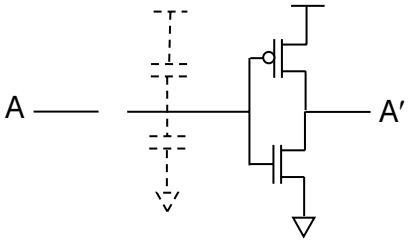
Failure Mode

- Cause of Rejection of Failed Device
  - "recognizable electrical symptom by which the failure is observed"
- Failure Modes
  - Catastrophic
    - Open Interconnect
    - Shorted Connection
  - Degradation
    - Parameter out of Specification
    - Excess supply current
  - Permanent
    - Failure is Always Present
  - Temporary (Intermittent)
    - Failure is Not Always Present
    - Can Depend on Temperature, Voltage, Vibration

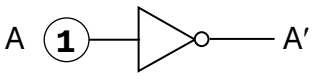
Open

Failure Mechanism: Particle on

Failure Mode: Open Metal



Electrical Fault: Open Signal

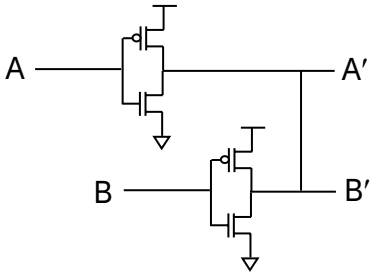


Logical Fault Model: stuck-at-1

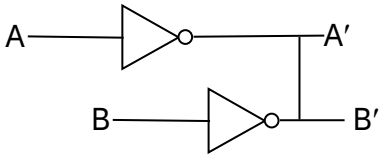
Short

Failure Mechanism: Particle on

Failure Mode: Shorted Metal



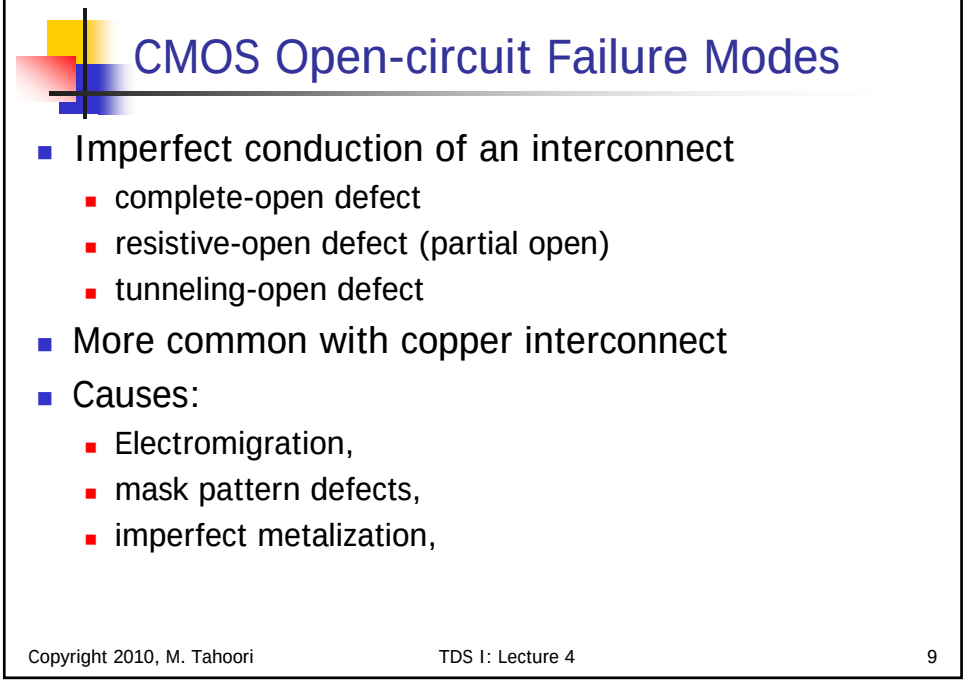
Electrical Fault



Logical Fault

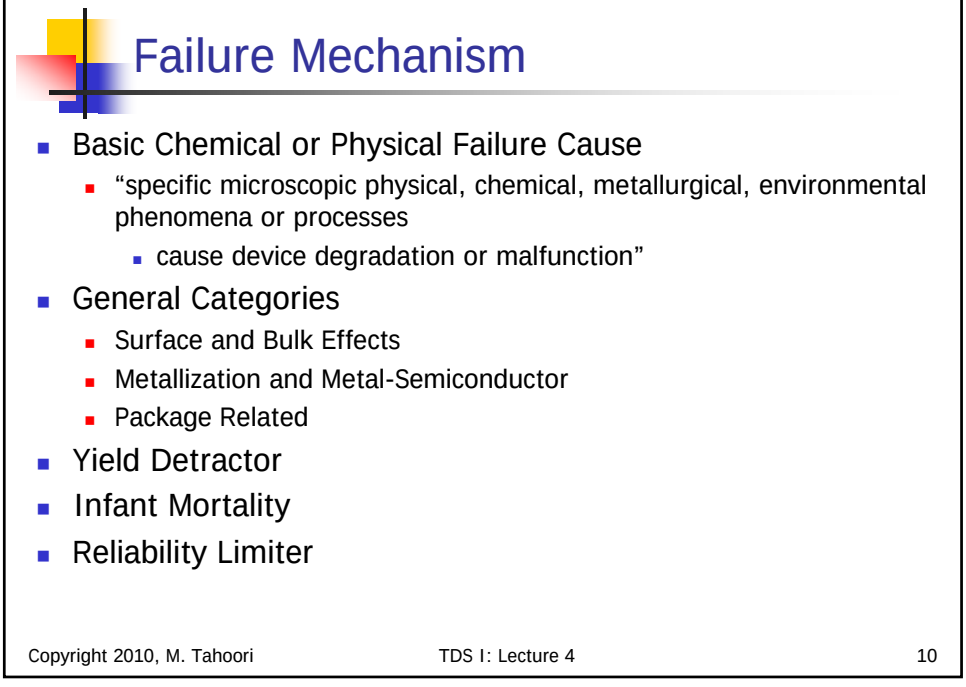
CMOS Short-circuit Failure Modes

