

Thermal and Mechanical Challenges for Test Handlers

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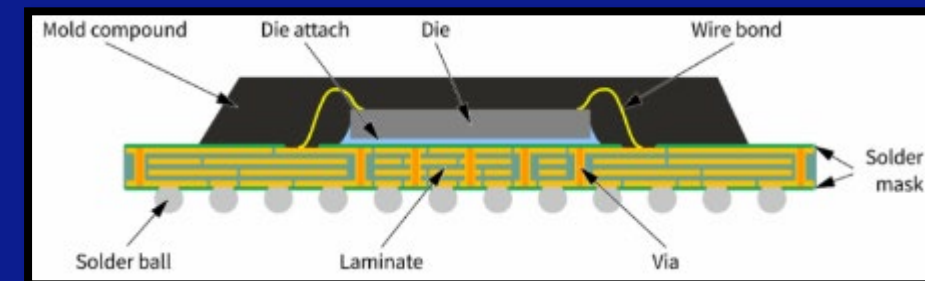
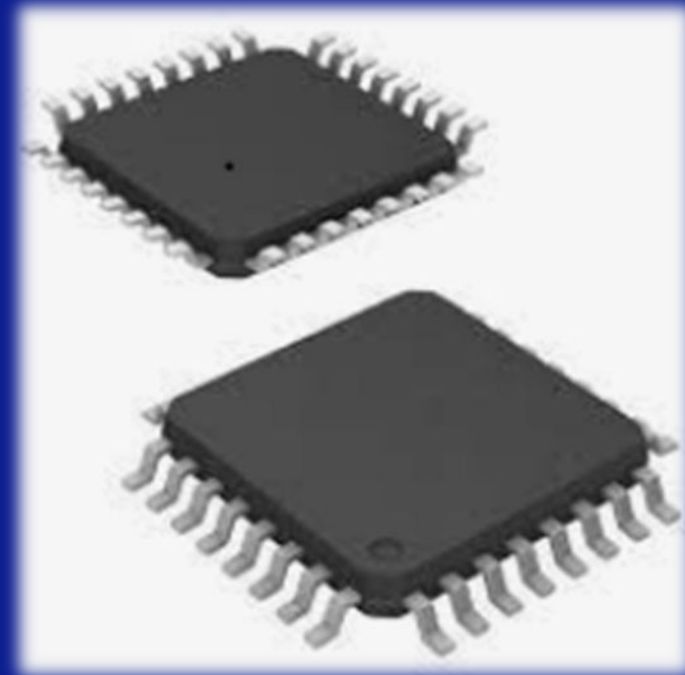
Industry Direction

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



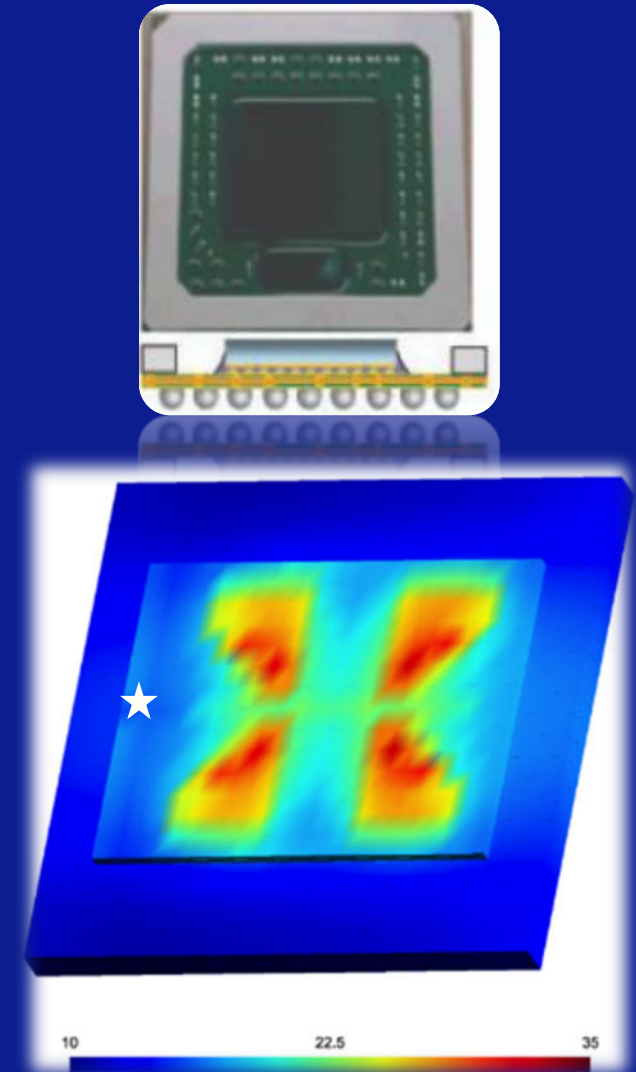
Different Device Types (Smaller devices)

- 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 < 2 mm x 2 mm
 - Pick & place vs thermal fighting for limited area
 - Mechanical alignments
 - Smooth handling a must!
 - Fragile leads on some devices (QFP shown)



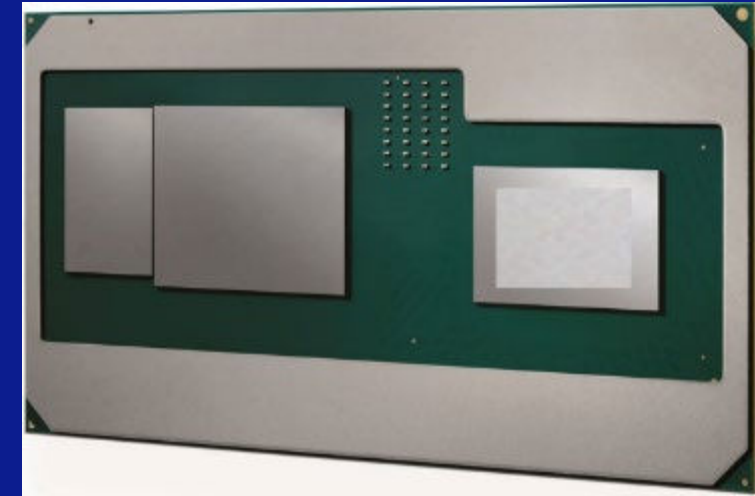
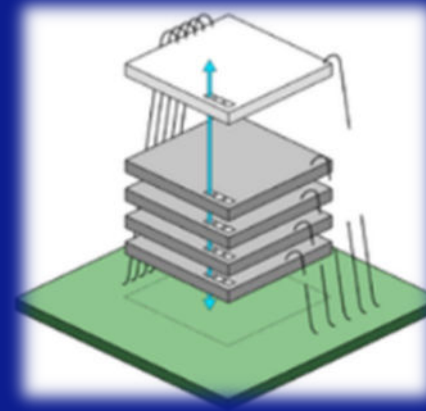
Different Device Types (Large devices)

- 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



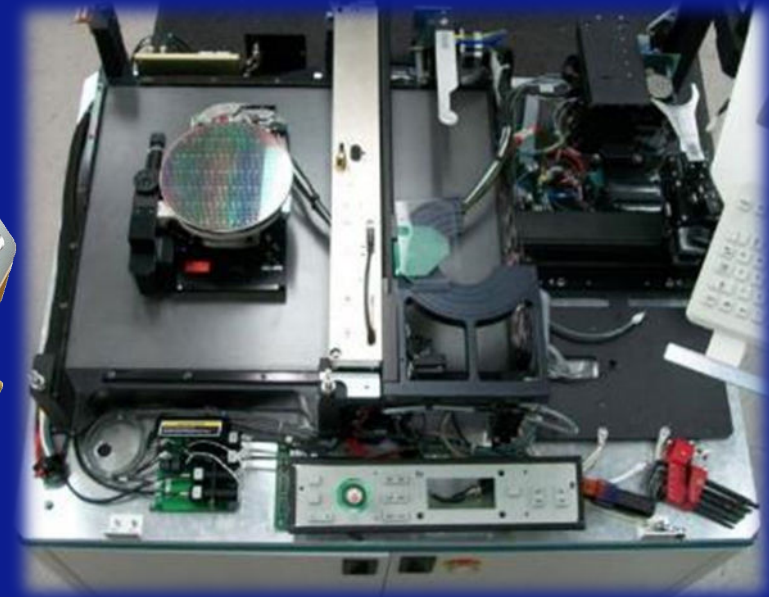
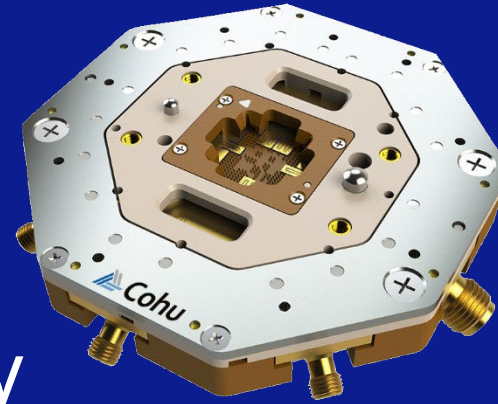
Different Device Types (Larger devices)

