Diagnosis

- Introduction
- Logic Diagnosis
- Scan Chain Diagnosis
- Failure Analysis *(not in exam)
- Conclusions

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Physical Failure Analysis, PFA

- **What is PFA**
  - **Open chip package, locate and examine failure mode of defect**
  - **Aka.**
    - ***Failure Analysis (FA)***

- **Why PFA**
  - **Verify diagnosis results**
  - **Improve fab/test/design**
    - **Improve yield**
  - **Improve design or test techniques**

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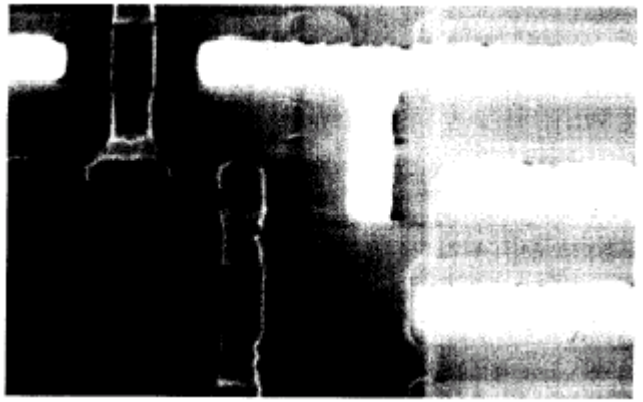
Failure Analysis

- Examine failure mode of defects
  - Failure mechanism can be inferred
- Usually requires lots of experience and equipments

- Example FA pictures [Soden 89]
  - Scanning Electron Microscope picture (Voltage Contrast)
  - Failure mechanism: photoresist failed to adhere
  - Failure mode: open circuit

good



defective

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FA Techniques

- Imaging without power
- Imaging with power
- Physical process
  - Etching, cross sectioning

- See more details [Soden D&T 97]

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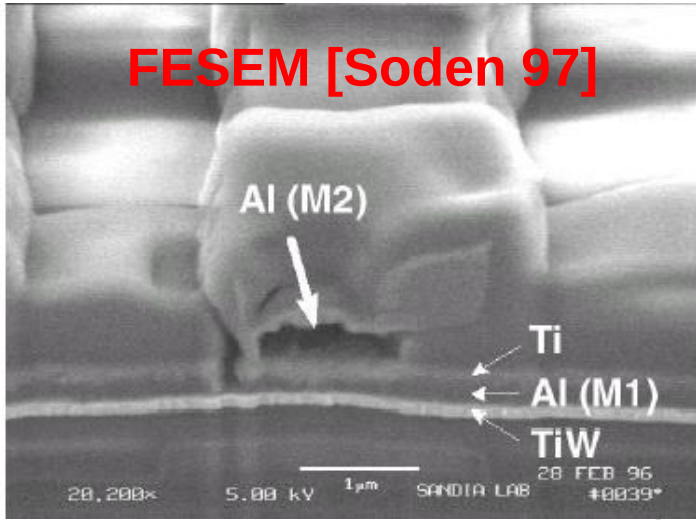
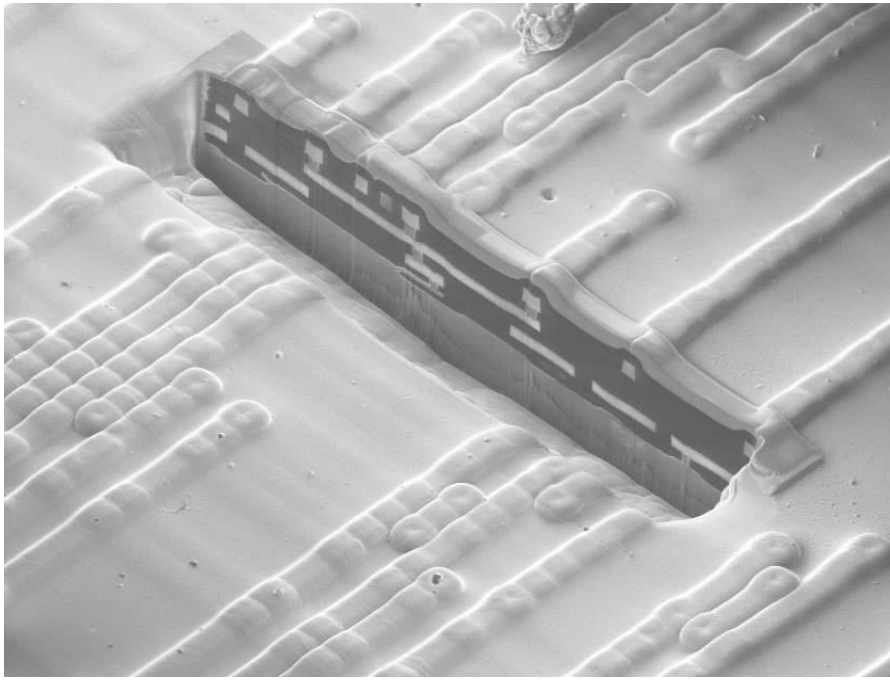
Imaging Techniques (no power)