- Gate Oxide Short
  - defect in insulating gate oxide
- Bridging Short
  - Incorrect additional connection between logic nodes
- Gate Circuit Internal Short
  - Incorrect additional connection between internal nodes



CMOS Open-circuit Failure Modes

- Imperfect conduction of an interconnect
  - complete-open defect
  - resistive-open defect (partial open)
  - tunneling-open defect
- More common with copper interconnect
- Causes:
  - Electromigration,
  - mask pattern defects,
  - imperfect metalization,

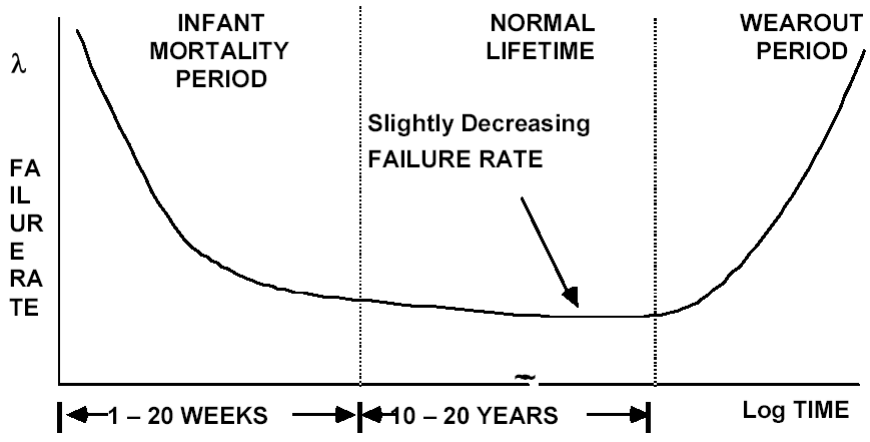


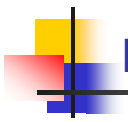
Failure Mechanism

- Basic Chemical or Physical Failure Cause
  - “specific microscopic physical, chemical, metallurgical, environmental phenomena or processes
    - cause device degradation or malfunction”
- General Categories
  - Surface and Bulk Effects
  - Metallization and Metal-Semiconductor
  - Package Related
- Yield Detractor
- Infant Mortality
- Reliability Limiter

