Embedded passives in housing

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Braham Ferreira, Jelena Popović-Gerber

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Outline

- Functional and Packaging Integration - Multifunctional Parts
- Embedded Passives in Housing
- Challenges
- Materials and Technologies
- Virtual Prototype
- Summary

Construction parts in power electronic converter

- Packaging breakdown - Based on construction parts and functions they perform

Fundamental functions

- Electronic (switching, conduction, information)
- Electromagnetic energy exchange
- Heat exchange

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Functional elements

Packaging functions

- Electrical interconnection
- Mechanical support
- Thermal
- Environmental protection
- Electrical insulation

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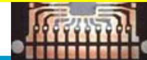
Packaging elements



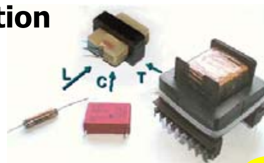
There is more to the system than the electrical circuit!

Functional and packaging integration

- Multifunctionality of parts – key to increasing the integration level; not only functional but also packaging parts

Functional elements integration

- Fewer components
- Fewer packaging elements
- Fewer manufacturing steps



Source: ST Microelectronics

electromagnetic manufacturing cost…

Packaging elements integration

- Multifunctional packaging elements (*e.g. lead frame*)
- Shared among functional elements

When functional integration reaches its limits packaging integration takes over!

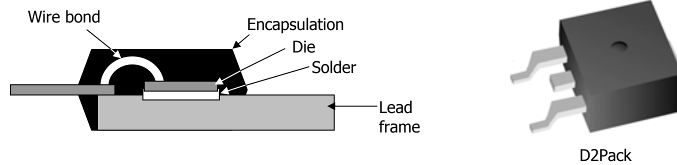
- Fewer parts, simplified assembly

Source: Powerex

Functional/packaging parts and integration – *power semiconductor example*

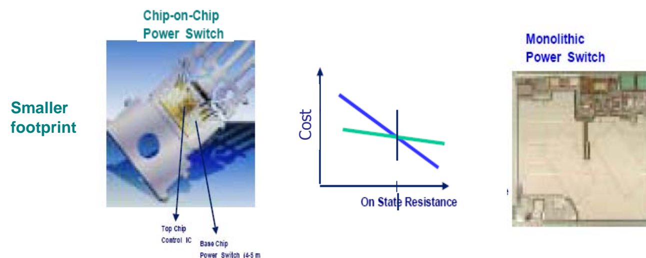
- Discrete power semiconductor – construction parts
  - Silicon die } Functional element
  - Lead frame – *electrical, mechanical, thermal*
  - Wirebonds – *electrical*
  - Housing – *protection, insulation*

  (Lead frame, Wirebonds, Housing: } Packaging elements)



Functional/packaging parts and integration – *power semiconductor example*

- SmartFET (Infineon) – System-in-Package
  - 2 silicone dies (DMOS power transistor, CDMOS logic circuitry for driving, sensing and protection)
  - Common leadframe
  - Common housing



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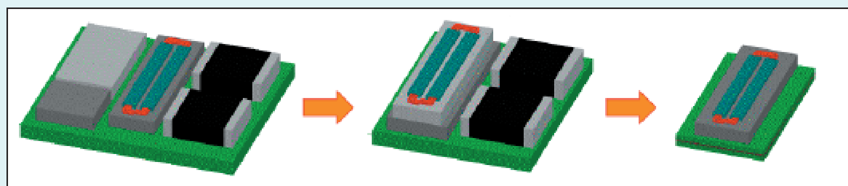
Power Supply on Chip

- Mainstream approach to increase the level of integration in lower power applications
  - Adding more functionality to silicon – monolithic integration – System-on-Chip.
  - Integration of passives main bottleneck

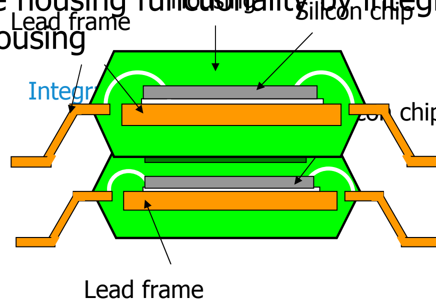


Above: Discrete components > Inductor mounted on-top of IC > Complete integration

Source: Tyndall

Embedded passives in housing

- IC housing traditional functions
  - Protection/insulation
  - Mechanical support
- Increase housing functionality by integrating passives in the housing



Embedded passives in housing

- What does the housing have to offer?
  - Cheap surface area in addition to the expensive Si area;
  - Volume – passive components need volume.
- Embedded passives in housing - potential advantages
  - Technology freedom – passive components technologies decoupled from silicon technologies;
  - Better performance – low resistance windings by using thicker copper conductors and low loss magnetic materials;
  - Size reduction – lower number of turns for the same inductance value due to thicker magnetic materials;
  - Cost reduction – lower cost technologies?

Challenges

- Interconnection technologies
  - Electrical interconnections between chip-passive components - leadframe.
- Thermal management
  - Novel thermal management techniques to accommodate the passives.
- Miniaturisation technologies for passives
  - Suitability of different materials and technologies.

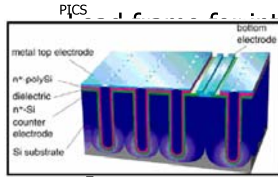
Materials and technologies

- Magnetic materials
  - Separate – thin, custom shaped ferrites;
  - Integral part of housing manufacturing process (e.g. Ferrite Polymer Composite plastic materials).
- Windings
  - Integral part of the lead frame
  - Separate copper foil
- Capacitive materials?

