

High power PCB-embedded inductors based on ferrite powder

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17/5/17

Embedding of magnetics for power electronics

Proposed Embedding Technique

Results

Conclusion

Embedding of magnetics for power electronics

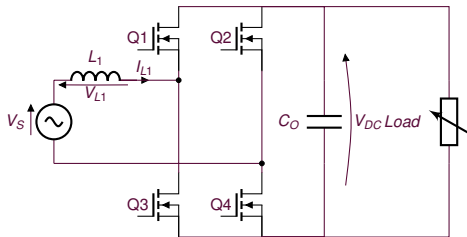
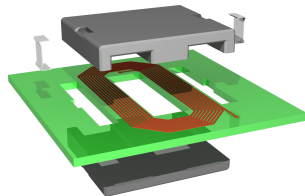
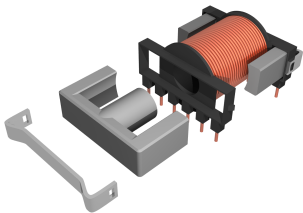
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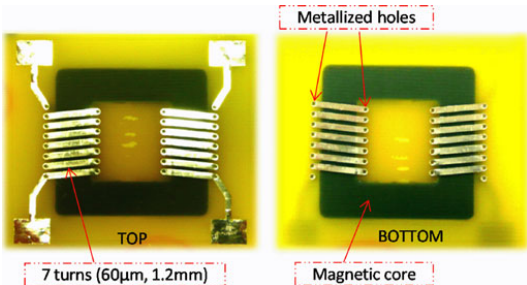
Conclusion

Passives for power electronics

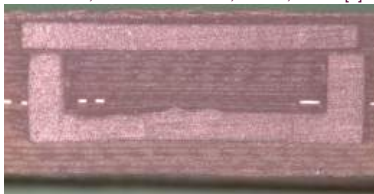
- ▶ Main role: **energy storage**
 - ▶ example:
 - ▶ 1 kW converter @ 100 kHz
 - ▶ 10 mJ charge/discharge per cycle
- They are large
- Large impact on efficiency
- ✓ Embedding in PCB to save space



Embedding of solid cores



M. Ali *et al.*, "Design of a hybrid integrated emc filter for a dc-dc power converter", IEEE Trans. on PE, vol. 27, no. 11 [1]



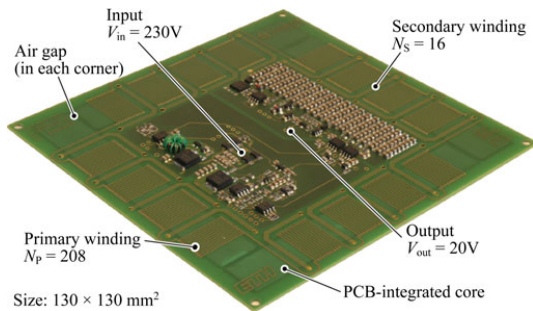
R. Perrin *et al.*, "2 MHz high-density integrated power supply for gate driver in high-temperature applications," APEC 2016 [2]

- ▶ Machine a cavity in laminate
- ▶ Insert core in stack-up
- ✓ Use of high-performance materials
- ✗ Few shapes available
- ✗ Machining difficult
- ✗ Brittle materials

Embedding of laminated cores

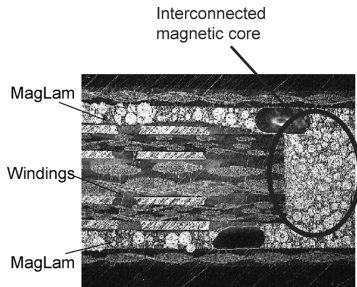
- ▶ Thin magnetic layers
 - ▶ Permalloy
 - ▶ Amorphous material

- ✓ More compliant
- ✓ Easier to machine
- ✓ Suited to flat geometry
- ✗ Need to isolate layers
- ✗ Complex for high power

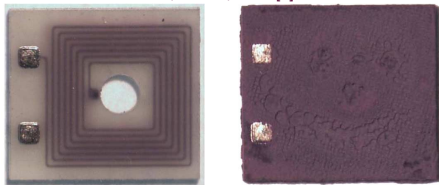


C. Marxgut *et al.*, "Multiobjective optimization of ultraflat magnetic components with pcb-integrated core," IEEE Trans PE, vol. 28, no. 7 [3]