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



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

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

- » E_a is the activation energy (from reference table)
- » k is Boltzmann's constant (8.617×10^{-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

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
⇒ More power dissipation

Device Tests (Leakage Current Effects)

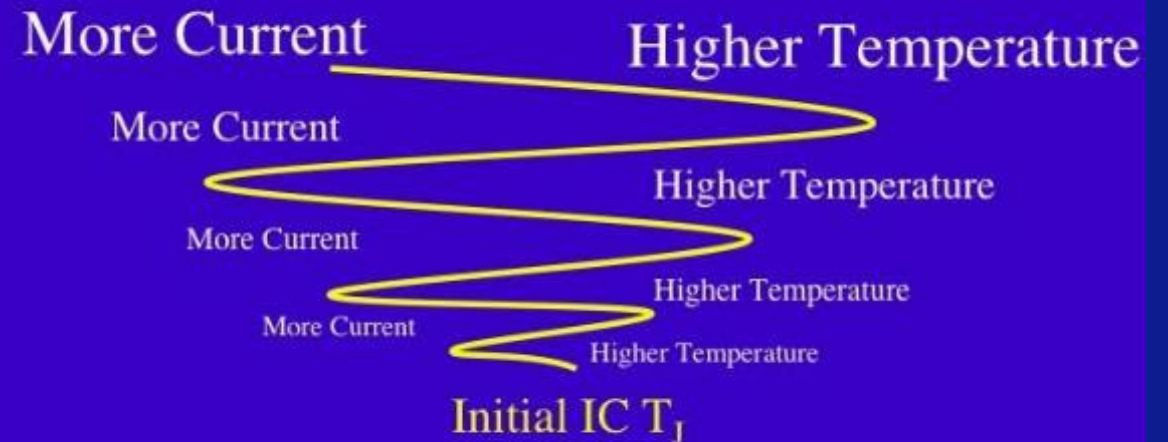
- Test stresses DUTs with voltage and temperature
 - Voltage and/or temperature increase will increase leakage current

$$I_{leak} = \mu_0 C_{OX} \frac{W}{L} e^{b(V_{dd} - V_{dd0})} V_T^2 \left(1 - e^{\frac{-V_{dd}}{V_T}} \right) e^{\frac{-|V_{th}| - V_{off}}{nV_T}}$$

- $\Rightarrow$ More power dissipation

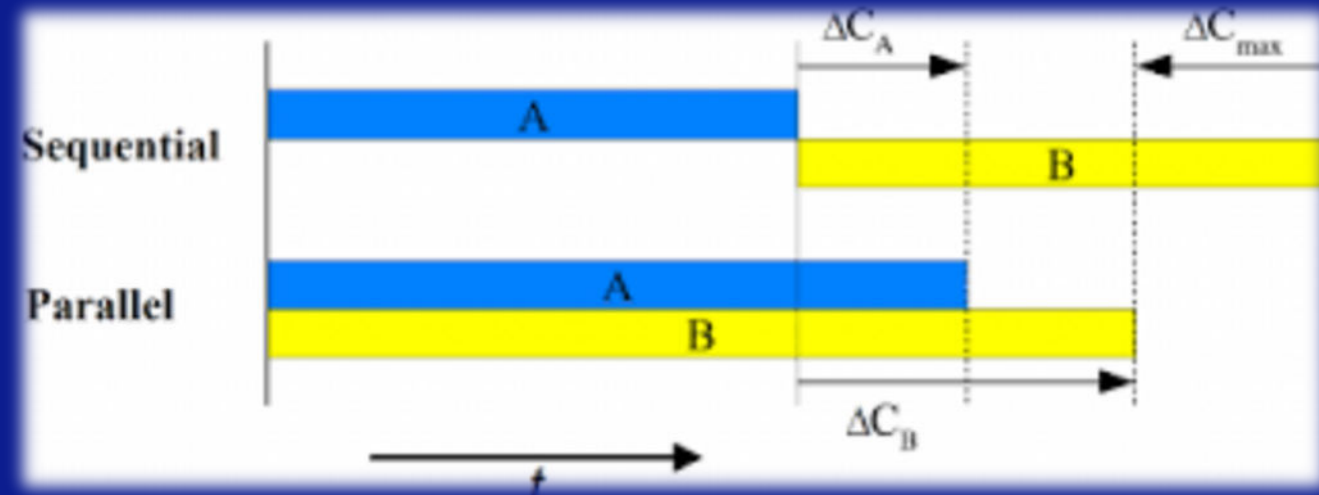
THERMAL RUNAWAY

- Thermal runaway is a positive feedback phenomena in which leakage current and temperature interact in an exponential fashion with each other



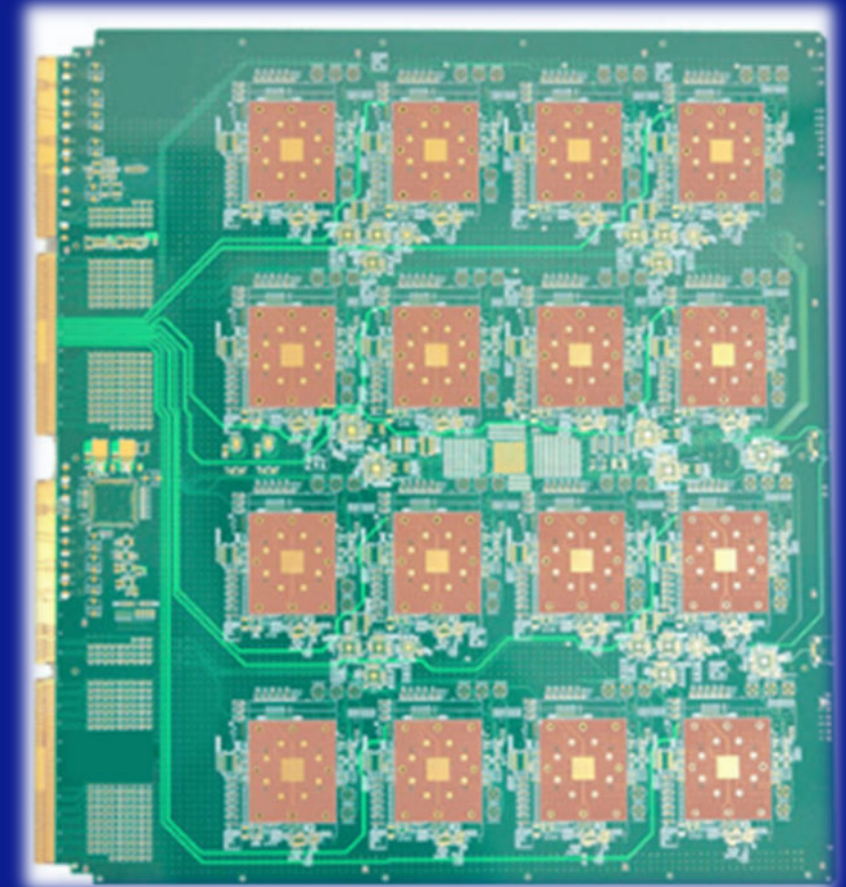
Parallelism (in Test)

- 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
 - $\Rightarrow$ increases device power