- Optical microscope (Resolution limit :0.2 to 0.3 μm)
  - One useful technique: Scanning Optical Microscope (SOM)
    - focus infrared laser spot scanning over sample
      - + Silicon transparent to infrared
      - – Resolution limit: 1μm
- Scanning Electron Microscope (SEM)
  - Field emission Scanning Electron Microscope (FESEM)
    - Resolution limit: 2 to 5 nm
  - Transmission Electron Microscope (TEM)
    - Resolution: sub nm
- Scanning probe microscope (SPM)
  - Sharp probe tip scans sample surface
- Focus Ion Beam (FIB)



Focus Ion Beam (FIB)

- Focused beam of Ga^+ ion
- Multiple usages
  - Image
  - Circuit editing (down to 45 nm),
  - FA cross-sectioning (wider than 200um) with e-beam imaging and ion channeling contrast
  - Ion Channeling Contrast for grain imaging of crystalline materials
  - Passive Voltage Contrast for FA
  - Micro-machining for MEMS
  - TEM sample preparation, both cross-sectional and plan-view (min. size 18 nm)
  - Ion implantation (Ga^+)



[image courtesy of SK Lu from FJU]

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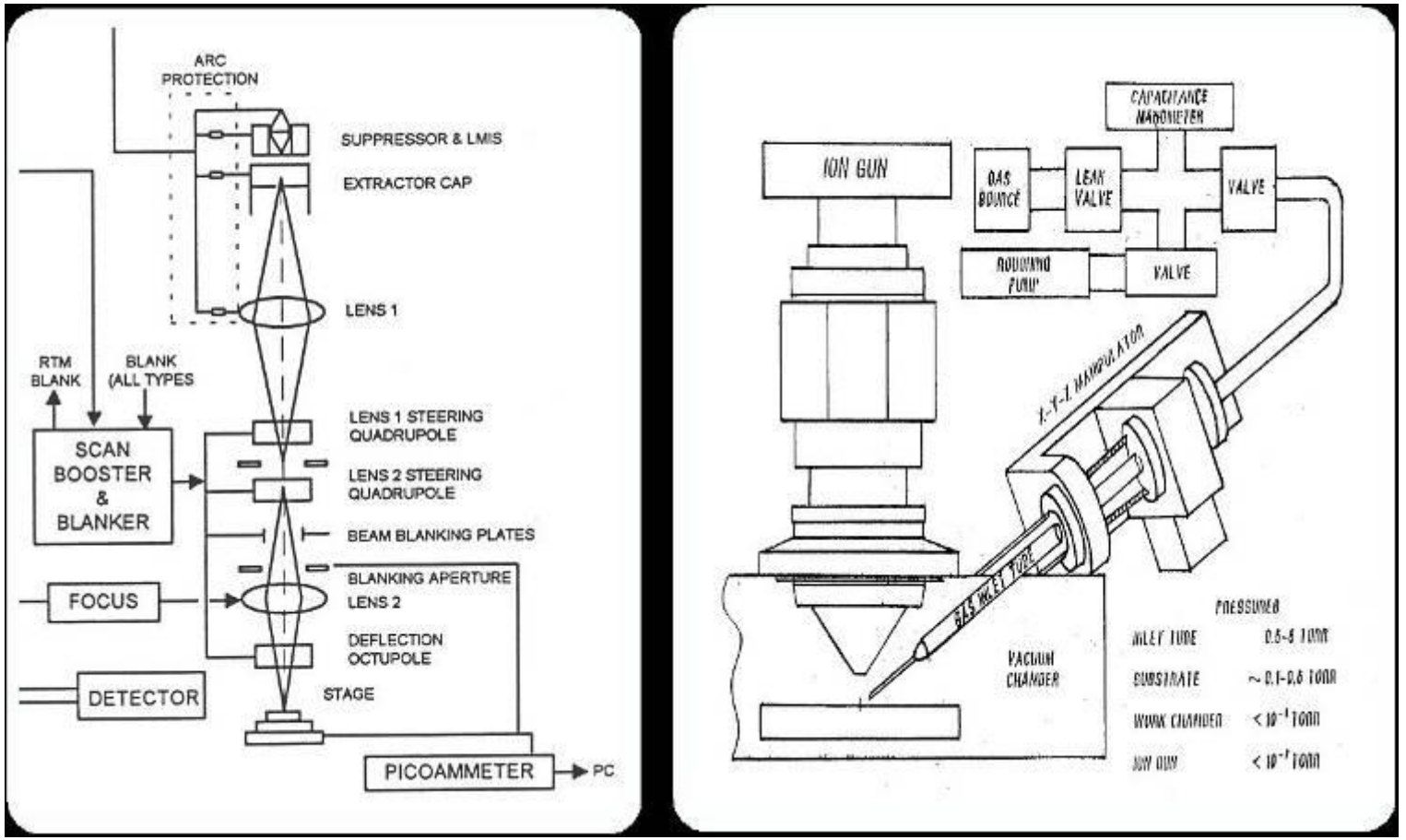
FIB system