Embedding of flexible cores



E. Waffenschmidt *et al.*, "Design Method and Material Technologies for Passives in Printed Circuit Board Embedded Circuits," IEEE Trans. on PE, vol. 20, no. 3 [4]



D. H. Bang *et al.*, "Ni-Zn ferrite screen printed power inductors for compact dc-dc power converter applications," IEEE Trans. on Mag. [5]

- ▶ Ferrite/polymer mix
 - ▶ "MagLam" Sheets
 - ▶ Polyimide/ferrite paste
- ✓ Suited to flat geometry
- ✓ Suited to complex shapes
- ✓ Mechanically compliant
- ✗ Distributed air gap
 - ▶ Low μ_r values (≈ 10)

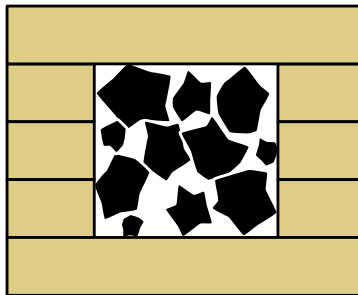
Embedding of magnetics for power electronics

Proposed Embedding Technique

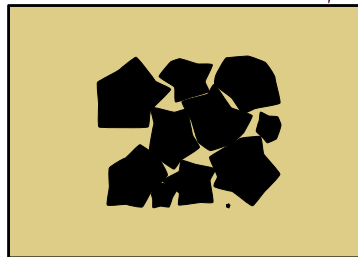
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Embedding of ferrite powder in PCB



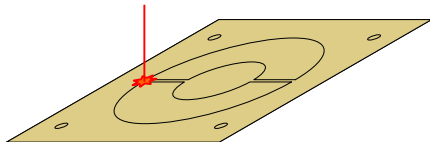
(a)



(b)

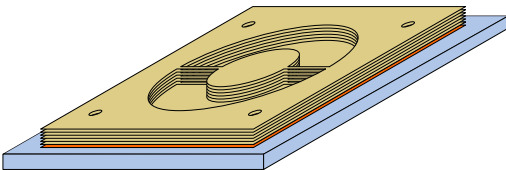
- ▶ Open cavities in a stack of pre-preg sheets
- ▶ fill cavities with ferrite powder
- ▶ laminate pre-preg to compact powder and infiltrate resin

The process flow



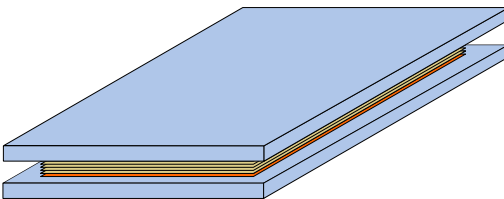
1. Cut prepregs with a laser
2. Stack cut prepregs
3. Press stack **at low temp.** (70 °C)
4. Remove from press
5. Trim bridges
6. Fill with ferrite powder
7. Complete stack and laminate (195 °C)
8. Drill and plate vias
9. Pattern copper