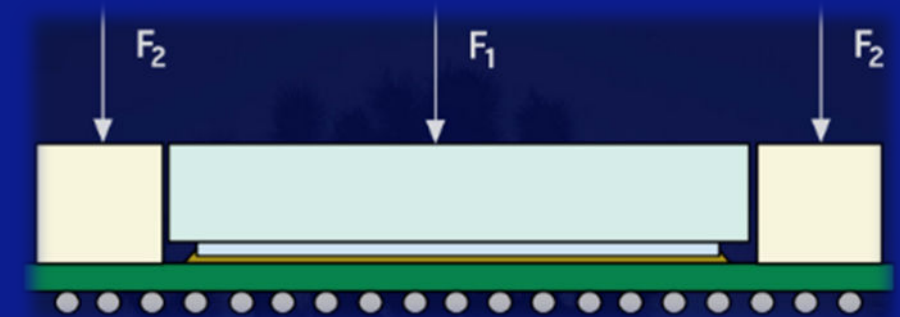
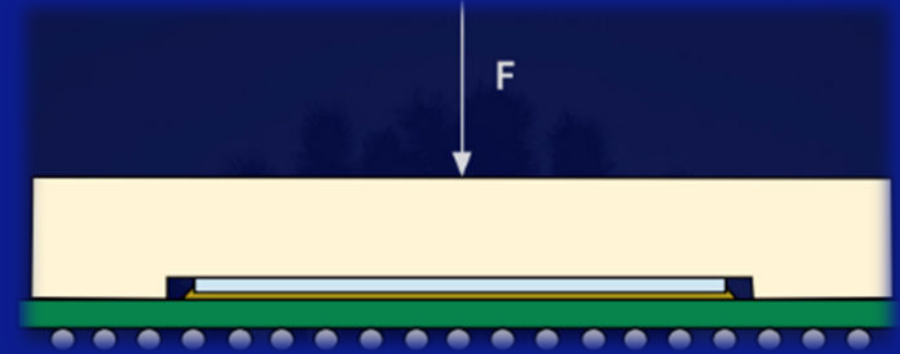
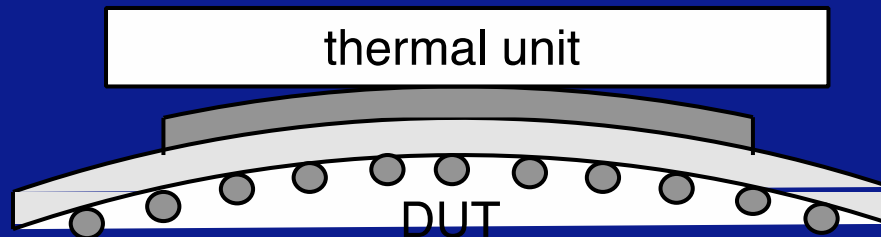
Parallelism (Mechanical)

- $\Rightarrow$ 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



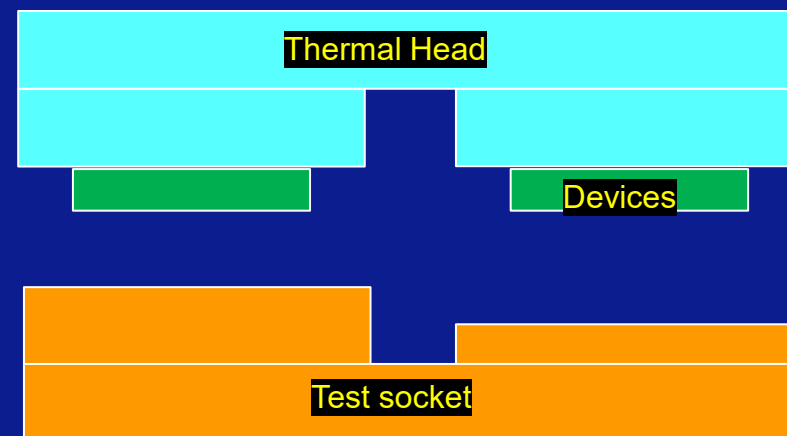
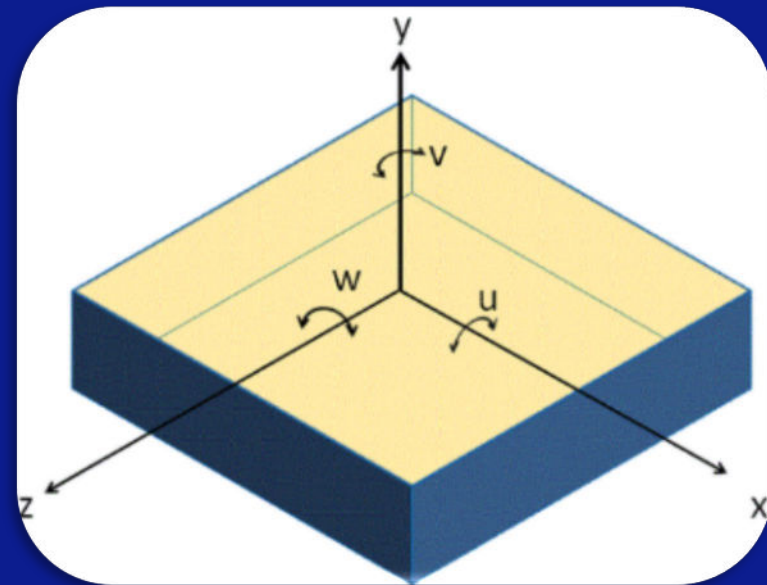
Device Handling (Forces)

- 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 coplanar & aligned with socket
- Compliance to account for tolerance stack up



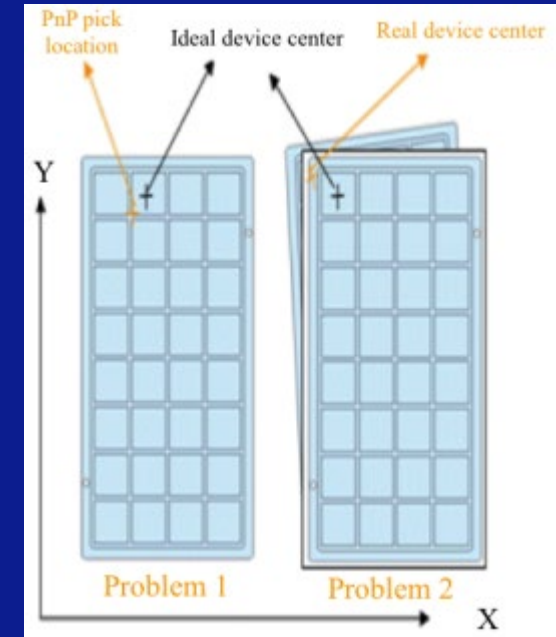
Device Handling (Thermal Considerations)

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



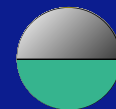
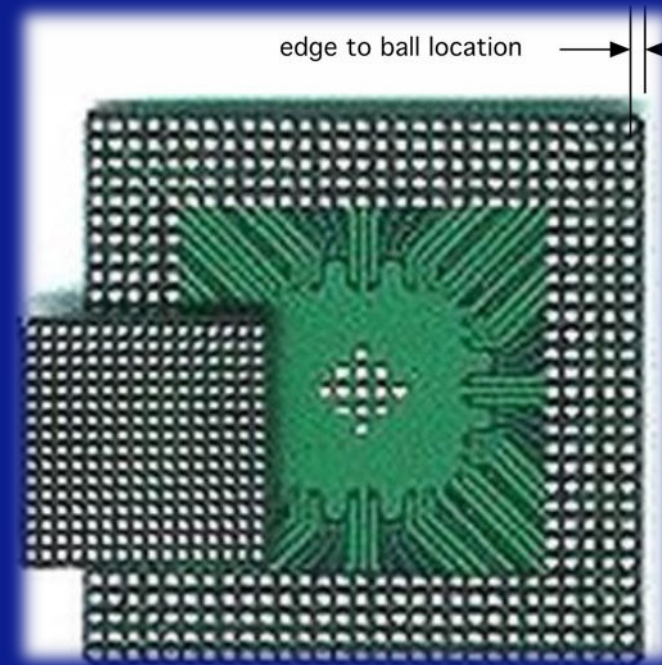
Device Handling (IO Alignments)