Materials and technologies

- Interconnections

PICS



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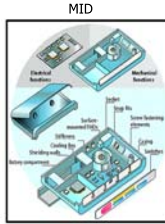
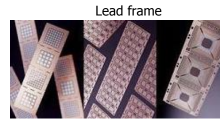


Lead frame



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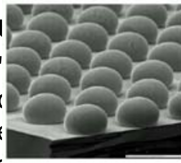
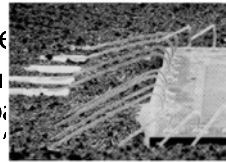
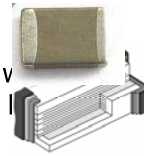
- Mo… ne
  - '… ou… e v… orates a … pa… es l… nical and … s.'
  - 3D technology



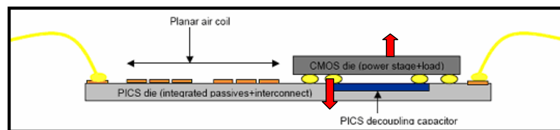


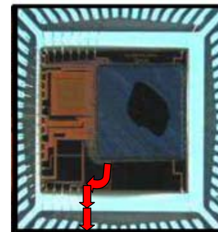


Endless possibilities to be explored!

Thermal management

- Is heat a problem?
  - **Why planar if not thermally limited?**
  - What is the main heat path?
    - Housing
    - Solder bumps/ passive die (through-wafer vias?)/ leadframe
    - Solder bumps/ metallisation/ wirebonds/leadframe

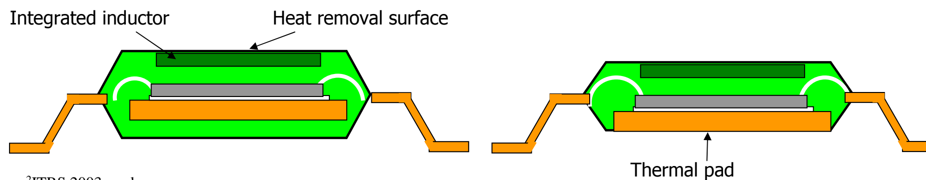




[1] **PESC08: An inductive down converter system-in-package for integrated power management in battery-powered applications**
Bergveld, H.J.; Karadi, R.; Nowak, K.;

Thermal management

- Integrating components into the housing – inhomogenous thermal conductivity
  - Still higher than epoxy resin thermal conductivity?
- For higher power/higher losses
  - E.g. 4A@0.8V[2], ~1W power loss, R_{thj_a} =59K/W→ ΔT~ 60C°
  - Heat removal from the housing top
  - Active die on the lead frame/thermal pad



[2]ITRS 2003 roadmap

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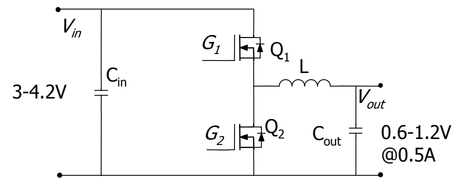
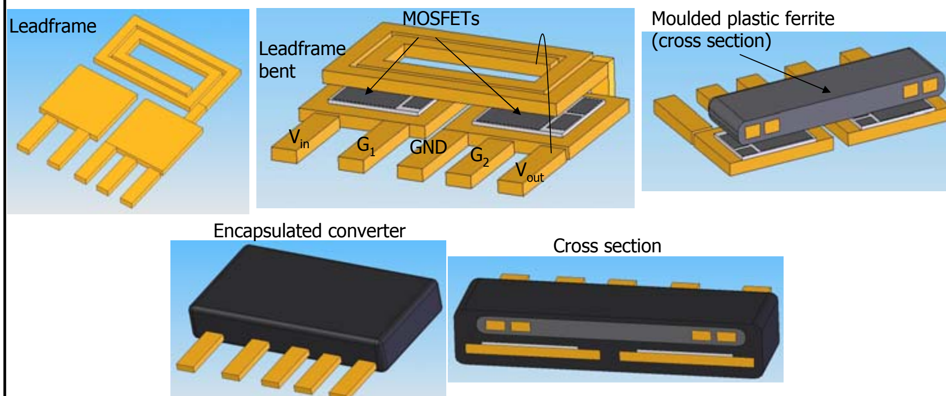
Virtual prototype example



- DC/DC buck converter
- Possible implementation
  - Inductance windings implemented as part of the lead frame
  - Moulded with FPC material
    - Air core inductor – 12 turns, track/gap 120 μm/60 μm, outside dimensions 5mm X 5mm, L ~ 0.4 μH
    - Sandwiched between FPC C302 (μ_r=17), L> 0.8 μH (depending on the thickness of the magnetic material)

Virtual prototype example

- 3D solid model
  - Wire bond interconnections
  - Capacitors not shown



Concluding statements

- When the limits of circuit integration is reached, the integration of functionality in the package creates new possibilities.
- The conductor losses and the slow penetration of electromagnetic fields in good conductors (skin effect) is a fundamental limitation. Therefore we need:
  - **3D instead of 2D layout to shorten distances.**
  - **Larger cross section cores.**
- Low loss bulk magnetic material for thick(er) magnetic cores to reduce the number of turns on the inductors is a key materials technology that has to be developed.