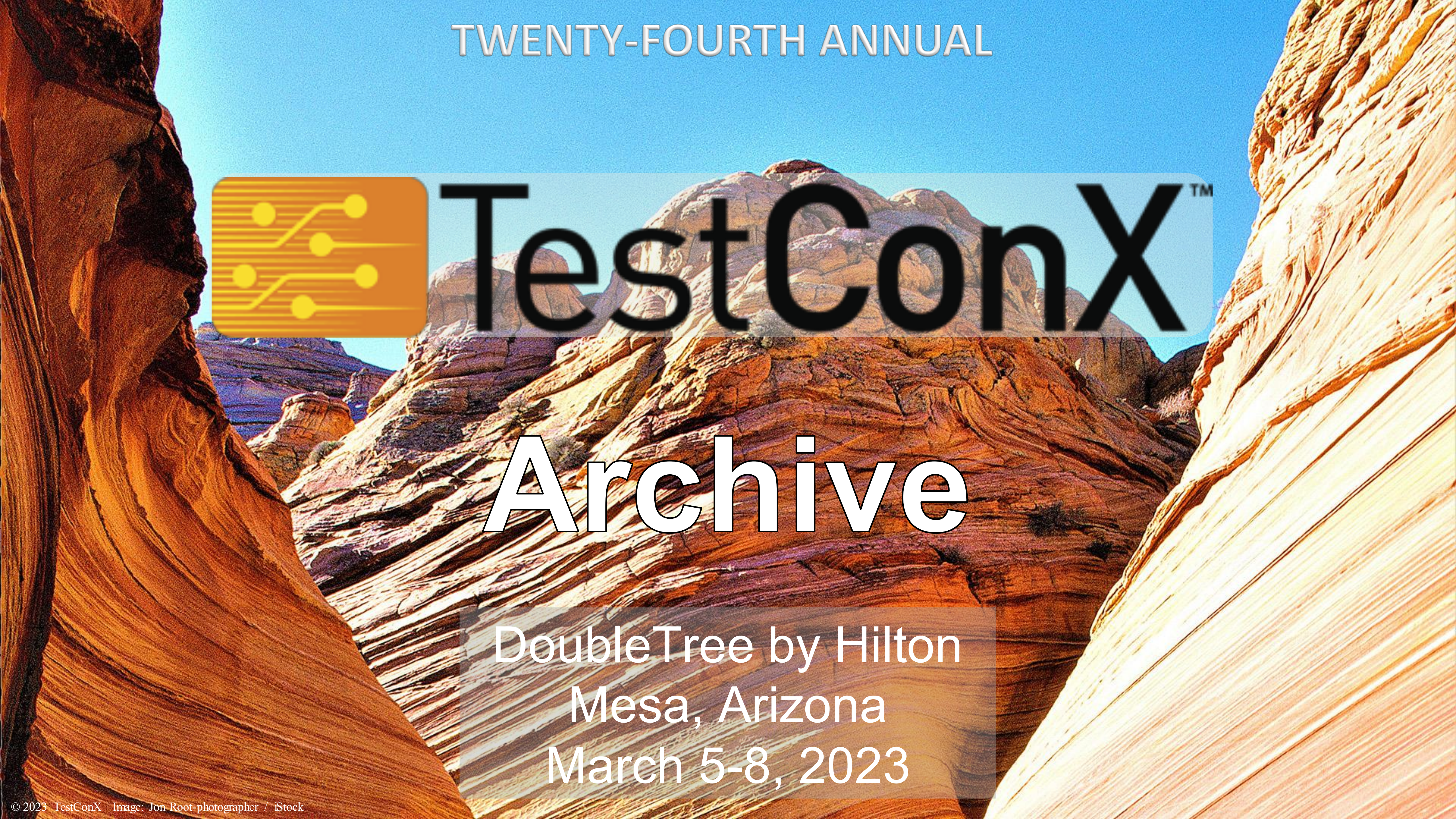

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Thermal and Mechanical Challenges for Test Handlers

Ernest Blanco & Jerry Tustaniwskyj
Cohu, Inc

Mesa, Arizona • March 5-8, 2023

Content

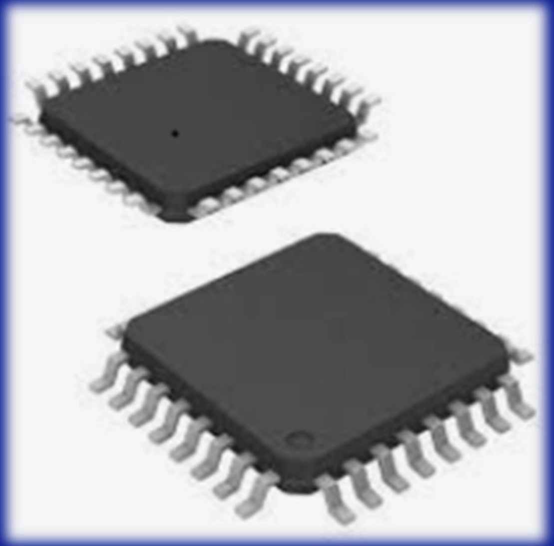
- Industry direction
- Different device types
- Device test flow
- Device tests
- Parallelism
- Device handling
- Temperature control
- Vision system
- MEMS

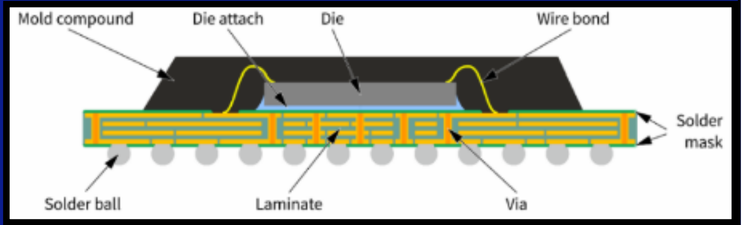
Industry Direction

- 2 trends:
  - Devices shrinking
    - Integrated into more / new applications
  - Devices size increasing
    - Greater power levels

Different device types (Smaller devices)

- Typical types: Over-molded & lidded
  - QFN, QFP & BGA
- Challenges:
  - Plastic over-mold thermally insulates die
    - Inverted thermal resistance (lower R_{jb} vs R_{jc})
  - Shrinking devices < 2mm x 2mm
    - Pick & place vs thermal fighting for limited area
    - Mechanical alignments
    - Smooth handling a must!
  - Fragile leads on some devices (QFP shown)