Reliability Defects

IC Failure Rate Versus Time





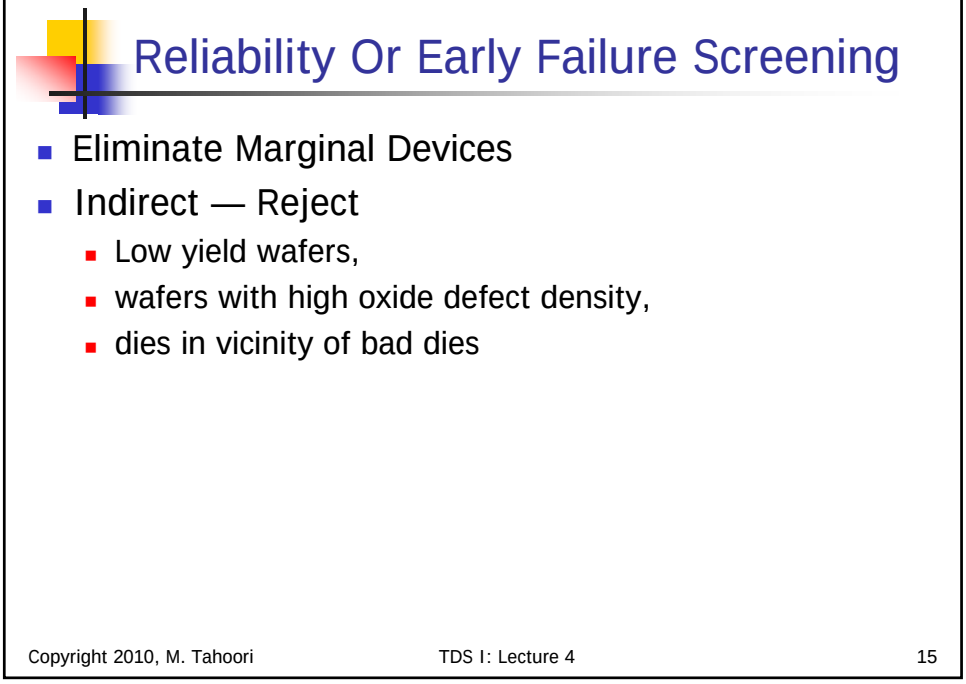
Life Cycle Failure Rate

- Three Time Periods
  - Early Failures -- Infant Mortality
    - Manufacturing Defects or Damage
    - One to Twenty Weeks
  - Normal Lifetime Failures (Stress or Random)
    - Low Constant or Slightly Decreasing λ
    - Stress: voltage, temperature, humidity, vibration
    - λ is failure rate
      - measured in FITs, number of units that fail in 10^9 hours
  - Wearout Failures
    - Rapidly Increasing Failure Rate After 10-20 Years
      - Not Factor for Microelectronics

Reliability Or Early Failure Screening

- "Process designed to detect incipient or latent flaws which if undetected would, in all likelihood, manifest themselves as early field failures."

- Reliability Or Environmental Stress Screening
  - "Process which implies the application of a specific type of environmental stress, on an accelerated basis, but within design capability, in an attempt to surface latent or incipient hardware flaws, which if undetected would in all likelihood manifest themselves in the early life of the system."


Reliability Or Early Failure Screening
Eliminate Marginal Devices
Indirect — Reject
Low yield wafers,
wafers with high oxide defect density,
dies in vicinity of bad dies
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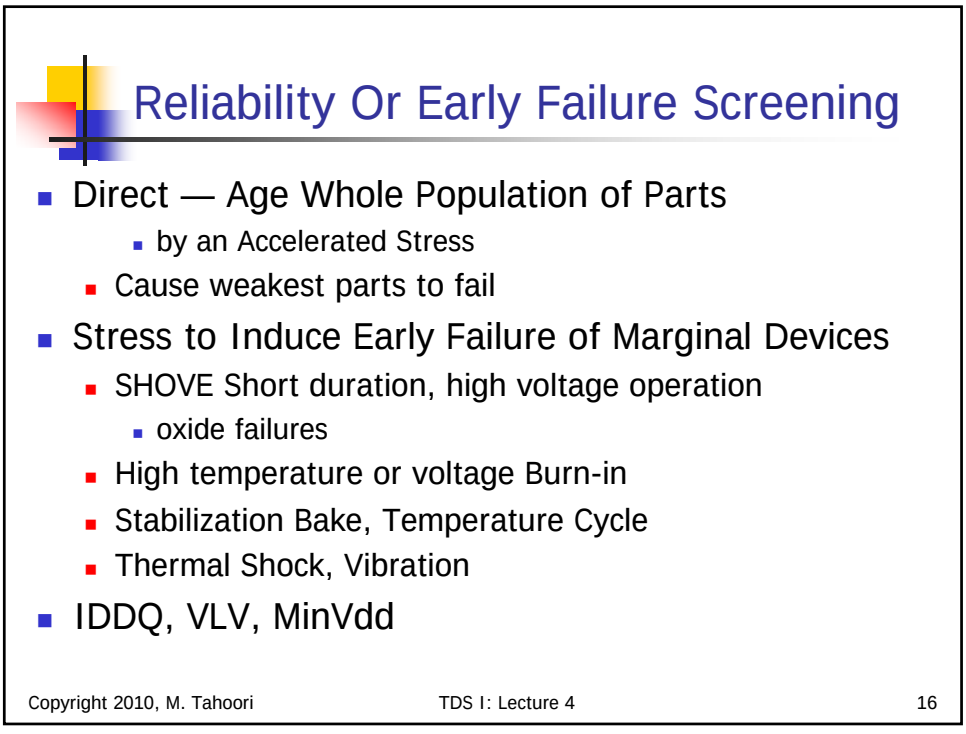
15


