3D Power Electronics Packaging and Additive Manufacturing

Packaging v. Manufacturing

PACKAGING: a “Design Process”
MANUFACTURING: creating the “Design Rules”

What is Manufacturing good at? Molding & Casting
M & C is great for 3D, but the easiest is FLAT

Power Electronics loves FLAT, which is the worst for heat removal and inductance

One-sided cooling, double-sided, four-sided, hex, …, cylindrical
The PSMA 2015 Tech Report (334 pp)

1. Embedding in PCBs & Inorganic Substrates
2. High Temp Die-Attach & High-Lead Solder
3. Thermal Management
4. Packaging Technologies
5. Interposers
6. Embedded Resistors
7. Embedded Capacitors
8. Embedded Magnetics
9. Additive Manufacturing & Laser Fabrication

www.psma.org
“Stacked Components”

Innovations in “brick-type” power converters

3D Stacked Die Packaging (Amkor)

Stacking Quarter Bricks

Embedding Process, e.g. Shinko Electric

Figure 1-23. The Transparent Cross-section of Shinko Electric’s MCEP® Package [1-29]

Courtesy of: www.psma.com, power@psma.com
“Embedded (Active) Components

• Other embedding technologies in the industry
  – Nanium’s embedded wafer level package (eWLP)
  – Integrated Module Board (IMB) from Imbera
  – Amkor’s Embedded Die/Passives in Substrate
  – SiPLIT from Siemens
  – DrBlade from Infineon
  – i2 Board®, p2 Pack® from Schweizer

Example of HERMES face-down technology with two embedded core FR-4 PCBs, Prepreg layers, and external components

Concept view of Crane Aerospace & Electronics embedded components in fusion bonded Multi-Mix® assembly

The 3rd IEEE Workshop on Wide Bandgap Power Devices and Applications

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Other 3D Power Packaging Approaches

The 3rd IEEE Workshop on Wide Bandgap Power Devices and Applications
Nov. 2-4, 2015, Blacksburg, Virginia, USA
IEEE Power Electronics Society

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Flexible PCB for Ultra Dense VRMs  
By Bo Gao

1. Stackable for FREE
   - Eliminates board to board connectors.
2. Flat surface for GaN
   - Lower stress caused by CTE mismatch, simple heat sink design.
3. No module substrate
   - FPC itself can be folded back to form pads.

A 12V Input, 100A Output High Density VRM

- 3-ph sync. buck
- From simulation:
  - ≤ 97% @ 2.5MHz,
  - ≤ 90% @ 10MHz

0.8kW/cu-in @ 1.2V/100A
1kW/cu-in @ 1.5V/100A
1.6kw/cu-in @ 2.5V/100A

Flexible Power Electronics Packaging

NEEDS ADDRESSED
High Density, Fast Response Power Delivery Converters
- Need Inexpensive converters with good thermal management
- Operate eventually at high Temp: 250°C+ packaging
- Suitable for high current for GaN & high voltage SiC

APPROACH
- Develop copper metallization on ceramic for ≥250 °C (no adhesives)
- Develop GaN & SiC high frequency electrical converter circuits
- Determine feasibility of R2R circuit assembly process

TECHNOLOGY
- Thin E-Strate flexible ceramic for:
  - High volume roll-to-roll manufacturing
  - High thermal management for highly dense power converters
- Thin 20 & 40 micron substrates for low thermal resistance
- Licensed from Corning

DELIVERABLES [In Process]
- Design and demonstrate two (2) electrical converter topologies:
  - Low voltage (~3V) GaN POL converter
  - High voltage (1200V) SiC ½ Bridge converter with embedded gate drive
Flexible, SiC-FET switching ckt dev.

The hybrid power substrate is laid out and fabricated as normal two layer PCB board. However, it's flexible and has very high temperature operation potential.

**TECHNOLOGY**

- Thin E-Strate flexible ceramic for:
  - High volume roll-to-roll manufacturing
  - High thermal management for highly dense power converters

**Flexible, SiC-FET switching ckt dev.**

Parallel MOSFET and Diode

Series MOSFET and Diode

**Quilted Power Packaging**

3D rendering of the entire DC/DC converter “quilt.” The layout showing the quilt nodule edge connectors is true to the actual proposed system layout.

(Pictures from Indiana Integrated Circuits.)

Solder reflowed between nodules. Nodule width is 10 microns.

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What about actual 3D PRINTED POWER?

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Toward Structured Metal (Cu, Al)

- Direct printed metals are being developed (along with ceramics)
- Fine vertical metal columns are used to provide electrical and thermal conduction with stress management.


“New ORNL electric vehicle technology packs more punch in smaller package,” M. Chinthavali, Oak Ridge, Tenn., 14Oct’14
WILL 3D PRINTING TAKE OVER THE WORLD?

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WILL 3D TAKE OVER THE WORLD?

FROM THE FORD WEBSITE (2014):

Ford’s 500,000th printed auto part is a prototype engine cover for the all-new Ford Mustang.

The next steps in Ford’s 3D printing strategy are auto industry firsts – mixed material applications, continuous 3D sand printing and direct metal printing.

One day, millions of car parts could be printed as quickly as newspapers and as easily as pushing a button on the office copy machine, saving months of development time and millions of dollars.

…An engineer would create a computer model of an intake manifold – the most complicated engine part – and wait about four months for one prototype at a cost of $500,000. With 3D printing, Ford can print the same part in four days, including multiple iterations and with no tooling limits – at a cost of $3,000.

Universal package for PSD device testing

Capabilities
- High voltage SiC device (>10kV)
- Kelvin design for hi-I GaN device
- Functional additions, e.g. gate drive
3D-PEIM
ALL FOR PAPERS
International Symposium on
3D Power Electronics Integration and Manufacturing
McKimmon Center, Raleigh, NC, USA

Papers are solicited on the following topics:
- Additive Manufacturing for shortened design cycles, and mass production
- Thermal Management and Systems Integration for high-density packaging
- Multiphysics Modeling and Simulation of integrated packaging and circuit solution
- Materials (e.g., interconnects, encapsulants, substrates)
- Active components and integrated driver circuitry for embedded systems
- Passive components (e.g., magnetics, capacitors, interposers) for 3D integration
- Manufacturability of circuits and packaging (processes, equipment, and standards)
- Quality & Reliability of integrated solutions, including Prognostics and Condition Monitoring

General Chair:  Prof. Douglas Hopkins, NC State University (dhopkins@ncsu.edu)
Technical Co-Chairs: Prof. Patrick McCluskey, Univ. of Maryland (mccluspa@umd.edu)
                 Prof. G.Q. Lu, Virginia Tech (gqlu@vt.edu)

The END