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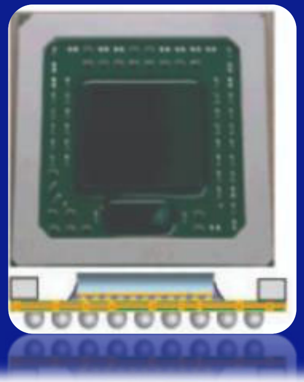
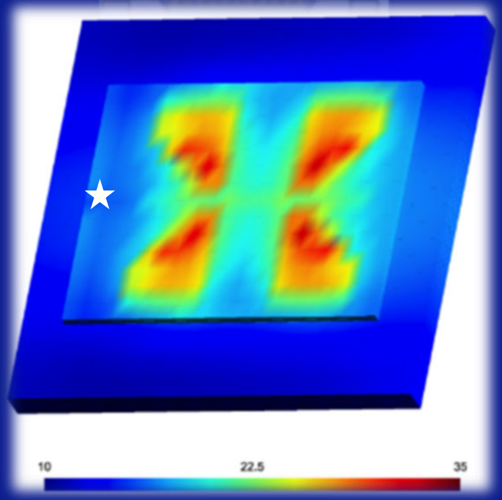
Different device types (Large devices)

- Typical types: Lidded & Bare die
  - BGA, LGA
- Challenges:
  - Bare die cracking from hard contact
  - Deep socket designs
    - Both (above) require interposer hurting thermal performance
  - Temp feedback sensor far from high power die zones
  - Marring / residue on die or lid





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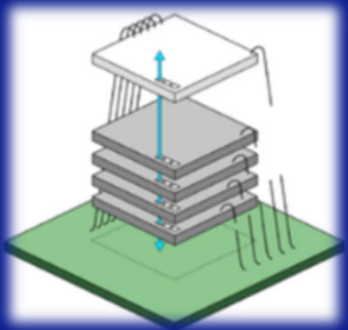
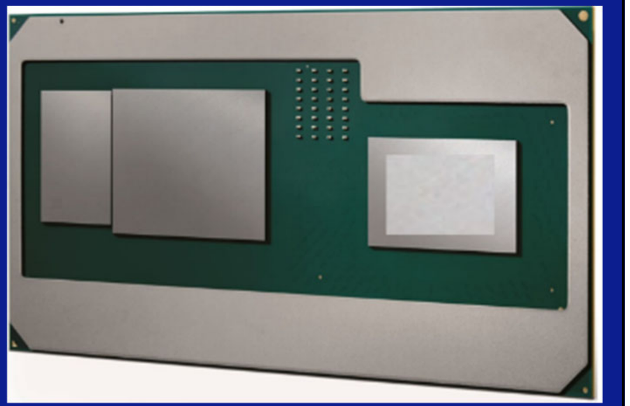
Different device types (Larger devices)





- Typical types: Multi chip modules
  - BGA, LGA
- Challenges:
  - Devices > 100mm x 100mm
    - Size & weight exceeding handler's capabilities
  - Power dissipation >1000W
  - Die stacking increases thermal resistance
  - Higher insertion forces driving thick stiffeners
    - Hide the die require interposer
  - Planarity between die affecting thermal contact

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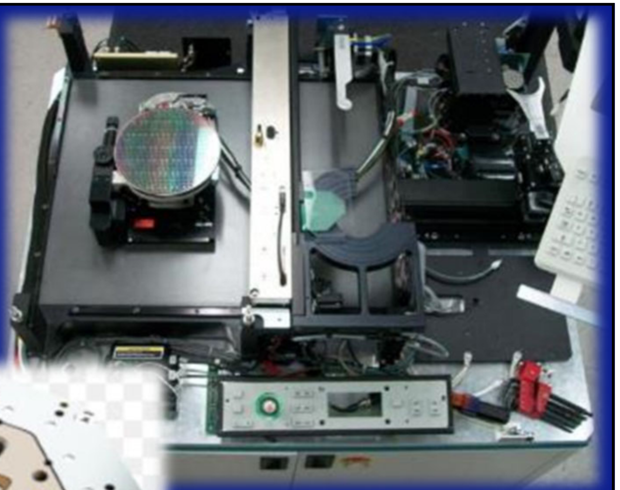
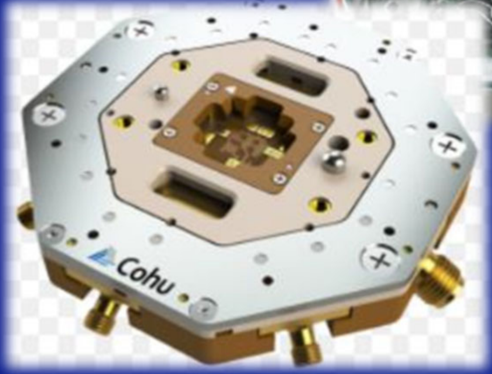
Device test flow

- Wafer: Test ICs on the Si
- Functional: Test device performance
- Burn in: Test for infant mortality
- System level: Test device in real world use context





Device tests (Temperature effects)

- Higher temperature results in lower reliability

$$A_T = e^{\frac{E_a}{k}\left(\frac{1}{T_{use}} - \frac{1}{T_{test}}\right)}$$ Arrhenius equation

  » E_a is the activation energy (from reference table)
  » k is Boltzmann's constant ($8.617\text{x}10^{-5}$ eV/K)
  » T_{use} is the DUT junction temperature at application use
  » T_{test} is the DUT junction temperature in test

  – Failure rate typically doubles every 15°C
- Circuits typically slow down with temperature
- Leakage current increases with temperature

  ⇒ More power dissipation

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Device tests (Voltage Acceleration)

- Voltage acceleration is given by:

$$A_V = e^{\beta(V_{test} - V_u)}$$

- Where:
  - V_u and V_{test} are use and test (stress) voltages, in volts
  - β is the voltage acceleration term (4 per volt is typical)
- Goal is to maximize V_{test} without damaging the DUT
- Leakage current increases with voltage

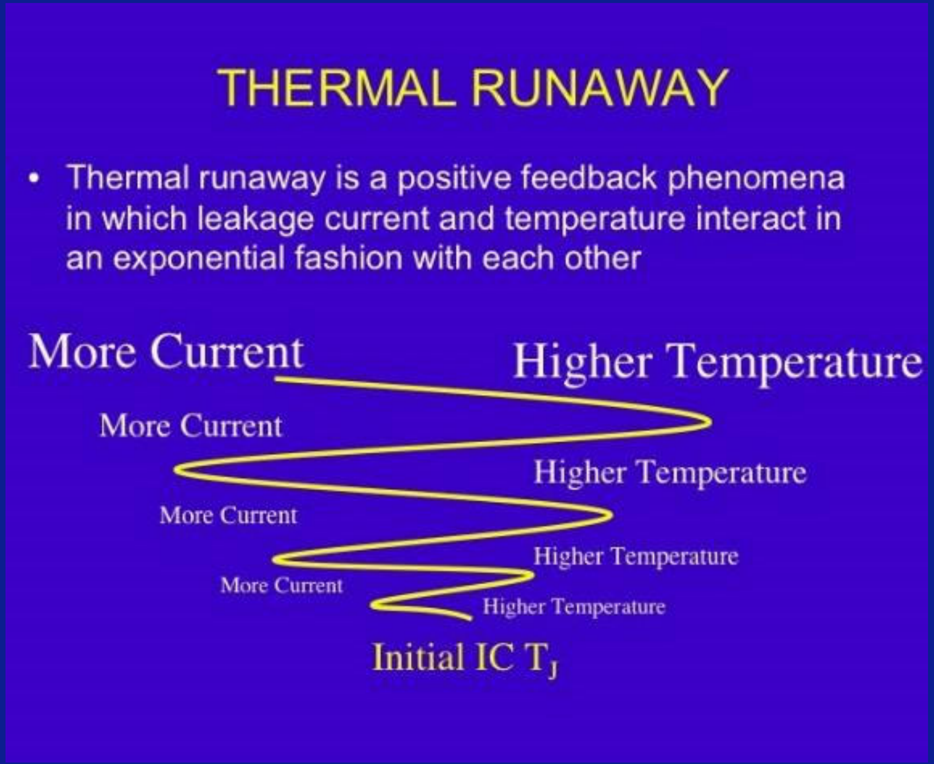
  $\Rightarrow$ More power dissipation

Device tests (Leakage current effects)