Reliability Or Early Failure Screening
Direct — Age Whole Population of Parts
by an Accelerated Stress
Cause weakest parts to fail
Stress to Induce Early Failure of Marginal Devices
SHOVE Short duration, high voltage operation
oxide failures
High temperature or voltage Burn-in
Stabilization Bake, Temperature Cycle
Thermal Shock, Vibration
IDDQ, VLV, MinVdd
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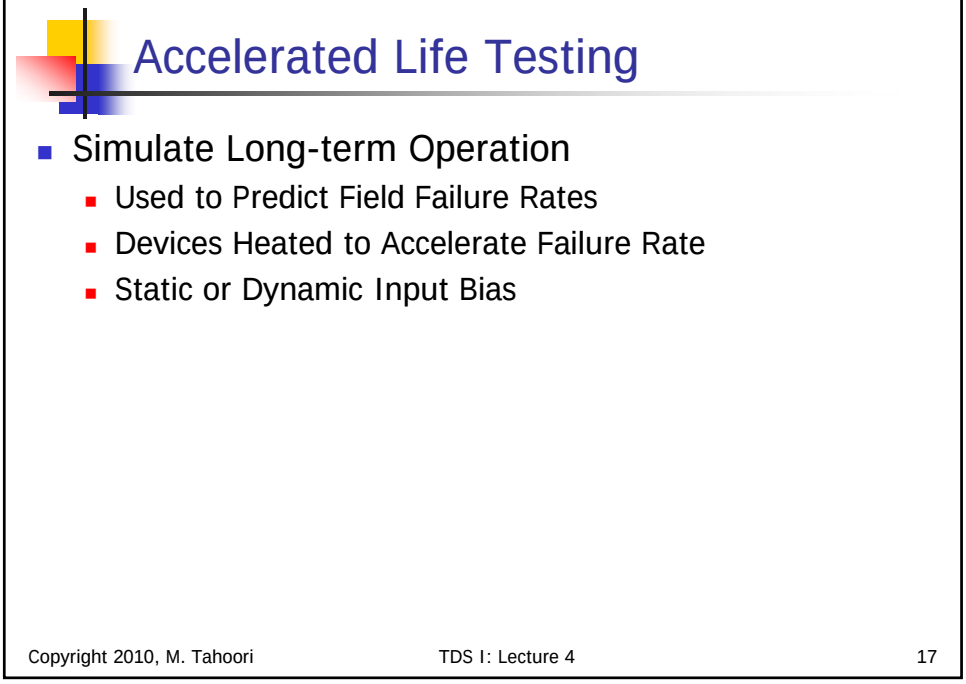
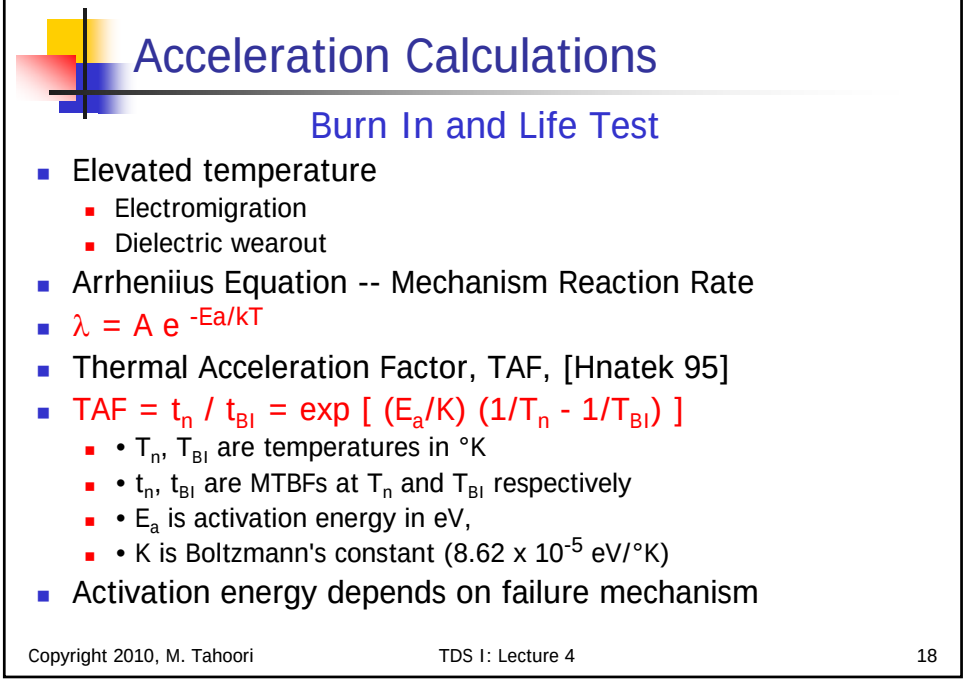
16