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FIB photo

- **Source : MA TEK**

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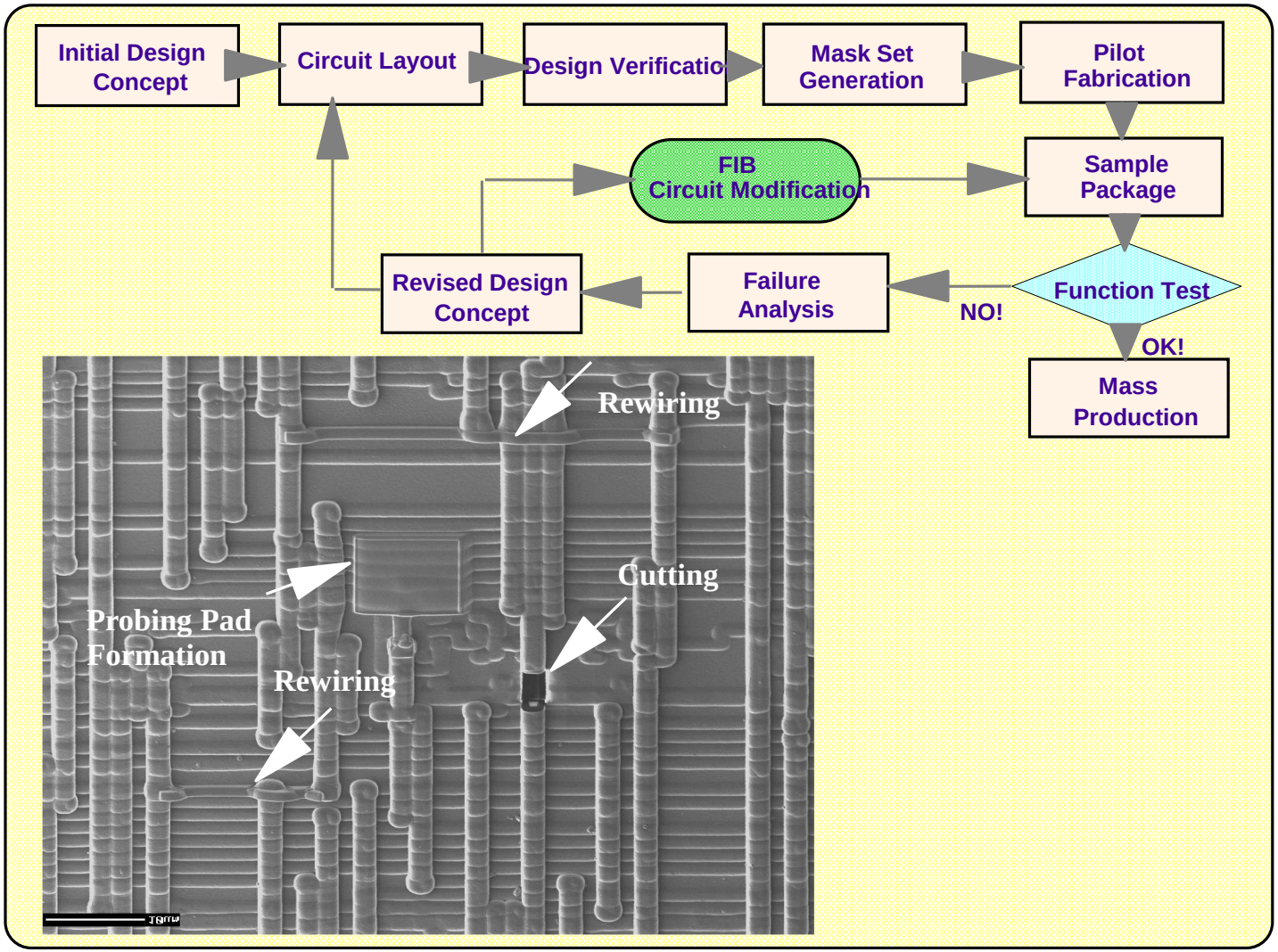
FIB Circuit Editing