- **Test stresses DUTs with voltage and temperature**
  - **Voltage and/or temperature increase will increase leakage current**

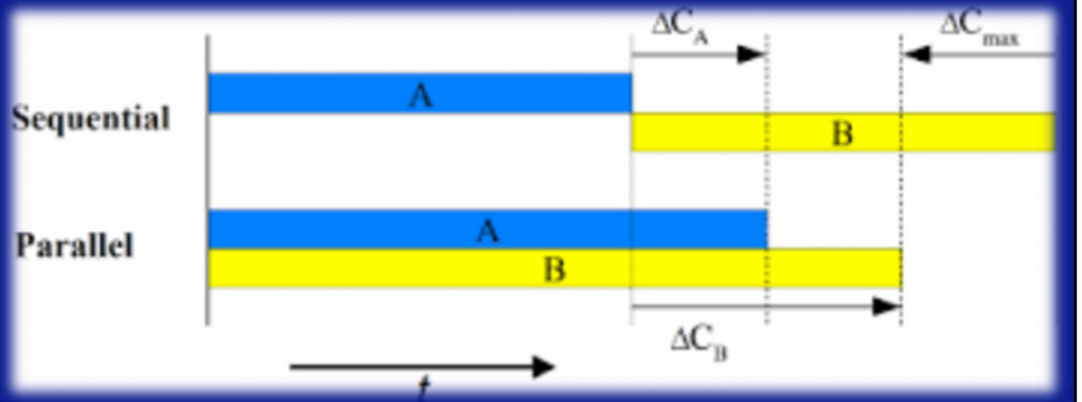
$$I_{leak} = \mu_0 C_{OX} \frac{W}{L} e^{b(V_{dd}-V_{ddo})} {V_T}^2 \left(1 - e^{\frac{-V_{dd}}{V_T}}\right) e^{\frac{-|V_{th}|-V_{off}}{nV_T}}$$

  - $\Rightarrow$ More power dissipation



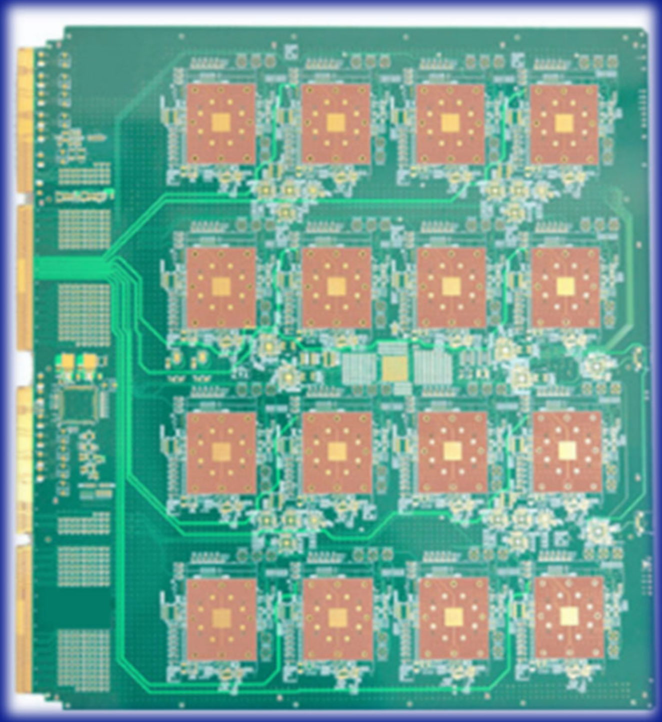
Parallelism (in test)

- Test time expensive on test floor
  - Target less test time per device
    - Maximize UPH (Units Per Hour)
- Push to run programs in parallel for test
  - ⇒ increases device power



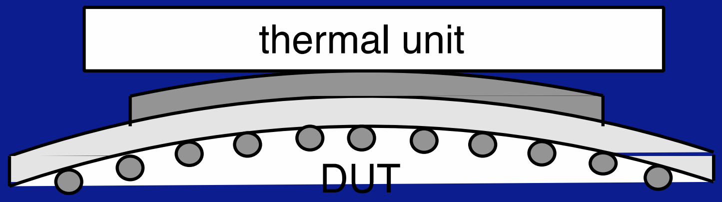
Parallelism (Mechanical)

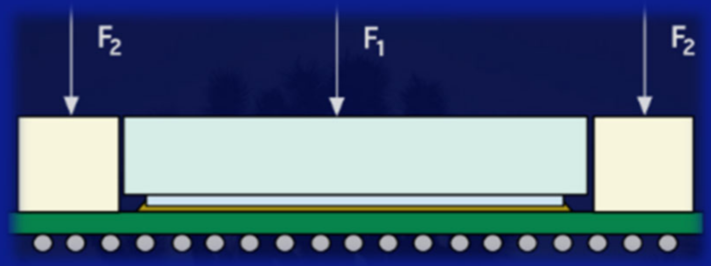
- ⇒ x64 and possibly higher
  - Maximize UPH (Units Per Hour)
- Power supply and cooling magnitude impractical
- Handler doesn't grow proportionally
  - Pitch is reduced
- Scaling of mechanism complexity
- Higher socket insertion force



Device handling (Forces)

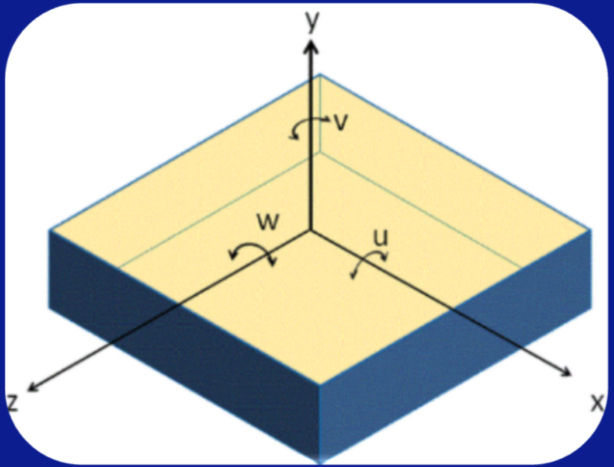
- Devices are not flat
- Devices can be bent with uneven loading
- Uniform applied force key to proper insertion
  - Socket and die force

