Packaging And Embedded Electronics For The Next Generation

Michael J. Sampson, NASA GSFC
Co-Manager NASA Electronic Parts and Packaging Program
Michael.j.sampson@nasa.gov

http://nepp.nasa.gov
Outline

- What is Electronic Packaging?
- Why Package Electronic Parts?
- Evolution of Packaging
- General Packaging Discussion
- Advanced non-hermetic packages
- Discussion of Hermeticity
- The Class Y Concept and Possible Extensions
- Embedded Technologies
- NEPP Activities
What is Electronic Packaging?

• It is not cardboard boxes and bubble wrap

• Electronic “Packaging” can have two basic meanings:
  – First (Part) Level: The “envelope” of protection surrounding an active electronic element, and also the termination system to connect it to the outside world
  – Second and Higher Levels: The assembly of parts to boards, boards to slices, slices to boxes, boxes to systems, instruments and spacecraft

• This discussion will cover examples of both
Why Package Electronic Parts?

• To protect the active element against:
  – Handling
  – Shock and vibration
  – Contamination
  – Light penetration or emission

• To provide a suitable system to make connection between the element and the printed wiring board

• To prevent conductive parts of the element from coming in contact with other conductive surfaces, unless intended
Package Options – Hermetic?

- Once, hermetic packages were the preferred option
- Now, few hermetic options for latest package technologies
  - Development of new hermetic options unattractive
    - Very high Non Recurring Expenses
    - Very high technical difficulty
    - Very low volume
    - Demanding customers
- Market is driven by consumer products
  - Low cost
  - High volume
  - Rapid turnover
  - “Green”
  - Minimized size

= Non hermetic, mostly plastic
The “General” Package

Typically, packages consist of the same basic features but achieve them in many ways:

- Functional elements - active die, passives etc.
- Interconnects between elements (2 or more elements)
- A substrate
- Interconnects to the external I/O of the package
- A protective package
- Interconnects to the next higher level of assembly
Continuous Packaging Challenges

- I/Os, increasing number, decreasing pitch
- Heat Dissipation, (especially in space)
- Manufacturability
- Materials
- Mechanical
- Installation
- Testability
- Inspectability
- RoHS (Pb-free)
- (Space Environment)

---

*Lunar Reconnaissance Orbiter (LRO)*, Built at GSFC, Launched with LCROSS, June 18, 2009
Commercial, Non-hermetic Package (PBGA)

Design Drivers:
- High I/O count
- Large die
- Environmental protection
- Performance/Speed
- Ancillary parts

Commercial Drivers:
- Low cost
- High volume
- Limited life
- Automated installation
- Compact

Space Challenges for Complex Non-hermetic Packages

- Vacuum:
  - Outgassing, offgassing, property deterioration
- Foreign Object Debris (FOD)
  - From the package threat to the system, or a threat to the package
- Shock and vibration
  - During launch, deployments and operation
- Thermal cycling
  - Usually small range; high number of cycles in Low Earth Orbit (LEO)
- Thermal management
  - Only conduction and radiation transfer heat
- Thousands of interconnects
  - Opportunities for opens, intermittent - possibly latent
- Low volume assembly
  - Limited automation, lots of rework
- Long life
  - Costs for space are high, make the most of the investment
- Novel hardware
  - Lots of “one offs”
- Rigorous test and inspection
  - To try to find the latent threats to reliability

ONE STRIKE AND YOU’RE OUT!
Non-hermetic Package, With”Space” Features (CCGA?)

- Substrate and Sn/Pb Column Grid Array
- Cover
- Die
- Underfill
- Flip Chip Die Bump
- “Enclosed” Package Option
- Capacitor, Resistor etc.

<table>
<thead>
<tr>
<th>Space Challenge</th>
<th>Some Defenses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>Low out/off-gassing materials. Ceramics vs polymers.</td>
</tr>
<tr>
<td>Shock and vibration</td>
<td>Compliant / robust interconnects - wire bonds, solder balls, columns, conductive polymer</td>
</tr>
<tr>
<td>Thermal cycling</td>
<td>Compliant/robust interconnects, matched thermal expansion coefficients</td>
</tr>
<tr>
<td>Thermal management</td>
<td>Heat spreader in the lid and/or substrate, thermally conductive materials</td>
</tr>
<tr>
<td>Thousands of interconnects</td>
<td>Process control, planarity, solderability, substrate design</td>
</tr>
<tr>
<td>Low volume assembly</td>
<td>Remains a challenge</td>
</tr>
<tr>
<td>Long life</td>
<td>Good design, materials, parts and process control</td>
</tr>
<tr>
<td>Novel hardware</td>
<td>Test, test, test</td>
</tr>
<tr>
<td>Rigorous test and inspection</td>
<td>Testability and inspectability will always be challenges</td>
</tr>
</tbody>
</table>
Hermeticity