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



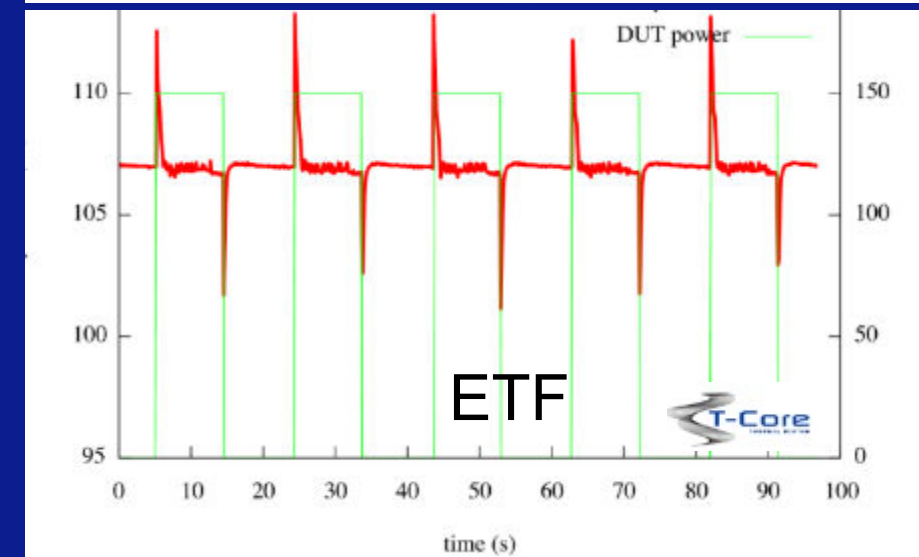
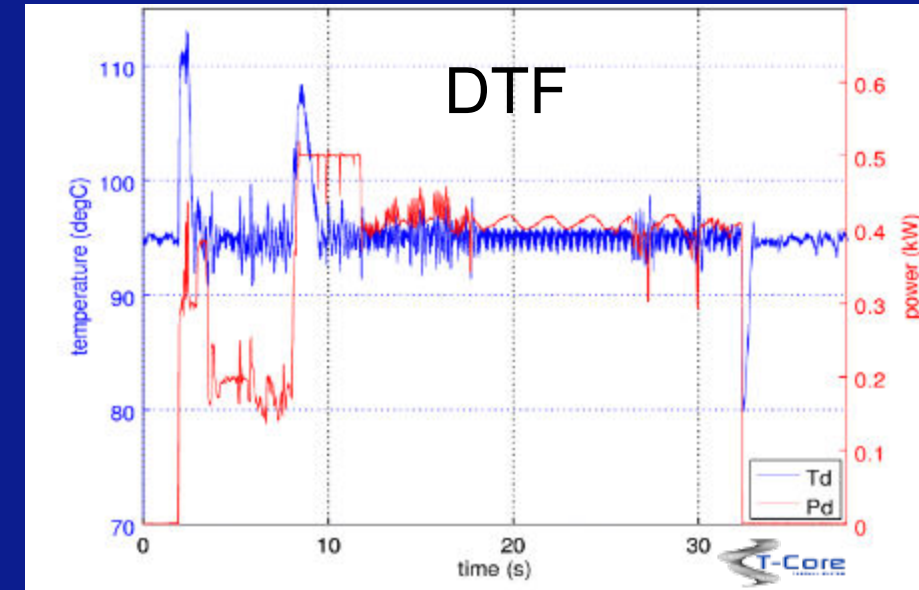
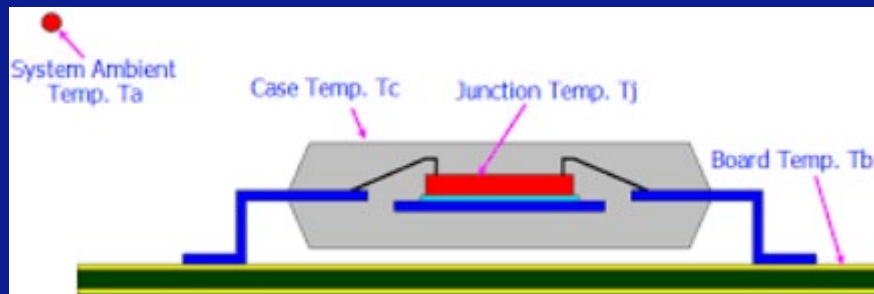
Device Handling (Contactor Alignment)

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



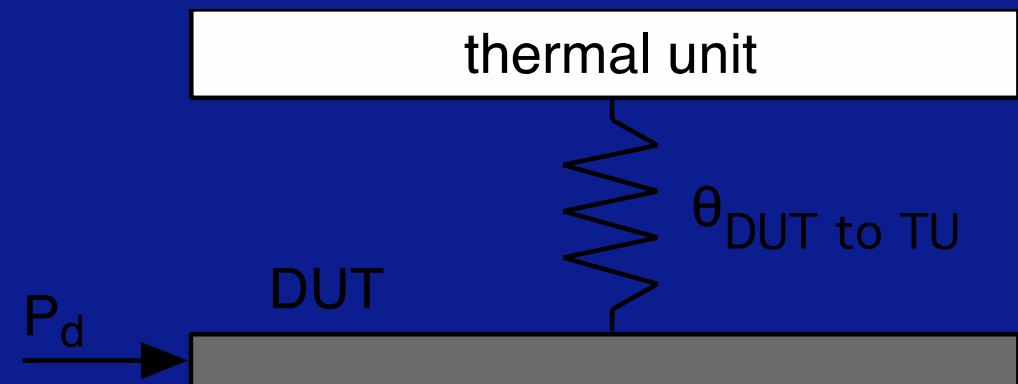
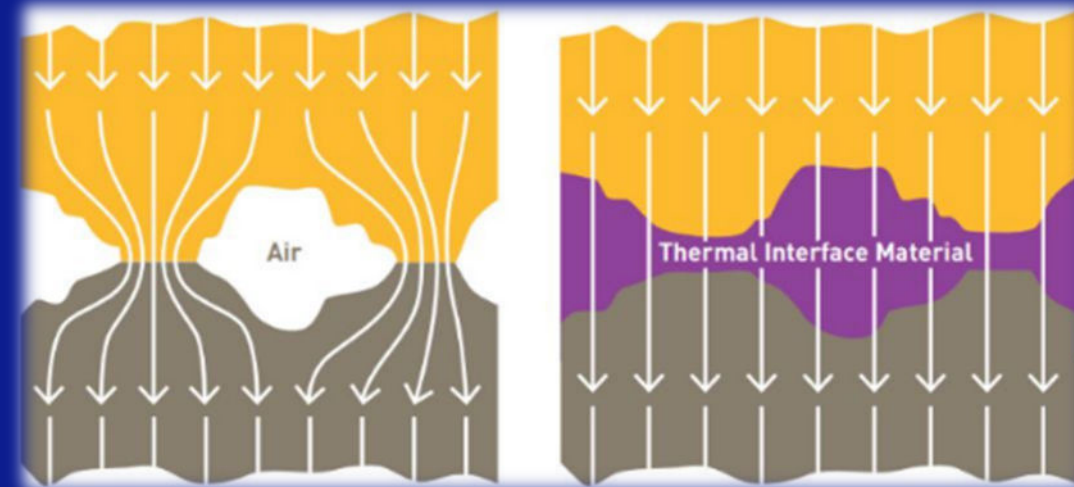
Temperature Control (Control Mode)

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



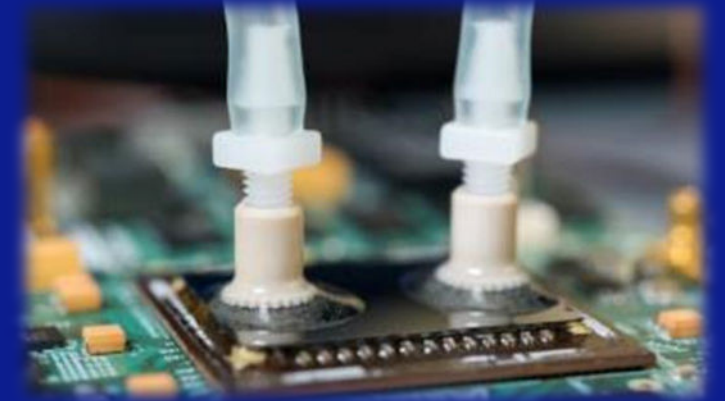
Temperature Control (Thermal Resistance)

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



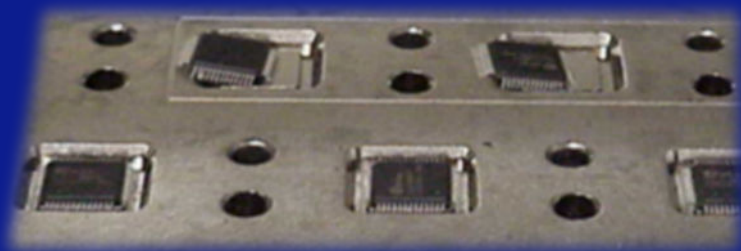
Temperature Control (Cooling Mediums)

- 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

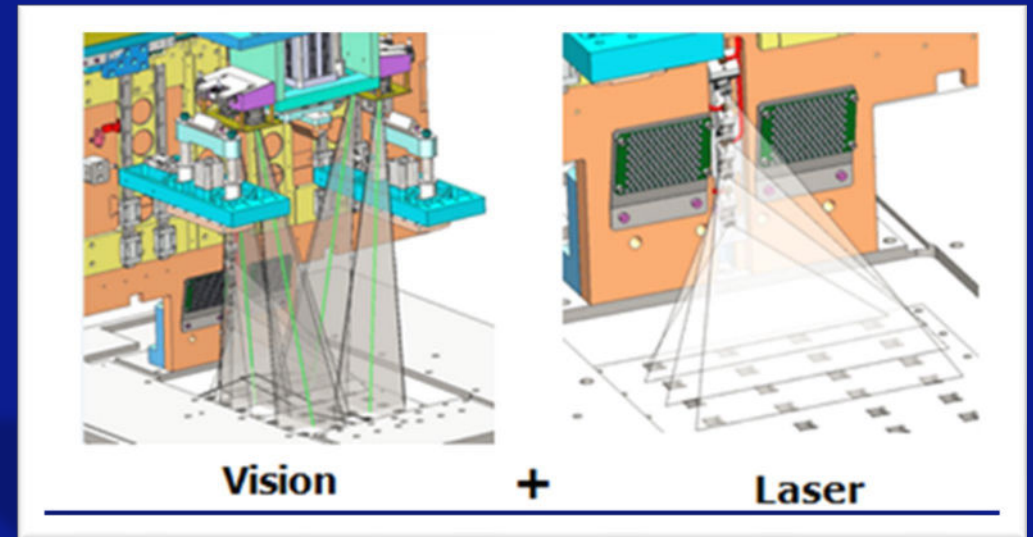


Vision System (Process Control)