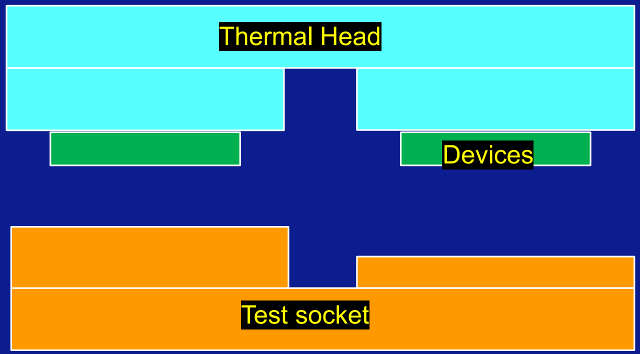




Device handling (Gimbaling and compliance)

- Accurately controlling device's 6 DOF is critical
  - Each device requires independent control
- Gimbal to make device co-planar & aligned with socket
- Compliance to account for tolerance stack up





Device handling (Thermal considerations)

- Thermal expansion mis-aligns components
- Multiple test temperatures
  - Re-alignment not practical
- Proper soak temps critical to test time
  - Direct effect on UPH

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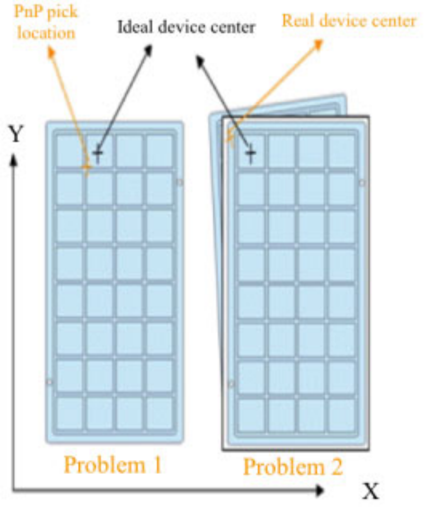
Device handling (IO alignments)

- Device transfer customer tray to handler
- Sub assembly tolerances must combine to small values
  - Tolerance stack up
- High speed moves > 1m distances
- Accelerations > 2 g's



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Thermal and Mechanical Challenges for Test Handlers

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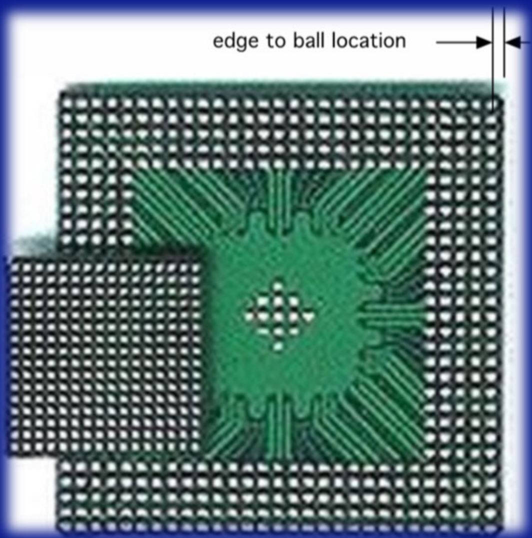
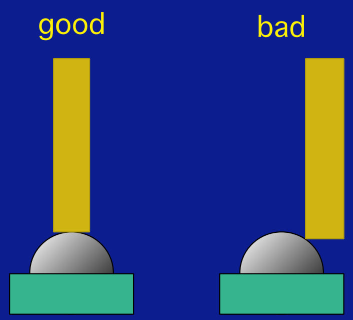
Device handling (Contactor alignment)

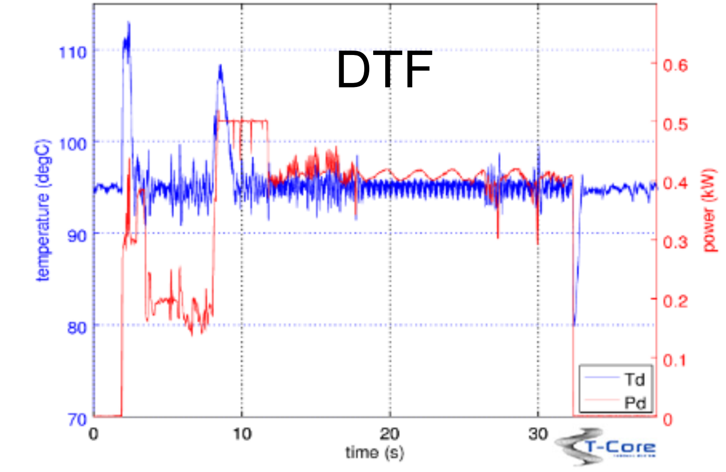
- 0.4mm pitch common
  - Tighter pitch coming
- Tolerances:
  - Device to edge tolerance
  - Other package tolerance
  - Thermal expansion
    - Cu lead frame 17 ppm/℃
    - Molding compound 10 – 25 ppm/ ℃
    - 100℃ temperature change
      - 25mm x 25mm package, 17 ppm/ ℃
      - → 0.04mm expansion (non-correctable)
      - Socket/contactor expansion must be considered

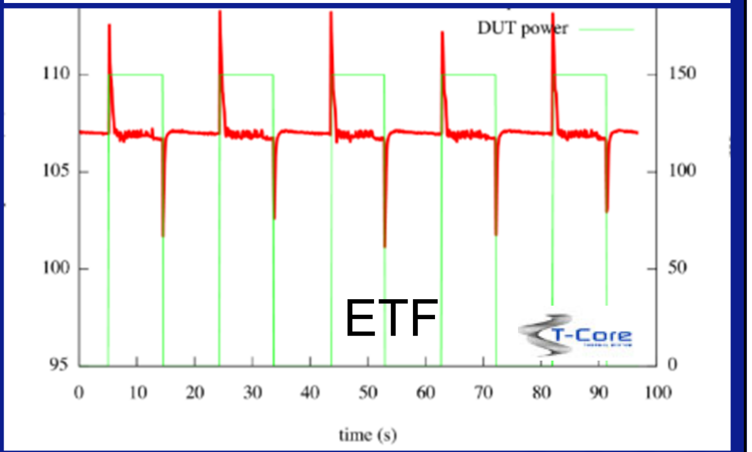


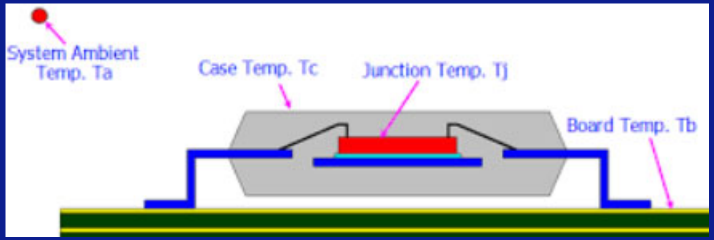


Temperature control (Control mode)

- Ideal test controls junction temp (Tj)
- Control system only as good as it's feedback
  - Tj feedback: DTF
  - Device power feedback: PF
  - No internal device feedback: ETF & HTF