- NASA prefers hermetic packages for critical applications
- Hermeticity is measureable, assuring package integrity
- Only 3 tests provide assurance for hermetic package integrity:
  - Hermeticity – nothing bad can get in
  - Residual or Internal gas analysis – nothing bad is inside
  - Particle Impact Noise Detection – no FOD inside
- NON-HERMETIC PACKAGE INTEGRITY IS HARD TO ASSESS - NO 3 BASIC TESTS
- Non-hermetic packages expose materials’ interfaces that are locked away in hermetic ones
But What is Hermetic?

- Per MIL-PRF-38534 Appx E and 38535 Appx A, hermetic packages must consist of metals, ceramic and glass in combinations ONLY, no polymerics

- Meets aggressive leak rate test limits
  - Verifies low rate of gas escape/ atmospheric interchange
  - Even so, small volume packages meeting “tight limits” theoretically exchange their atmosphere very quickly:
    - 0.001 cc, exchanges 93% in 1 month at 5X10^{-8} atmosphere/cc/sec!
    - 1.0cc, 96% in 10 years at 1 X 10^{-8}
  - Even large packages with quite small leaks can surprise
    - 10 cc, 96% in 1 year at 1 X 10^{-6} !

- For applications in space vacuum why care?
  - Risk for contamination on the ground
  - Risk for outgassing in vacuum
Non-hermetic Package Variations

- Current and future package options mix and match elements in almost infinite combinations
- Elements include:
  - Wire bonds
  - Ball interconnects
  - Solder joints
  - Conductive epoxies
  - Vias
  - Multi-layer substrates
  - Multiple chips, active and passive (hybrid?)
  - Stacking of components
  - Embedded actives and passives
  - Polymers
  - Ceramics
  - Enclosures/encapsulants
  - Thermal control features
Some Large Device Package Options

Embedded Capacitor
Some Large Device Package Options

From Amkor’s Website http://www.amkor.com/go/packaging
More Complexity is Coming

• Stacking of chips to provide a third dimension of density and complexity
  – Stacking of Field Programmable Gate Arrays (FPGAs) appears imminent
  – Stacking of memory die is “old hat”
  – Through-silicon vias instead of bond wires
    • Maintain speed and allow lots of I/Os
    • High volumetric efficiency
  – Significant manufacturability challenges
    • Material and dimensional interfaces
    • Testability
  – Significant usability challenges
    • Design complexity
    • Handling, testing, rework/replace, risk management
    • Cost versus benefit trades

MIL-PRF-38535, Class Y

- Y Not Non-hermetic for Space?
- Proposed new class for M38535, monolithic microcircuits
- Class Y will be for Space level non-hermetic
- Class V will be defined as hermetic only
- Addition to Appendix B, “Space Application”
- Package-specific “package integrity” test requirements proposed by manufacturer, approved by DSCC and government space
- The Package Integrity Test Plan must address:
  - Potential materials degradation
  - Interconnect reliability
  - Thermal management
  - Resistance to processing stresses
  - Thermo-mechanical stresses
- G12 Task Group established 01/13/01
Level 2 Packaging Evolution

- **Through-hole**
- **Surface Mount**
- **Surface Mount with Embedded C or R Layer**

- **1950’s**
- **1980’s**
- **1990’s**

Embedded Technologies + and -

• Advantages:
  – Increases volumetric efficiency – reduces parts count on Printed Wiring Board (PWB) surface
  – Enhances performance – speed
  – Increases reliability (reduces number of solder joints)
  – Distributes heat more evenly
  – Aids high volume production and reduces cost

• Challenges:
  – Design/layout – introduces constraints, complicates re-spin
  – PWB quality – more difficult PWB fabrication
  – PWB robustness – material mismatches
  – Testing – can’t access individual parts
  – Rework and repair – problems buried inside PWB
  – “One-offs”
NEPP Activities

• Continuous surveillance of emerging trends
• Have evaluated embedded passives
  – Partnering with Navy Crane
  – Quite mature technologies, bulk capacitive layer
  – Works but “space” low quantities a challenge
• Have tried to evaluate a novel, flexible, embedded active-die technology
  – Considerable promise
  – Beset by technical problems, particularly die thinning
  – Consider revisiting as technology improves
• Initial evaluations of technical readiness of die thinning, through-hole vias and advance die stacking are needed
• Continue development of Class Y concept
http://nepp.nasa.gov