The process flow



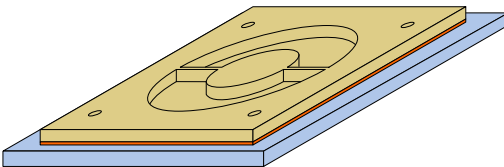
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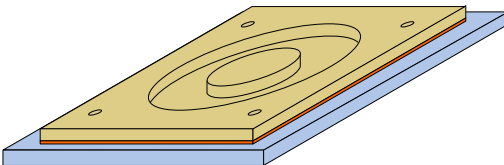
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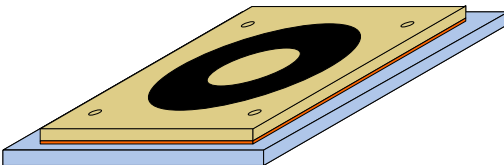
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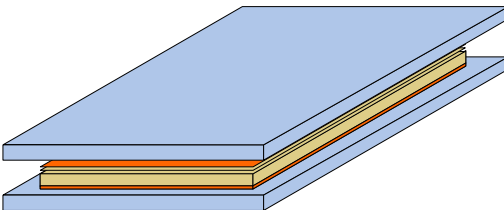
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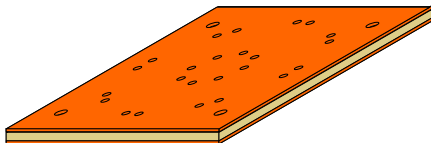
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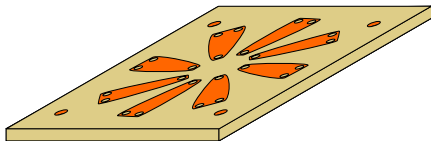
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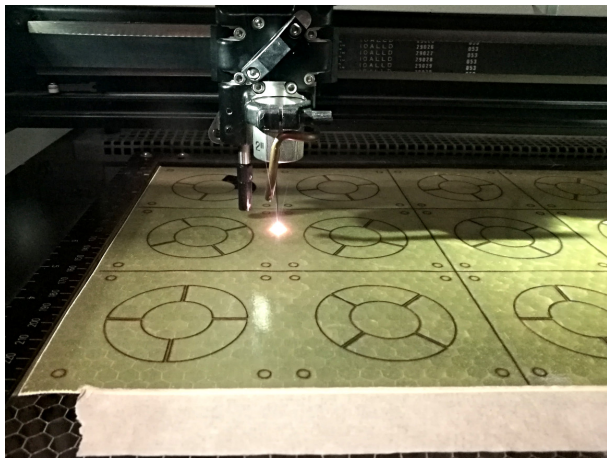
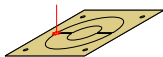
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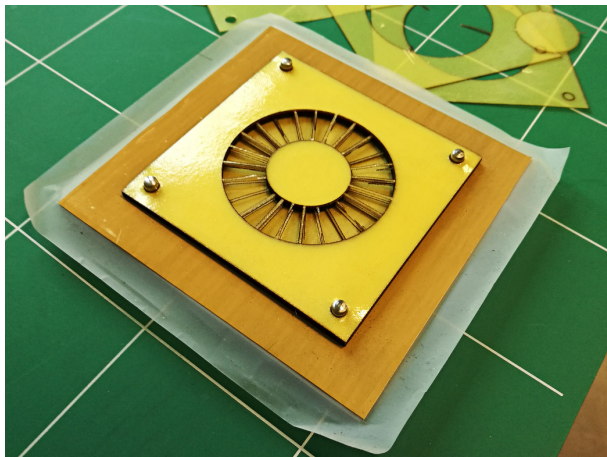
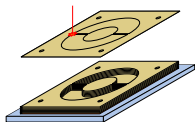
Some pictures



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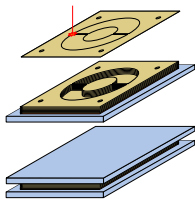
Some pictures



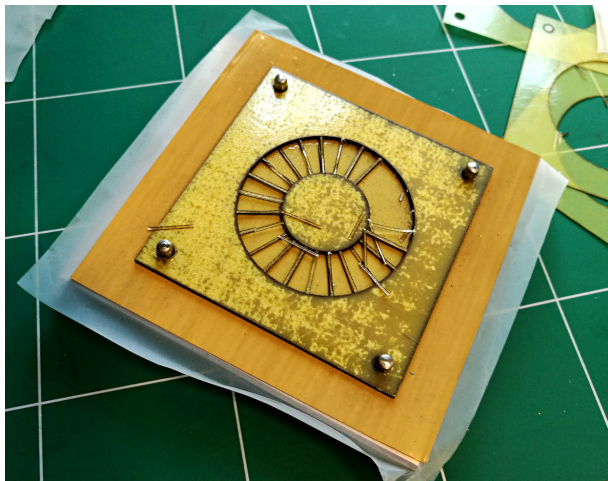
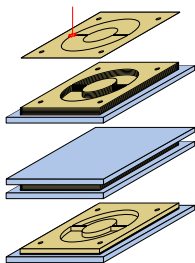
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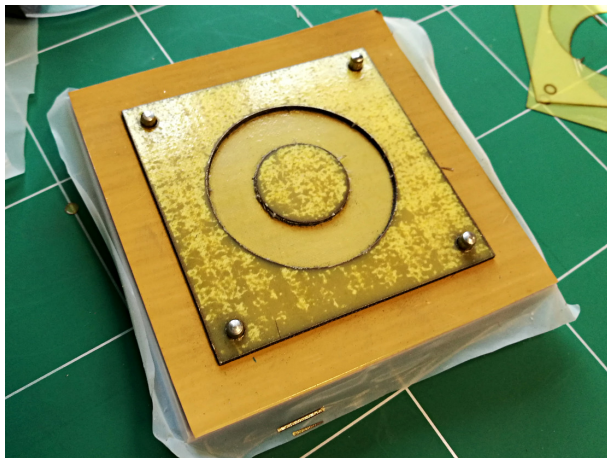
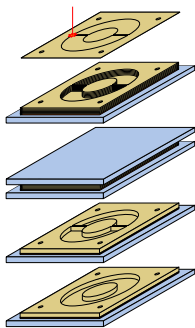
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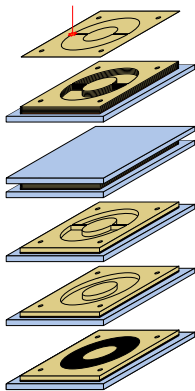
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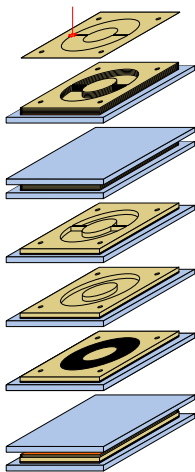