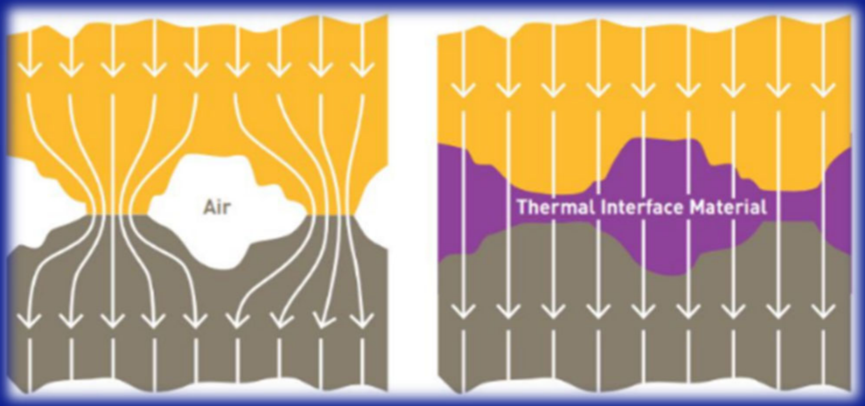


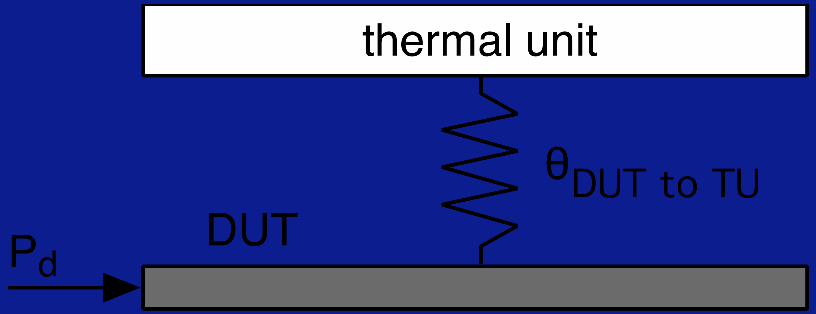




Temperature control (Thermal resistance)

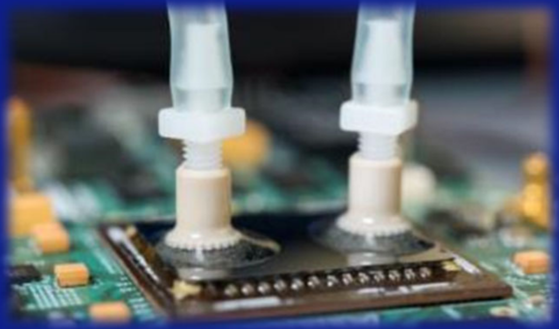
- 2 knobs for increased power dissipation
  - Lower thermal resistances
    - Interfaces
    - Device construction
  - Lower coolant temperature
    - Hot test best for power dissipation





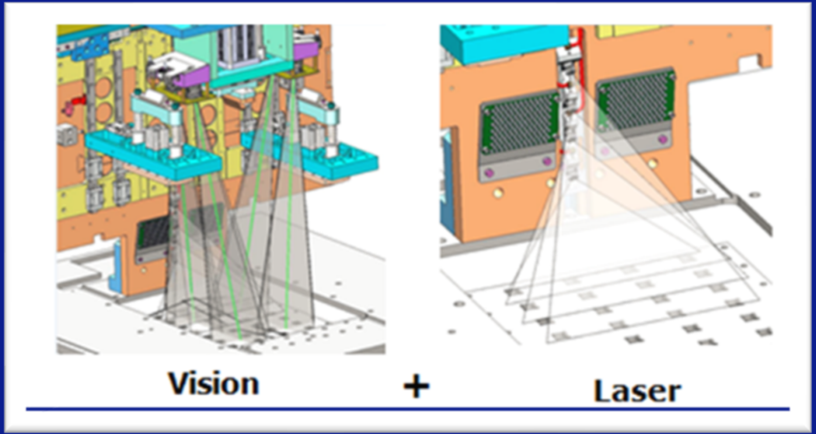
Temperature control (Cooling mediums)

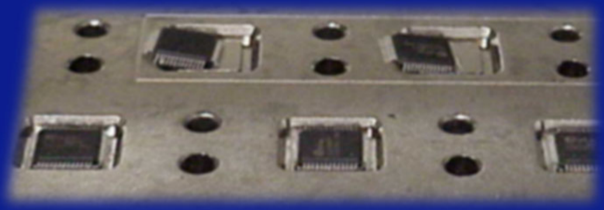
- Many options with different pros and cons
  - Customer preference/capabilities vary
  - Options: Air, water, HFE, LN2 & refrigerant
- Changing cooling mediums impractical in the field
  - Leads to over-engineered solutions



Vision System (Process control)

- Out of pocket detection
  - Prevent damaging parts during pick and place
- Damaged devices
- Dropped devices
- Stuck devices
- etc.

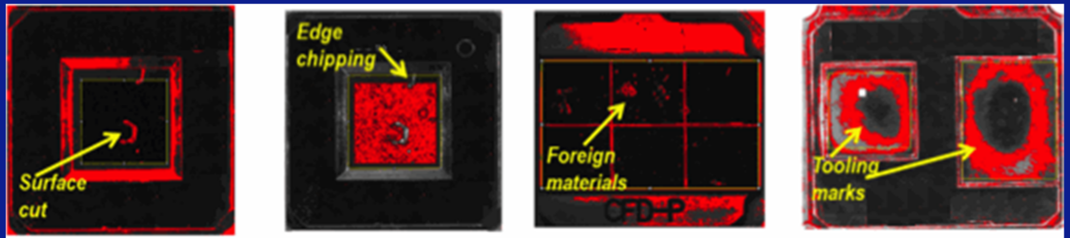




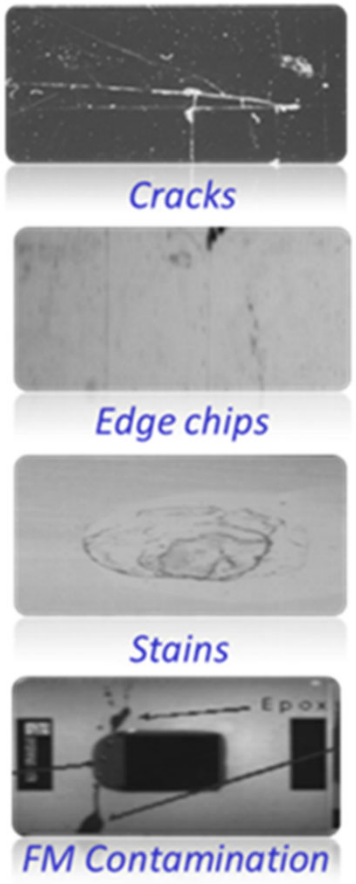
Device out of pocket

Vision System (Quality control)