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

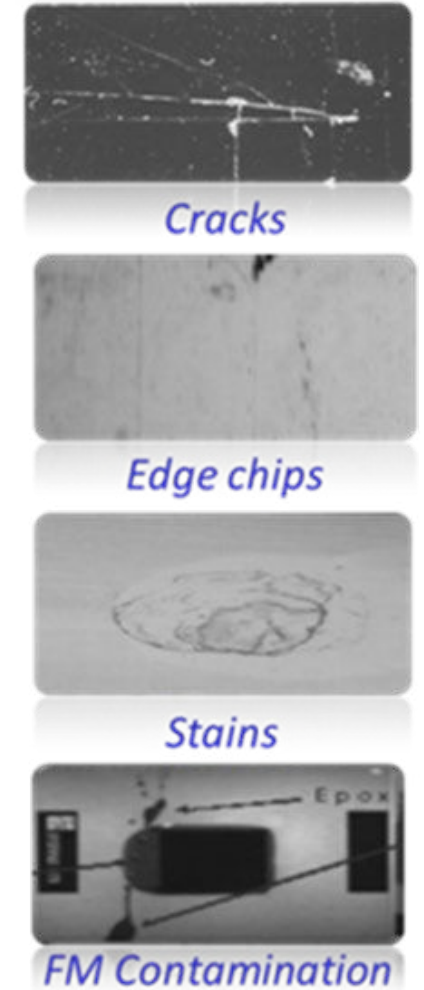
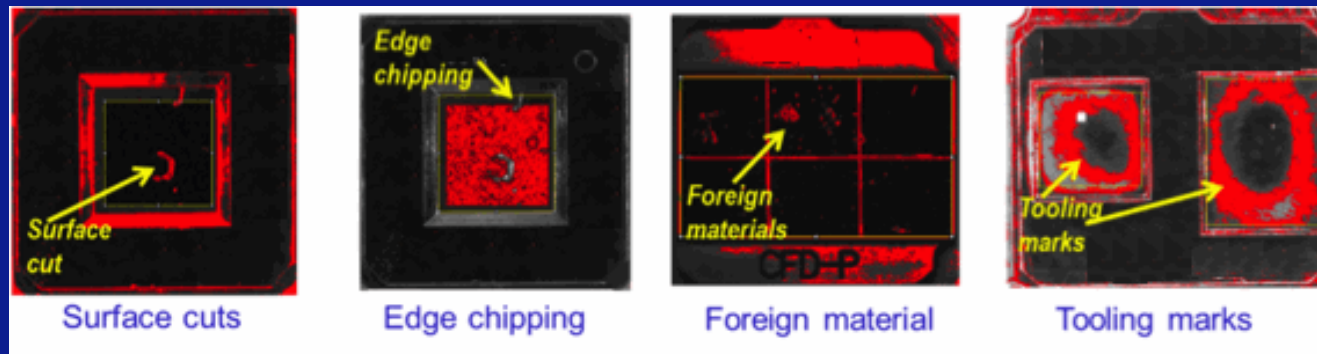


Device out of pocket



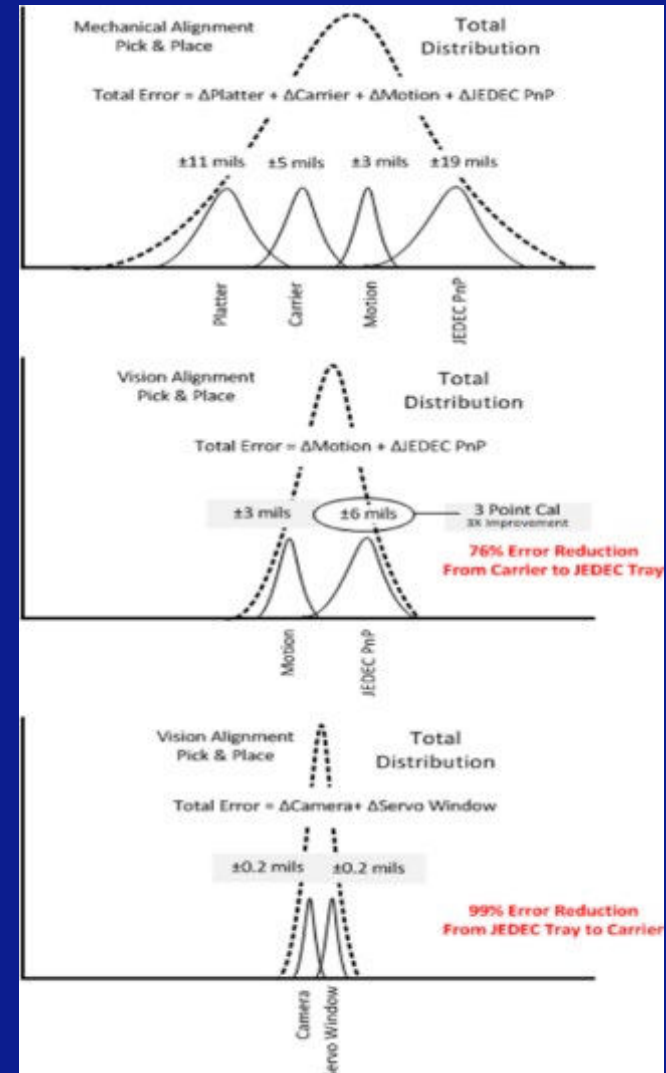
Vision System (Quality Control)

- 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)



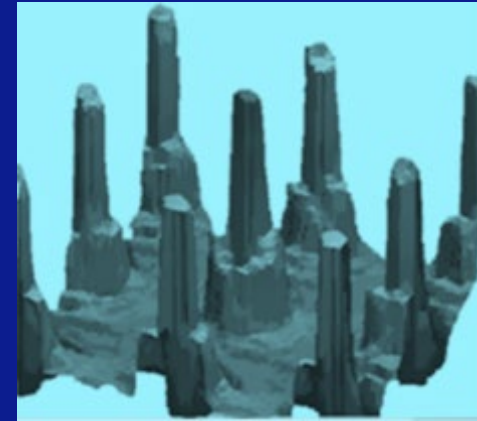
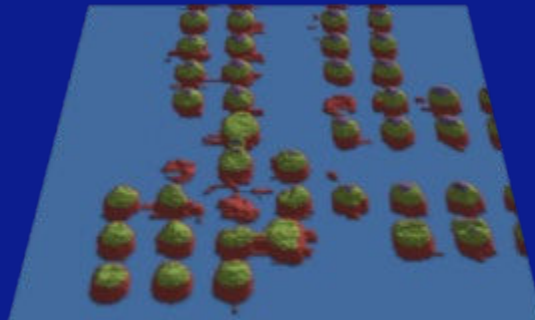
Vision Systems (Alignment)

- 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

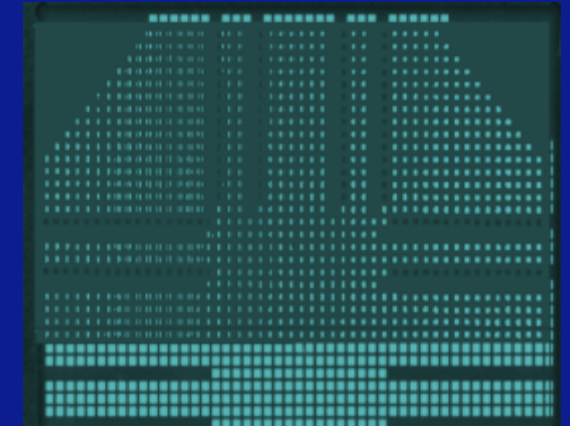


Vision System (Bottom Side Defects)

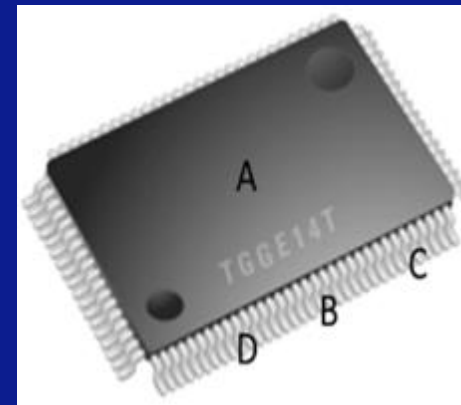
- BGA:
 - Damaged balls
 - Missing balls
 - Extra balls
 - Solder debris