Accelerated Life Testing

- Simulate Long-term Operation
  - Used to Predict Field Failure Rates
  - Devices Heated to Accelerate Failure Rate
  - Static or Dynamic Input Bias



Acceleration Calculations

Burn In and Life Test

- Elevated temperature
  - Electromigration
  - Dielectric wearout
- Arrheniius Equation -- Mechanism Reaction Rate
- $\lambda = A\, e^{-Ea/kT}$
- Thermal Acceleration Factor, TAF, [Hnatek 95]
- $TAF = t_n / t_{BI} = \exp [(E_a/K) (1/T_n - 1/T_{BI})]$
  - • T_n, T_{BI} are temperatures in °K
  - • t_n, t_{BI} are MTBFs at T_n and T_{BI} respectively
  - • E_a is activation energy in eV,
  - • K is Boltzmann's constant (8.62×10^{-5} eV/°K)
- Activation energy depends on failure mechanism

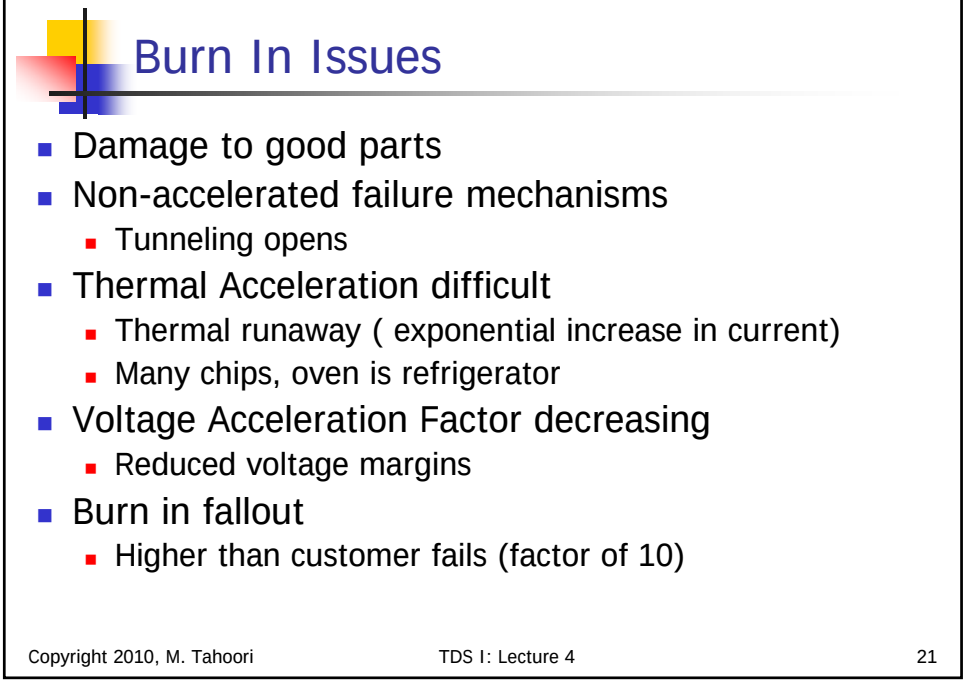
Acceleration Calculations

- Example
  - TAF = t_n / t_{BI} = exp [(E_a/K) (1/T_n - 1/T_{BI})]
  - K is Boltzmann's constant (8.62 x 10^{-5} eV/°K)
  - E_a = 0.6 eV
  - T_n = 50°C (323°K)
  - T_{BI} = 125°C (398°K)
  - t_{BI} = 168 hours (7 days)
  - t_n = 9,840 hours (1.1 years)

Acceleration Calculations