- Look for device defects
  - Compare incoming to outgoing devices (handler induced?)
- Inspect chuck
  - Examine surface contacting device for contamination
    - Heater on thermal chuck
    - Pedestal (part of heater)



Surface cuts Edge chipping Foreign material Tooling marks



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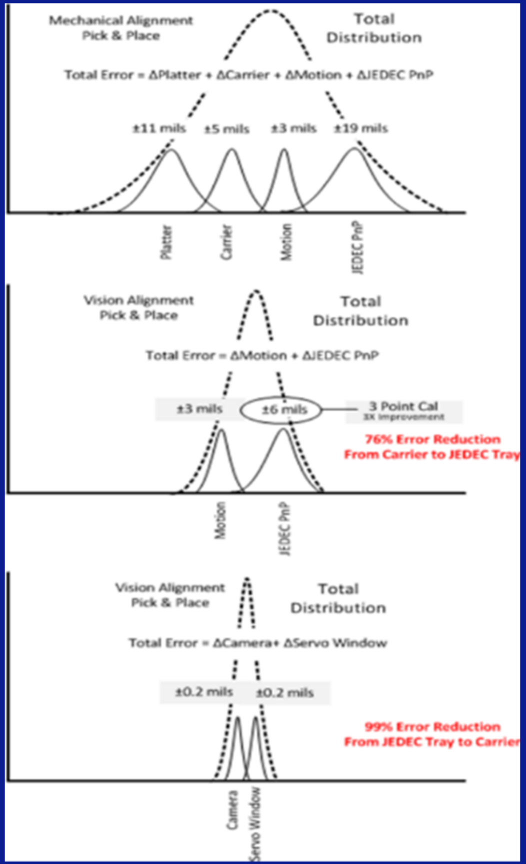
Vision Systems (Alignment)

- Tool calibration reduces ~75% of alignment errors
- In situ alignment eliminates ~99% of errors
- Based on device IO matrix (solder balls, etc) corrections in X, Y, and θ



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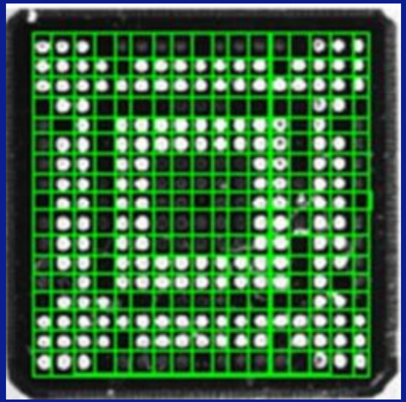
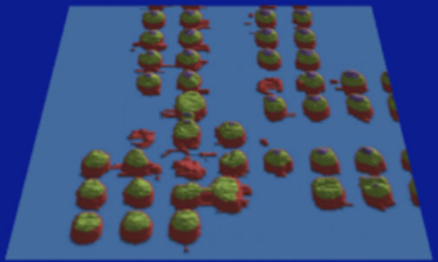
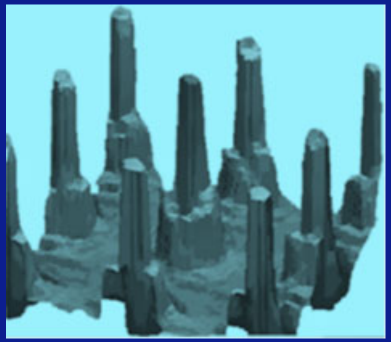
Vision system (Bottom side defects)

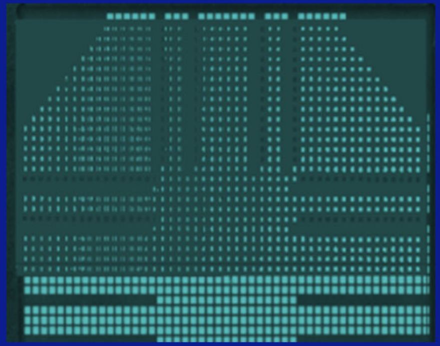
- BGA:
  - Damaged balls
  - Missing balls
  - Extra balls
  - Solder debris



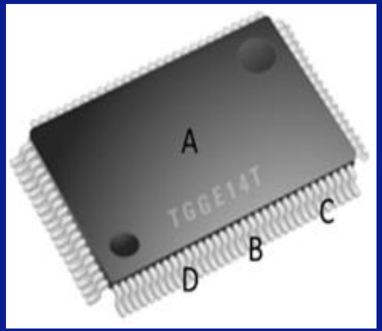




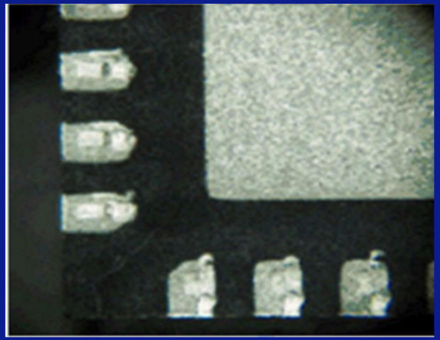
PGA – bent pin



LGA - contamination



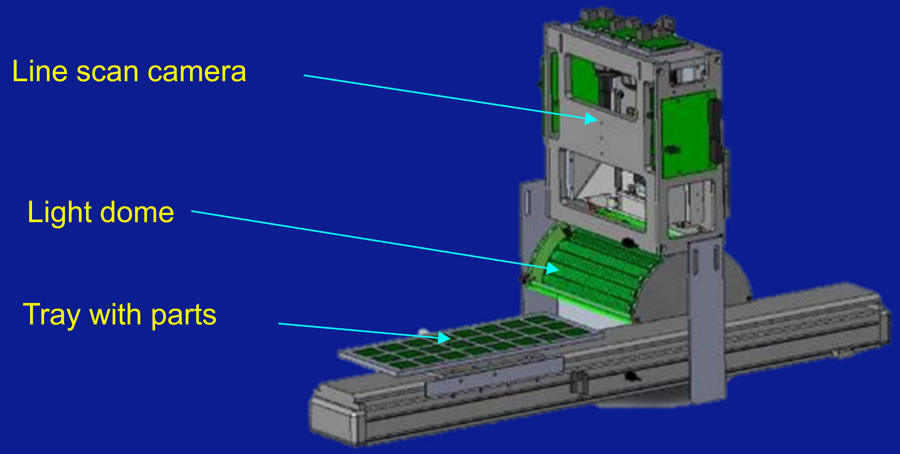
QFP – bent lead

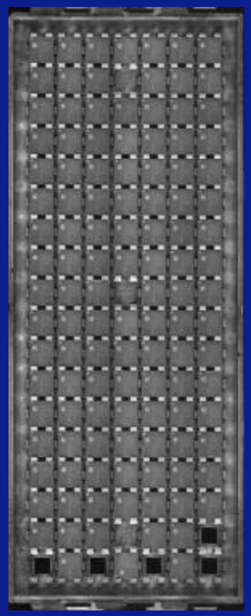


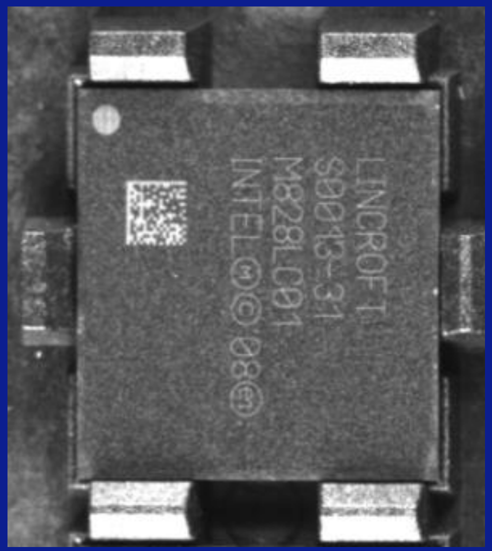
QFN – damaged pad

Vision system (Tray level)