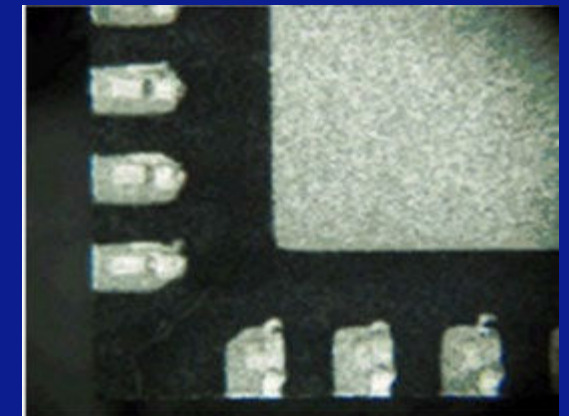
PGA – bent pin



LGA - contamination



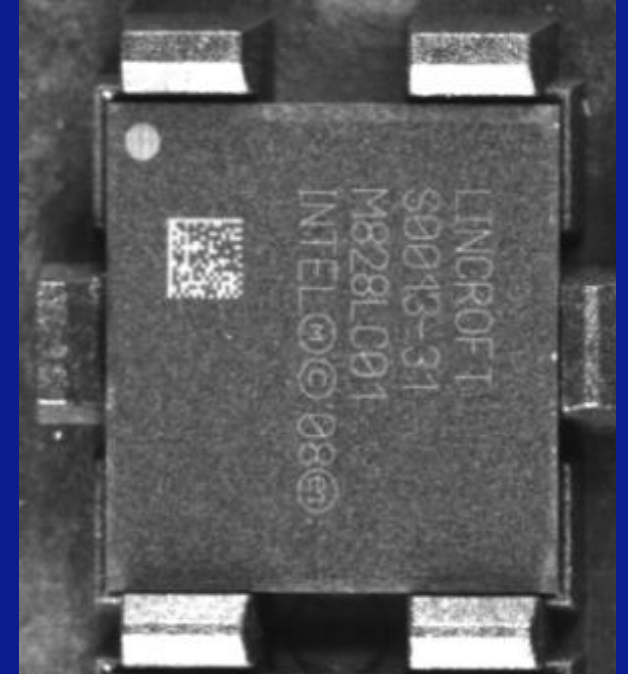
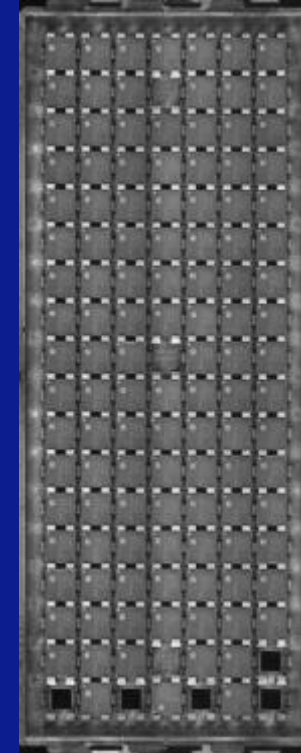
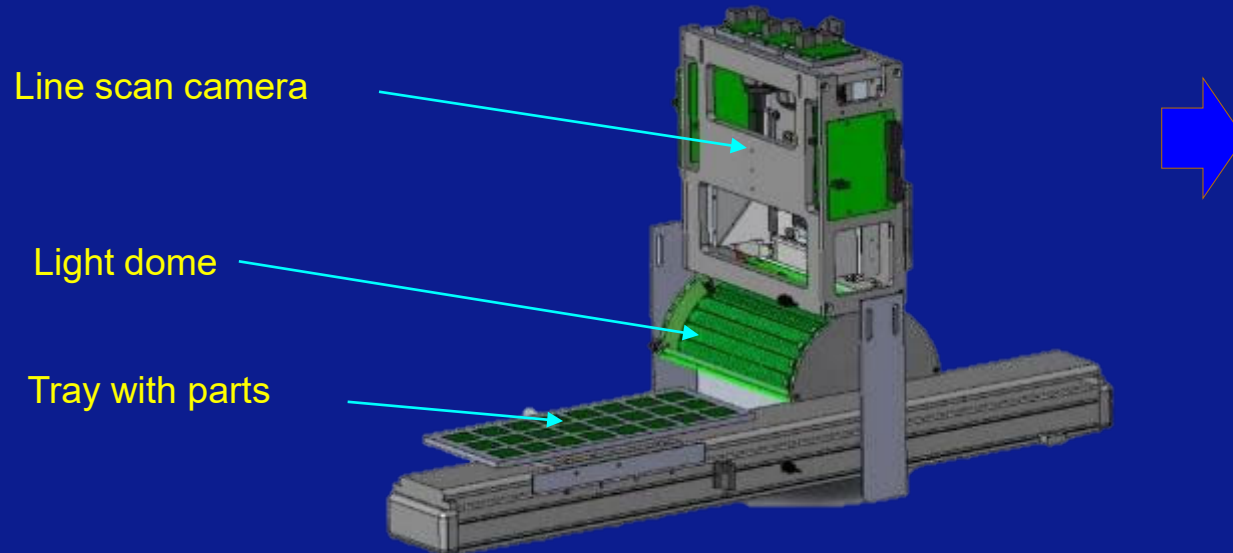
QFP – bent lead



QFN – damaged pad

Vision System (Tray Level)

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



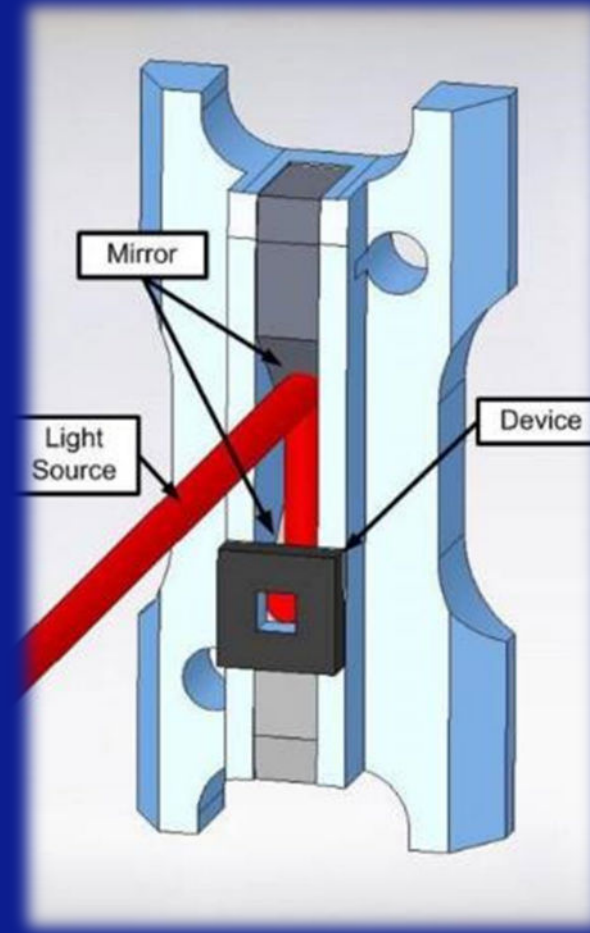
Microelectromechanical Systems (MEMS) Cohu

- 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°C to 160°C)



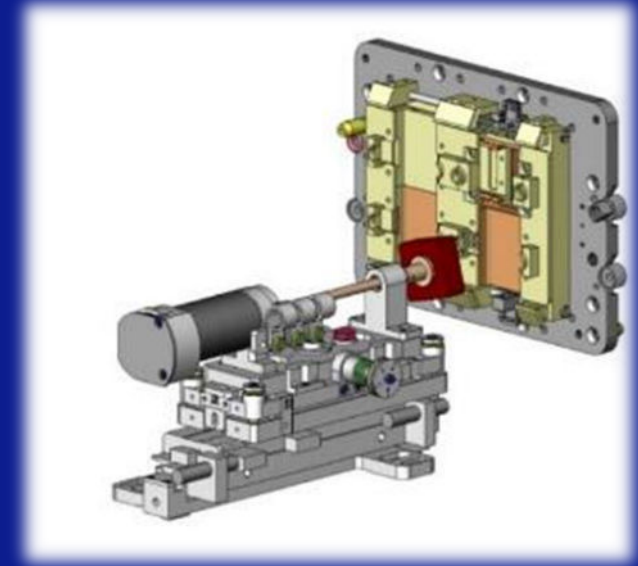
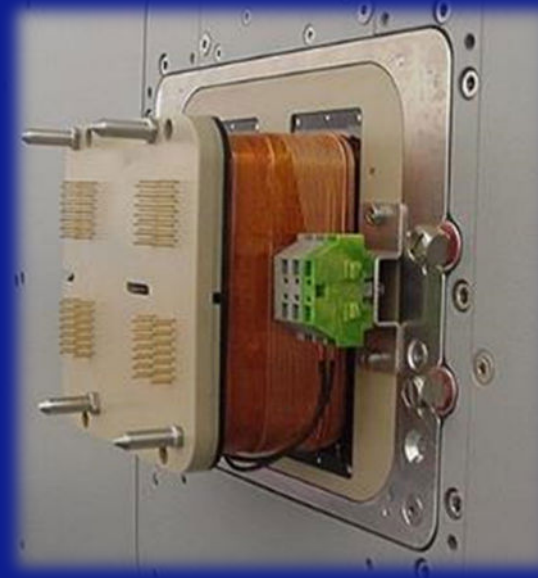
MEMS (Optical Sensors)