MITSUBISHI ELECTRIC
Changes for the Better

Amperex
POWER HYBRID INTEGRATION



Some pictures

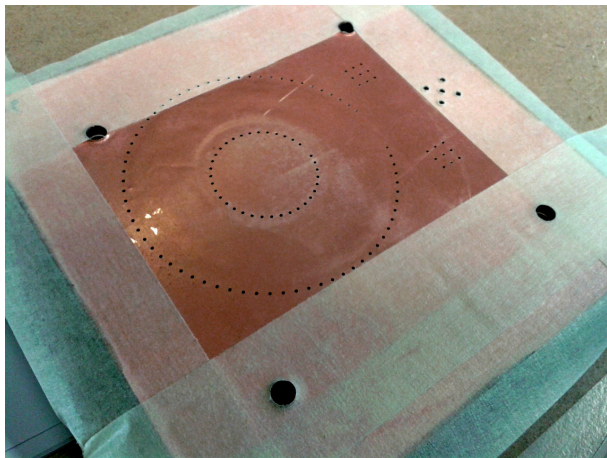
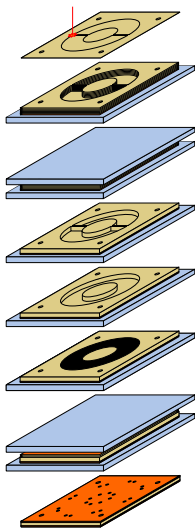


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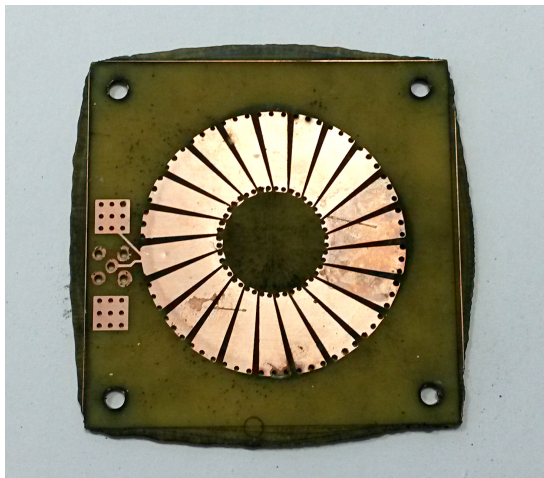
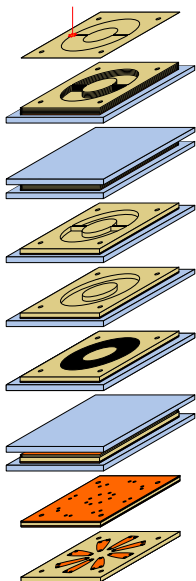
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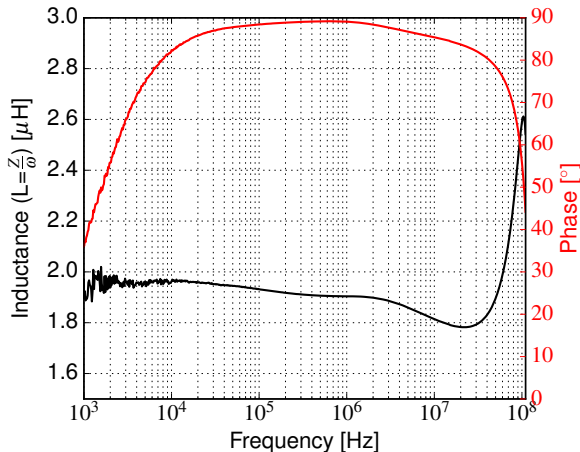