- Tray level line scans:
  - Empty pocket detection
  - 2DID for sort/binning
  - Part orientation using pin 1





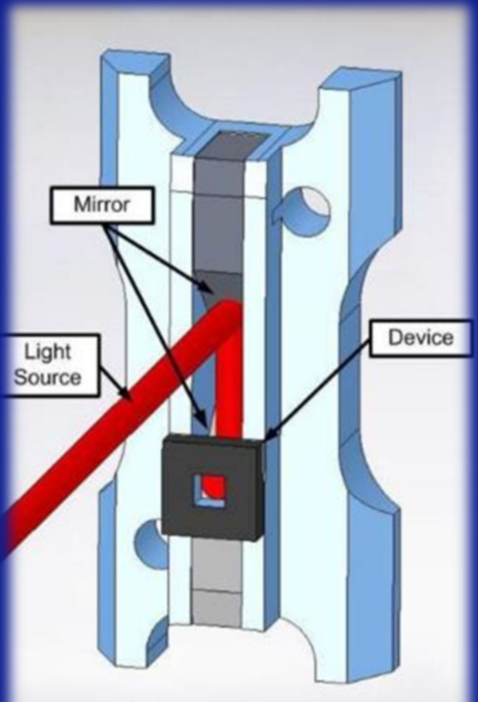


Microelectromechanical systems (MEMS)

- Testing requires physical stimulus
- Cost of test up to 50% of device cost
- Market drivers:
  - Lower cost over time
  - Higher functionality (i.e., complexity) over time
- Stimulus mechanism temperature range (-55 ℃ to 160 ℃)

MEMS (Optical sensors)

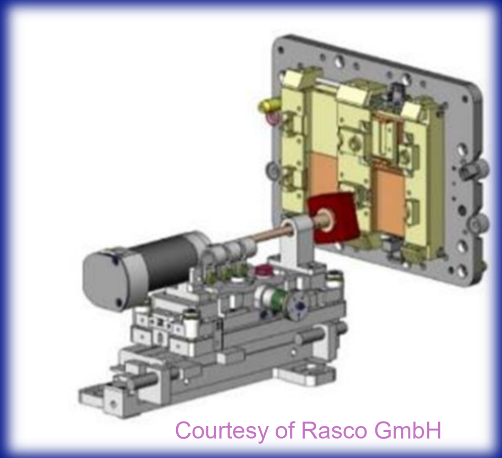
- Geometric accuracy
  - Positioning accuracy
  - Precision mirrors
- Intensity control
- Light source needs to be thermally isolated from temperature conditioned device



Courtesy of Rasco GmbH

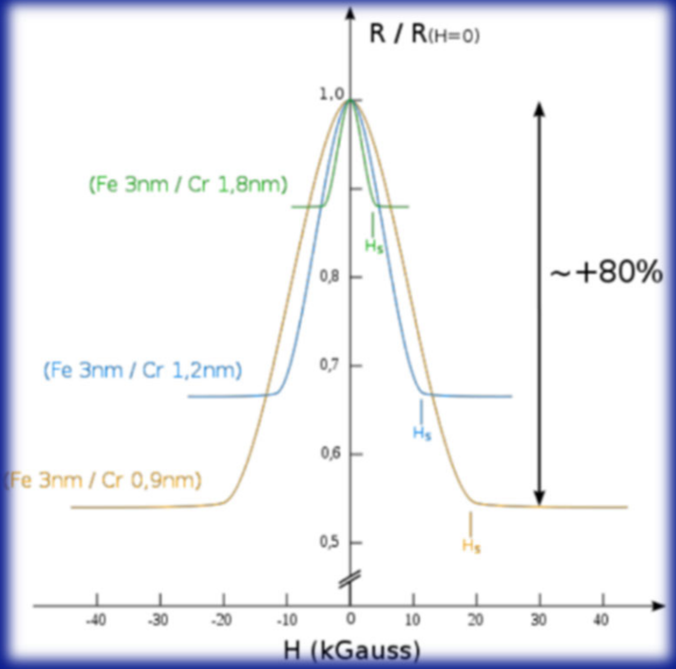
MEMS (Hall sensors)

- Measurement of magnetic flux density
- Moving a device into magnetic field of a coil
  - Change magnetic field intensity
- Moving a device into magnetic field of a permanent magnet
  - Change orientation of magnetic field (rotate magnet)



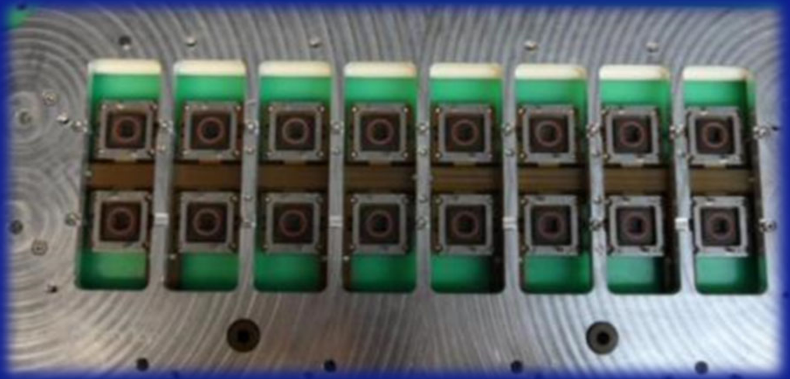
MEMS (GMR)

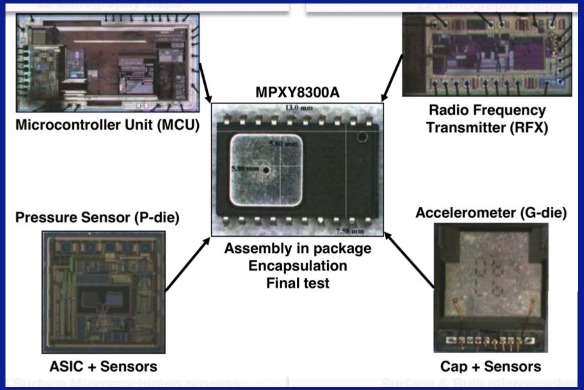
- GMR – giant magnetoresistance
- Resistance dependent on magnetic field
- For test
  - Change of the magnetic field in the contactor
  - Measurement of magnetic field intensity