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



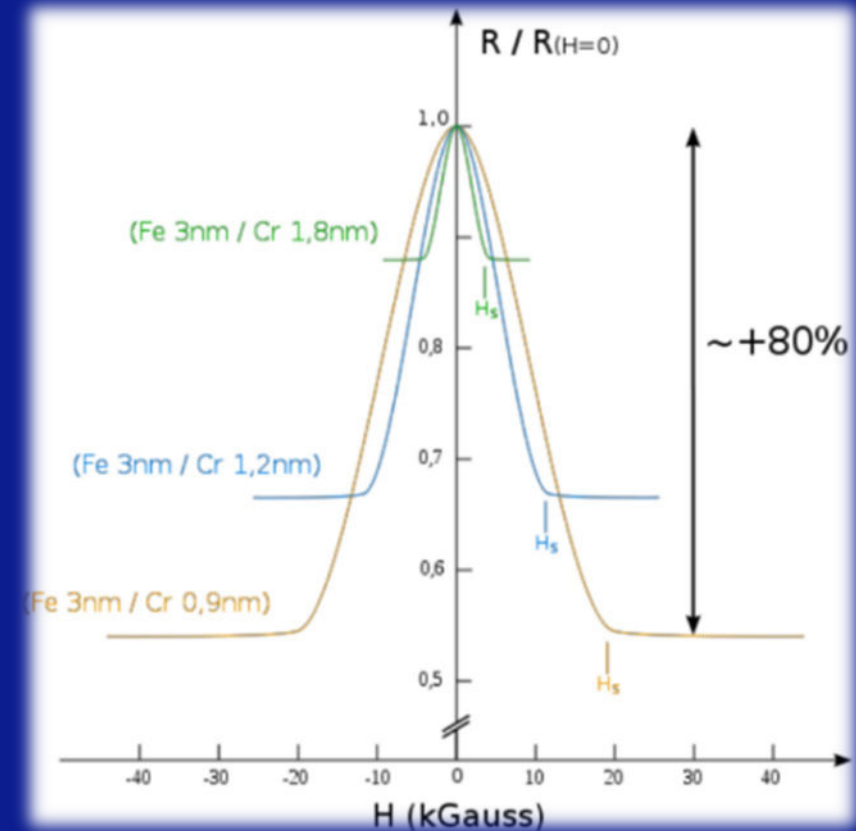
MEMS (Hall Sensors)

- 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)



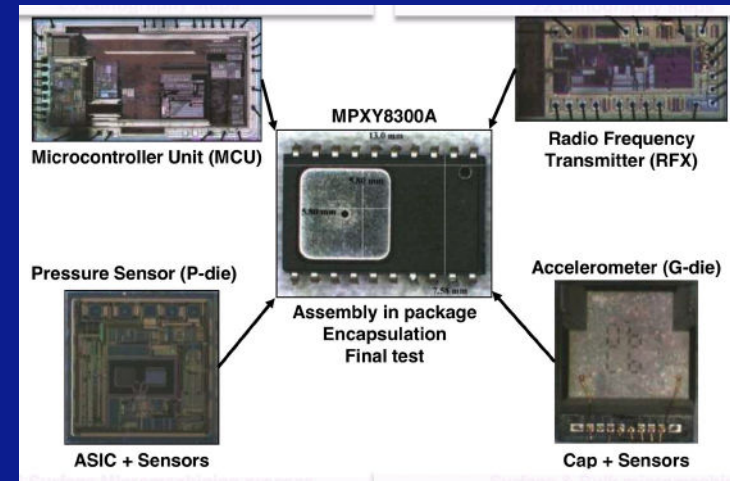
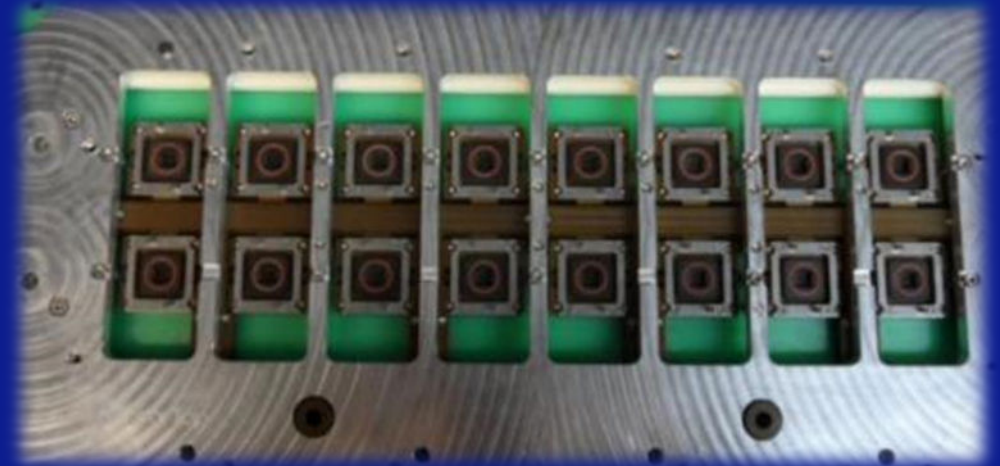
MEMS (GMR)

- 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

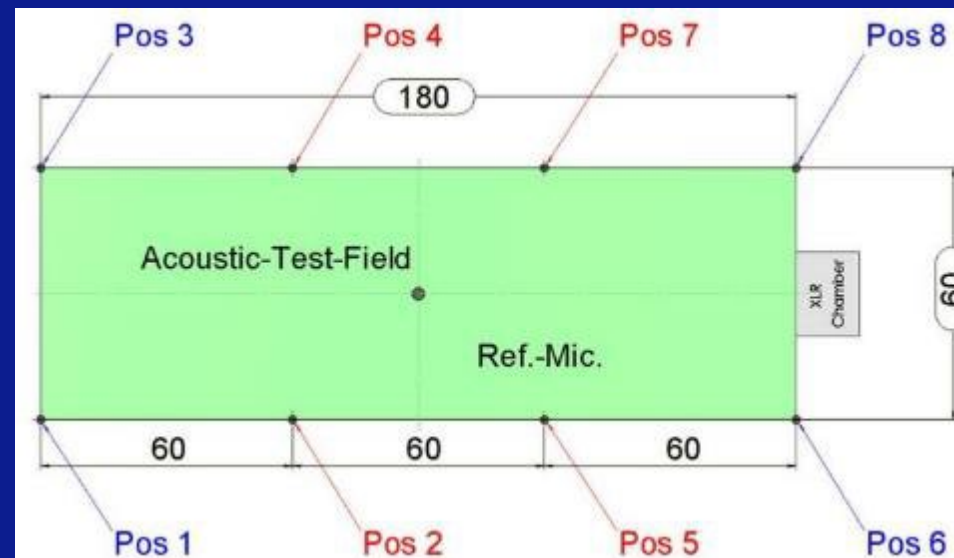
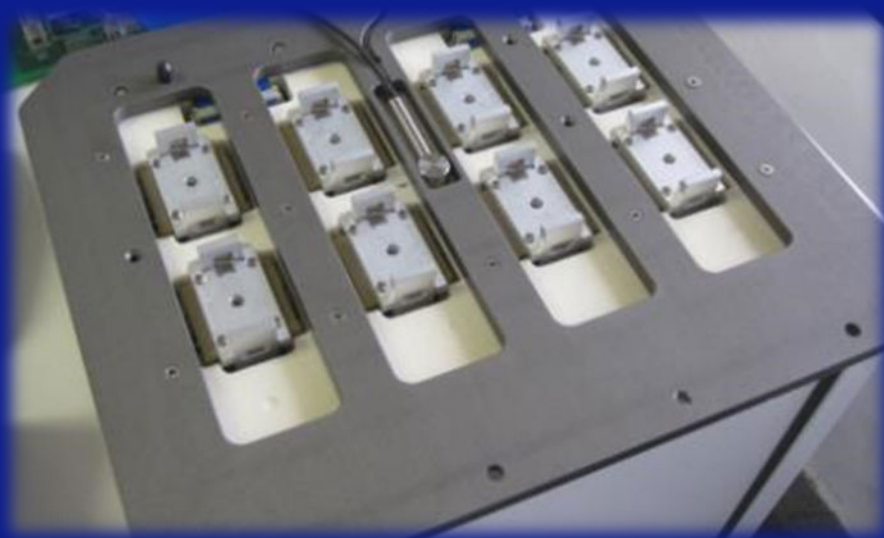
MEMS (Acoustic Sensors)