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Imaging Techniques (powered)

- **Light emission (aka photo emission microscope)**
  - **Apply test patterns, capture light by camera**
  - **Very commonly used**
    - **Feature size independent**
    - **Infrared light enable analysis form die backside**

Light emission microscopy [Soden 97]

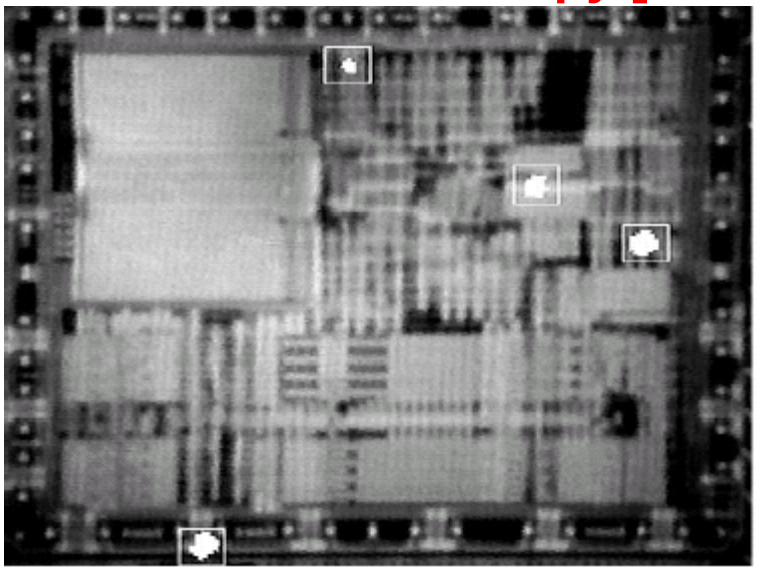

Figure 2. *Low-magnification light emission microscopy image of a 32-bit microprocessor with four gate oxide shorts (bright areas in the four boxes).*

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Imaging Techniques (powered)

- Voltage Contrast (VC) and Electron Beam (E beam)
  - Probe change of signals as well as voltage measurement
    - + Nondestructive
    - – Cannot probe Flip chip package
    - – More nose for small geometry and high frequency
    - – Difficult to probe lower layer of metals
- Resistive Contrast Imaging (RCI)
  - SEM that generates relative resistance image between two nodes
  - Useful for open defects

RCI [Soden 97]

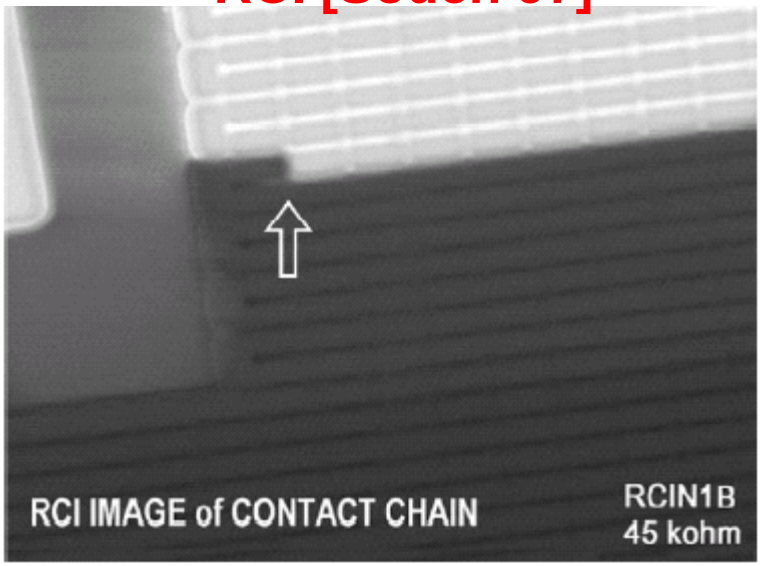

Figure 11. RCI image of contact chain with contrast discontinuity at high-resistance contact (arrow).