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“Small core”

- ▶ Intern. Dia. 6 mm
- ▶ Outer Dia. 19 mm
- ▶ ≈ 1.4 mm thick
- ▶ 16 Turns
- ▶ MnZn ferrite

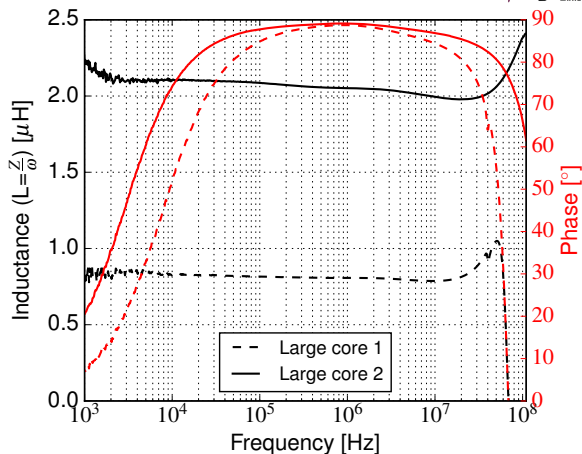
→ $\mu_r = 28$

Electrical measurements

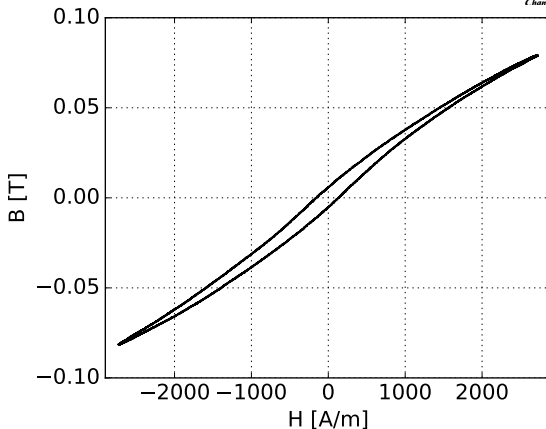


“Large” cores

- ▶ Intern. Dia. 25 mm
- ▶ Outer Dia. 50 mm
- ▶ ≈ 1.4 mm thick
- ▶ 22 Turns
- ▶ MnZn ferrite
- $\mu_r = 9$ or 24