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



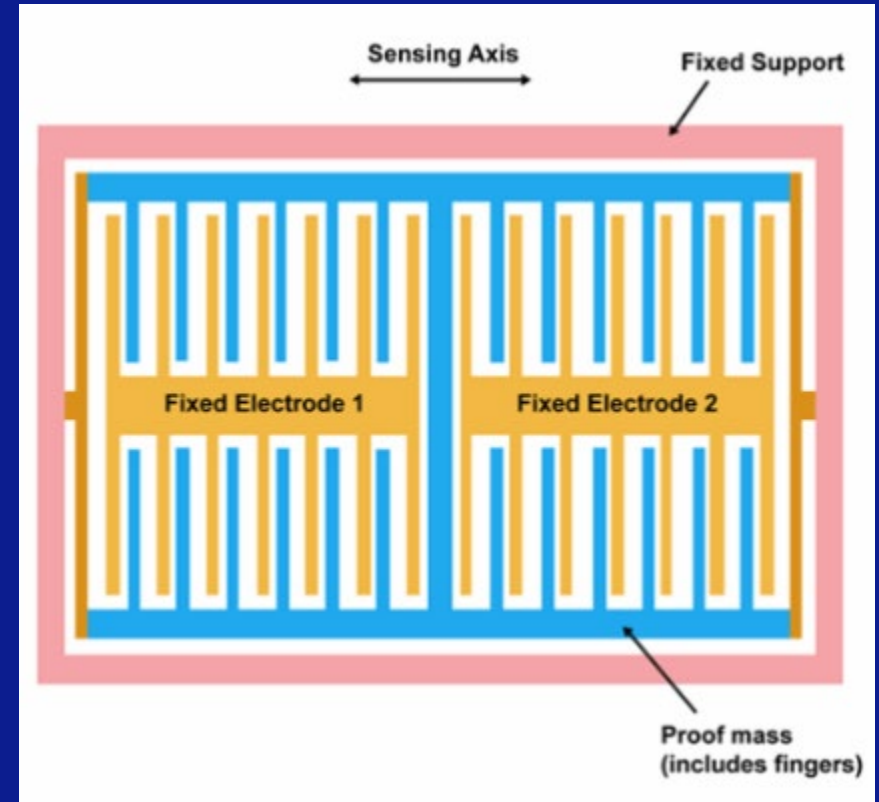
MEMS (Acoustic Sensors)

- Stimulus uniformity over parallel test sites



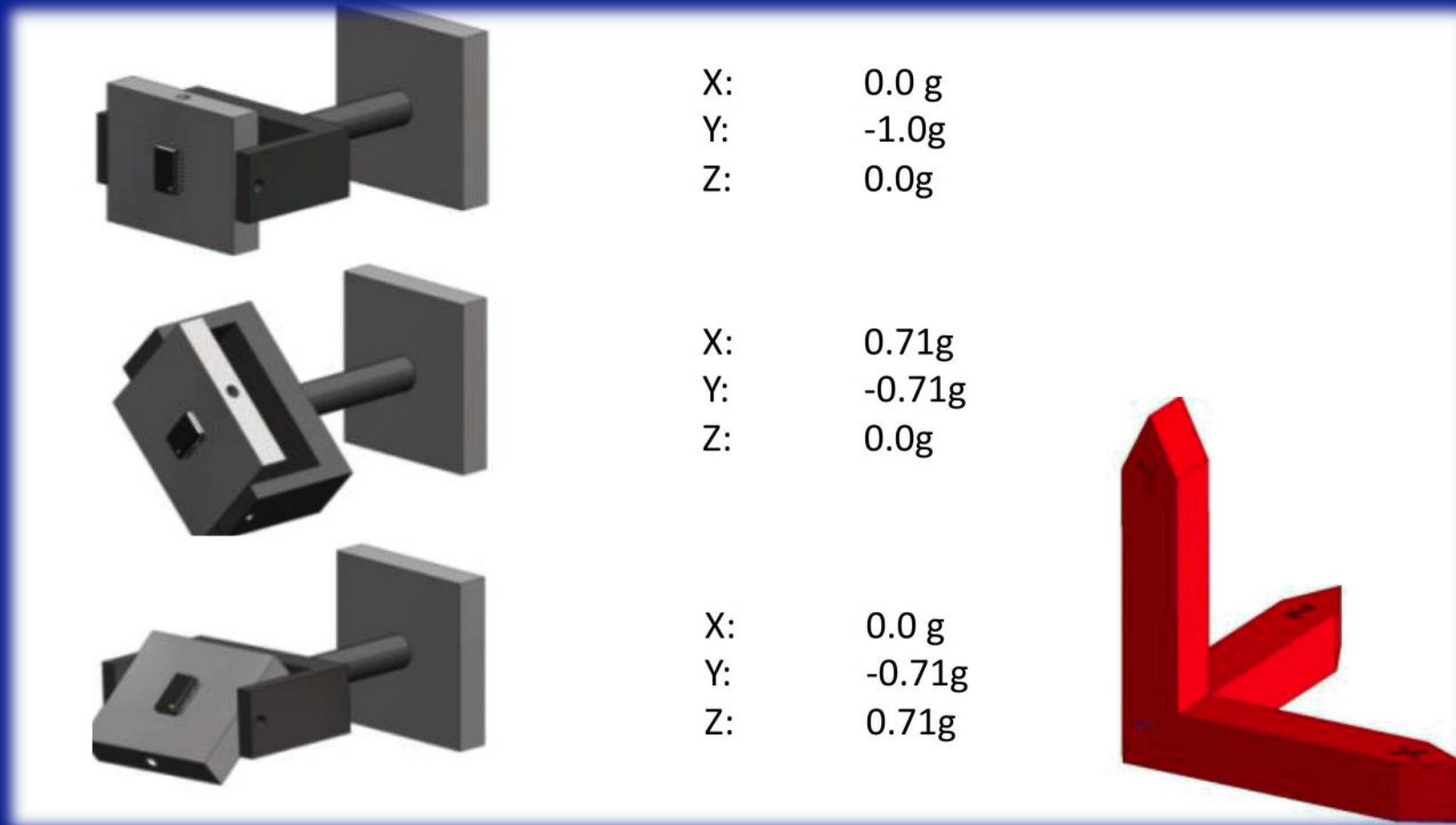
MEMS (Low g/gyro)

- 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)



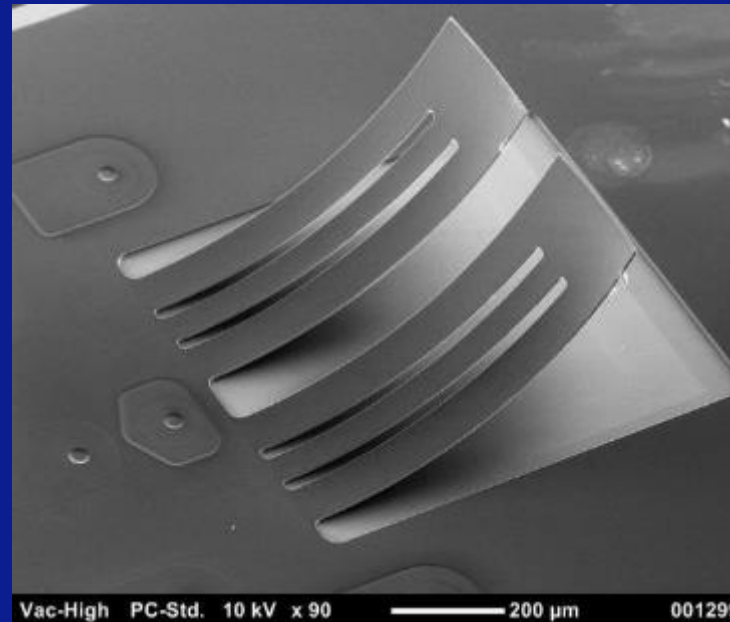
MEMS (Multifunction)

- 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!!