Imaging Techniques (powered)

- Charge and Light-Induced Voltage Alteration (CIVA/ LIVA)
  - Useful for open defects
- Scanning Probe Microscope
- FIB
- Thermal imaging
  - Detects “hot spots” caused by defects
  - Commonly used techniques:
    - Liquid crystal
    - Infrared thermography

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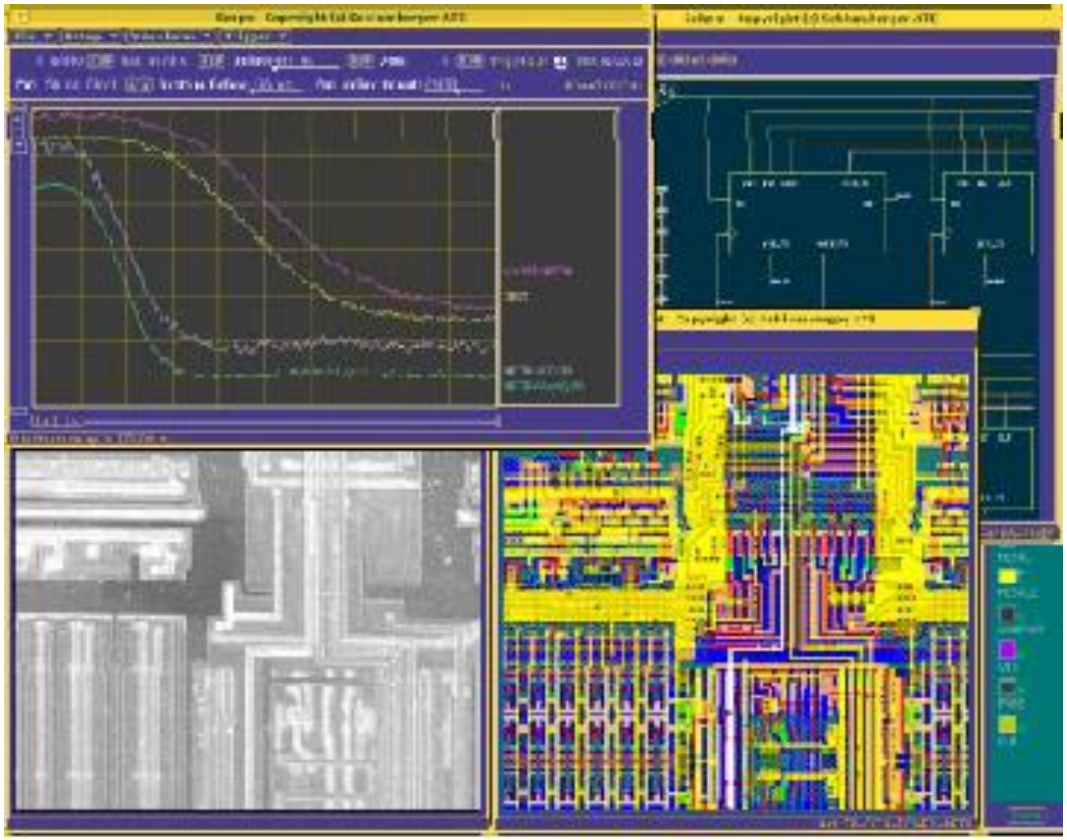
Integrated E-Beam Probe System

- **Show different view all together**

Scope

Schematic



SEM

Layout

[image courtesy of SK Lu from FJU]