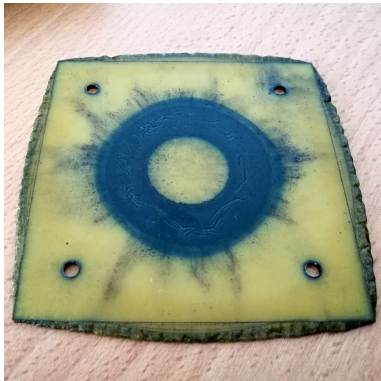


Electrical measurements – 2

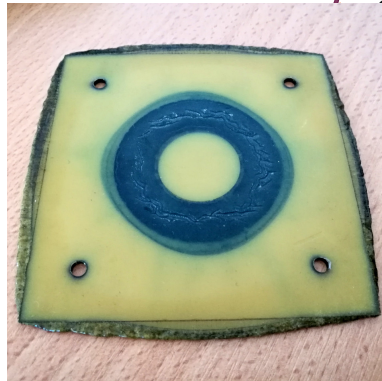


- Measured at 100 Hz, power limited by test setup

Powder residues



Recto

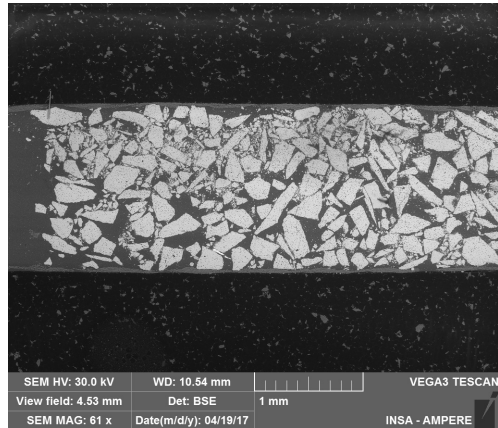


Verso

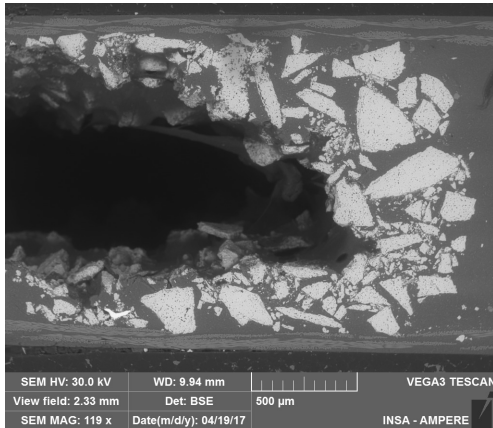
- ▶ Powder residues remain despite cleaning (brush) before lamination
- ▶ Powder used contains large ($500\text{ }\mu\text{m}$) but also much smaller particles
- ▶ Dark grey ring caused by laser cutting, not ferrite.

Microsections

- ▶ Clean limit of ferrite area
- ▶ Measured density 3.36 g/cm³
 - ▶ Consistent with datasheet
- ▶ Good penetration of resin
 - ▶ No voids
- ▶ Particle distrib. not uniform
 - ▶ Small particles segregated
 - ▶ Might be due to tapping



Microsections – 2



- ▶ Often poor penetration of resin
 - ▶ “Dry” areas
 - ▶ Particles fall during cut-off
- ▶ Might be due to:
 - ▶ Trapped air
 - ▶ Process control
 - ▶ Resin flowing outwards

► Interesting electrical properties:

- μ_R up to 28, vs. 7.2 to 17 reported in literature for “ferrite in polymer”
- Distributed airgap ≈ 3.5 to 4 %
- Need for proper measurement of losses
 - Used powder not intended for power applications (Ferroxcube FMS250)

► Manufacturing process:

- Ferrite residues due to small particles (“dust”)
- High particles density achieved
- Issues with resin infiltration
- Process relies on many pre-preg sheets

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 - Requires better granulometry control
- High particles density achieved
 - Not perfectly consistent: effect of lapping, prepreg flow?
- Issues with resin infiltration
 - Process control: pressure application, max ferrite/prepreg ratio?
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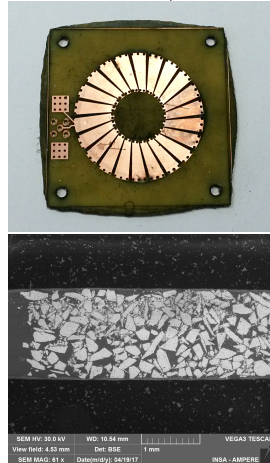
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Conclusion

- ▶ **New embedding solution for magnetics**
 - ▶ Suited to many core shapes
 - ▶ Better than existing “ferrite in polymer”
- ▶ **Presentation of manufacturing process**
 - ▶ All details in the paper (if any missing, please contact me)
- ▶ **Scale-up would require:**
 - ▶ Better powder (controlled granulometry and dispensing)
 - ▶ Design rules (max ferrite volume, etc.)
 - ▶ The availability of thick prepreg sheets (≈ 1 mm)
 - ▶ Reliability testing



Bibliography I



-  M. Ali, E. Labouré, F. Costa, and B. Revol, “Design of a hybrid integrated emc filter for a dc–dc power converter,” *IEEE Transactions on Power Electronics*, vol. 27, no. 11, pp. 4380–4390, 2012.
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-  D. H. Bang and J. Y. Park, “Ni-zn ferrite screen printed power inductors for compact dc-dc power converter applications,” *IEEE Transactions on Magnetics*, vol. 45, pp. 2762–2765, June 2009.

Thank you for your attention

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The authors thank Mr Gilles BRILLAT for his technical help.