Burn In and Life Test

- Elevated voltage
- Voltage Acceleration Factor, [Hnatek 95]
  - VAF = $e^{[\,C\,(\,Vs - Vo\,)\,]}$
  - V_s = Applied stress voltage
  - V_o = Standard operating voltage
  - C = constant, depends on dielectric type
    - C = 1.8 for dielectrics, 0.41 for junction defects


Burn In Issues
Damage to good parts
Non-accelerated failure mechanisms
Tunneling opens
Thermal Acceleration difficult
Thermal runaway (exponential increase in current)
Many chips, oven is refrigerator
Voltage Acceleration Factor decreasing
Reduced voltage margins
Burn in fallout
Higher than customer fails (factor of 10)
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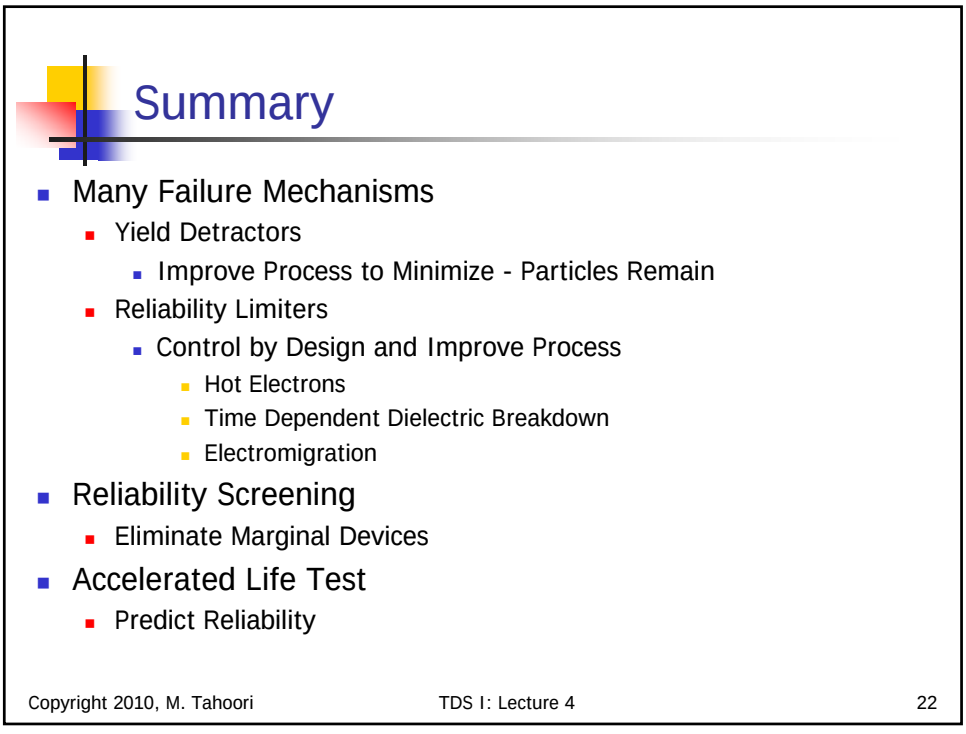
21


Summary
Many Failure Mechanisms
Yield Detractors
Improve Process to Minimize - Particles Remain
Reliability Limiters
Control by Design and Improve Process
Hot Electrons
Time Dependent Dielectric Breakdown
Electromigration
Reliability Screening
Eliminate Marginal Devices
Accelerated Life Test
Predict Reliability
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22