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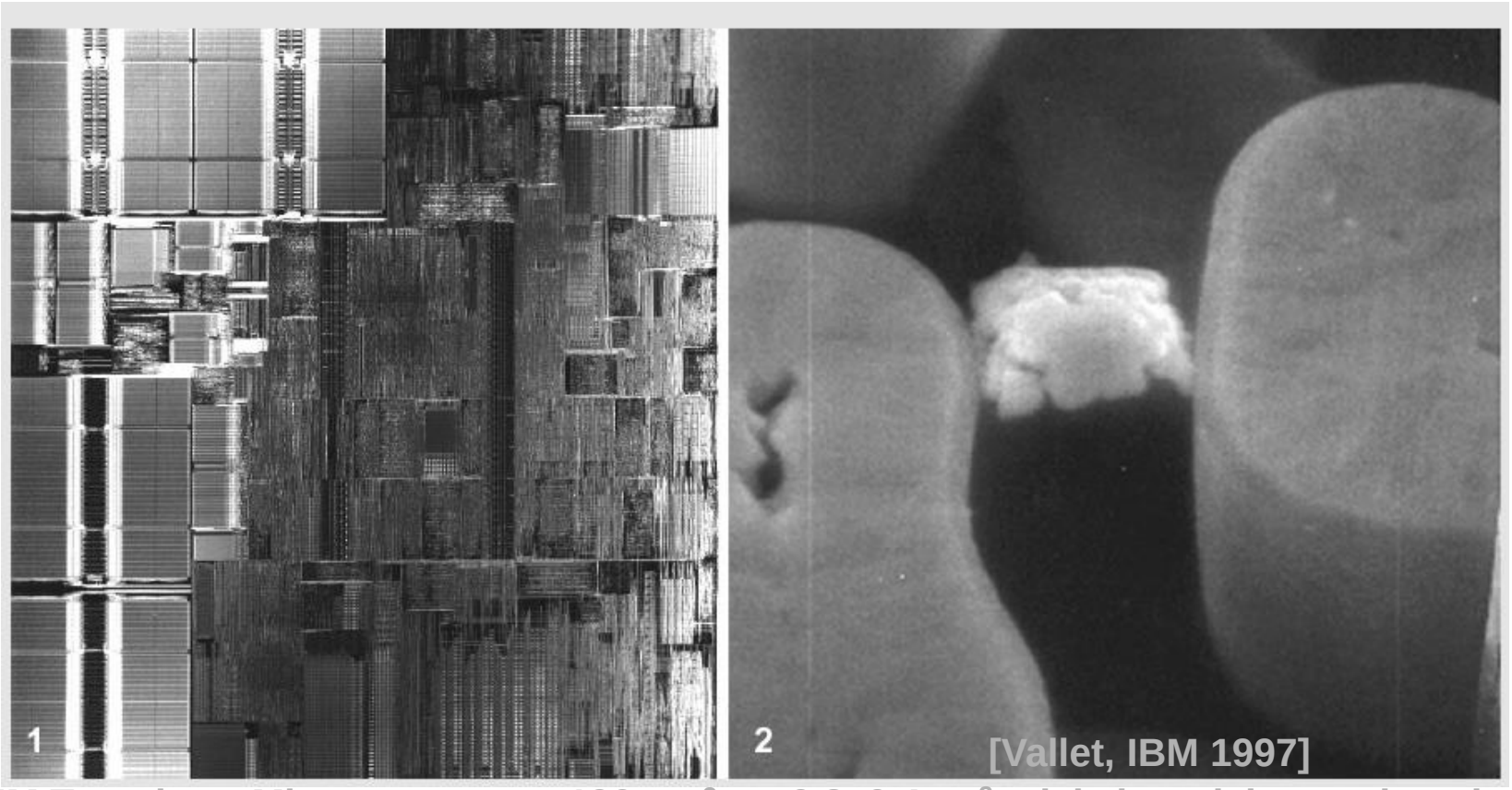
Challenges of Failure Analysis

- **# 1 challenge: Looking for a needle in haystack …**
  - **Good software diagnosis is very important**



5M Transistor Microprocessor, 196mm^2 0.2x0.4μm^2, nickel particle causing short

- **FA equipment are expensive**

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FA Equipment Costly

- **Cost of useful FA tools (USD)**
  - **Microscope: 50K**
  - **X-ray: 150K**
  - **CSAM: 150K**
  - **Decapsulator: 40K**
  - **Automatic curve tracer: 100K**
  - **SEM: 200K**
  - **LEM: 150K**
  - **Probe station: 100K(semi-auto)**
  - **FIB: 500K**
  - **E-Beam probe: 300K**

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Diagnosis

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Conclusion

- Diagnosis important for yield improvement and quick time to market
- Categories
  - Logic Diagnosis
    - Model-based diagnosis: SSF, delay fault
    - Modeless diagnosis: inject and cure, SLAT
  - Scan chain diagnosis

- Diagnosis was usually embedded in ATPG
  - Mentor Graphics: Fastscan
  - Synopsys: Tetramax
  - Cadence: Encounter Test
- Now, diagnosis also available as independent tool
  - Mentor Graphics: Yield assist

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