MEMS (Pressure transducers)

- From millibars (absolute) to 10 bar
  - Vacuum/pressure in single test
- Multiple pressure levels
  - Minimum stabilization time
- Live or dead bug access
- Seal to device
- Minimal air consumption
- High accuracy to set point
- Temperature/humidity control
- Low noise
- Radio RFX transmission (tire sensor)





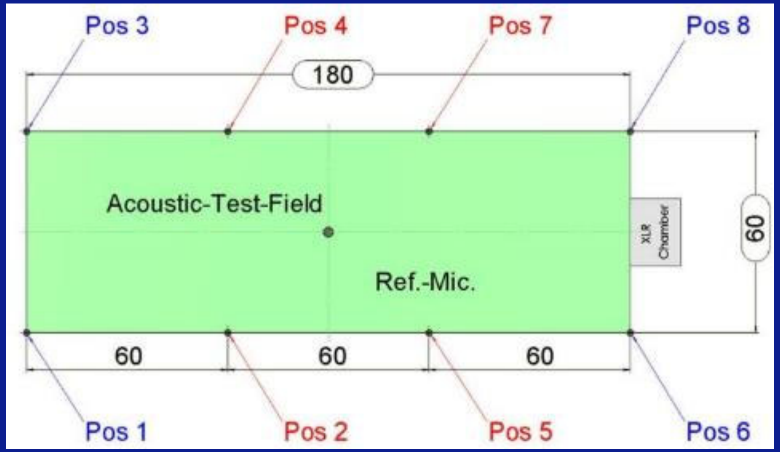
tire sensor

MEMS (Acoustic sensors)

- Frequency response
  - 50Hz. to 20kHz.
  - 100Hz. ←→ 3.4m wavelength
- Sound pressure level
- Sensitivity
- Distortion
- Signal to noise ratio
- Isolation from ambient noise (handler!)
- Live and dead bug configurations

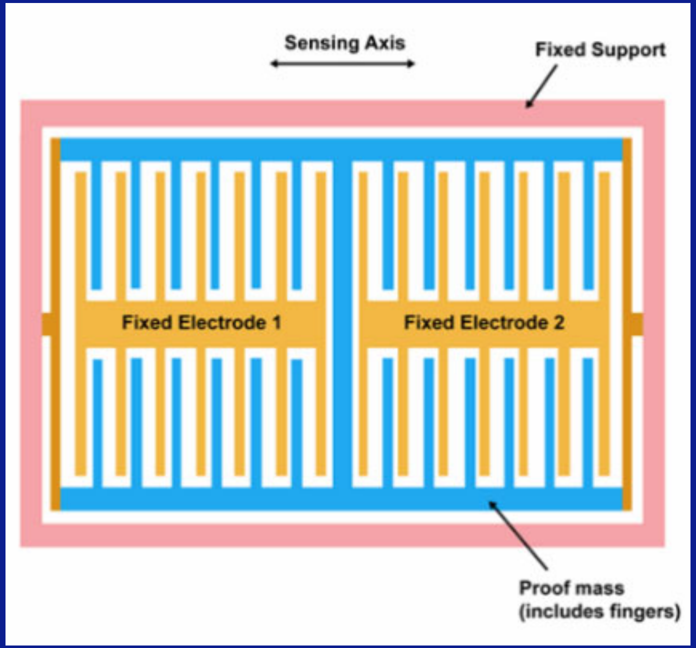
MEMS (Acoustic sensors)

- Stimulus uniformity over parallel test sites



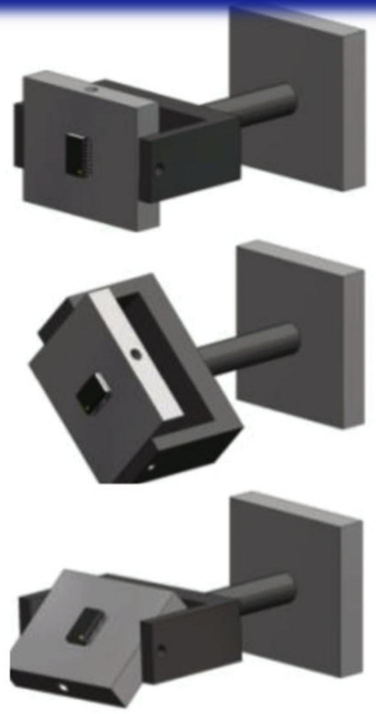
MEMS (Low g/gyro)

- Static test
  - Measure low g by aligning to gravity
  - Can measure multiple axes
  - *Any strain exerted on device can affect output!*
- Dynamic test
  - Values of g > 1
  - Gyro performance
- Connectivity to devices complex
- BIST available but requires more device area (higher cost)
  - Tradeoff: cost of test vs. extra area



https://www.siliconsensing.com/technology/mems-accelerometers/

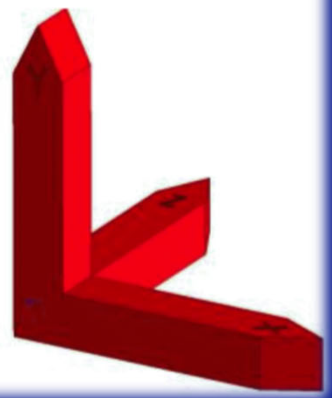
MEMS (Low g/gyro – static test)



X: 0.0 g
Y: -1.0g
Z: 0.0g

X: 0.71g
Y: -0.71g
Z: 0.0g

X: 0.0 g
Y: -0.71g
Z: 0.71g

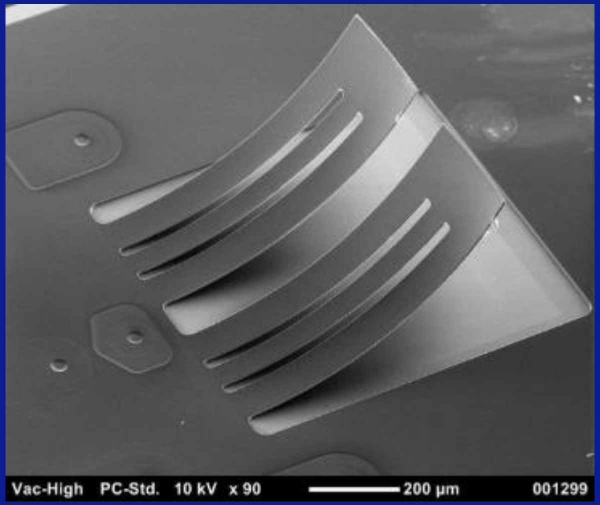


MEMS (Multifunction)

- Inertial measurement units (IMUs)
  - Tri-axis, digital accelerometer
  - Tri-axis, digital gyroscope
  - Tri-axis, digital magnetometer
  - Digital pressure sensor

MEMS (Viscosity sensor)

- Bio-sensor, measures blood viscosity
- Not practical to test with fluids!



Conclusion

- Devices will continue to get more difficult to test
- Must continue to innovate and keep up with technology
- Must avoid being the bottleneck to progress!!