Soft magnetic Metal-flake Composite Material Suitable for High Frequency Power Modules

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19 Mar. 2019

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TOKIN History

TOKIN
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April 1938 *as University Startups*

Established to commercialize KS magnetic steel (by Prof. Kotaro Honda) and Sendust (by Prof. Masumoto Hakaru), both invented at Tohoku Imperial University, Sendai, Japan.

April 2002

Became NEC TOKIN Corporation
(3 SBUs from NEC: capacitors, relays, and batteries)

Main Products

Tantalum capacitors,
Electric double-layer capacitors,
EMI/Noise suppression components,
Power inductors, Transformers,
Piezoelectric devices, Sensors.

April 2017

Name changed to TOKIN Corporation
become a 100% subsidiary of the United States based KEMET Corporation

1930 1990 2000 2010

October 1988

Name changed to
TOKIN Corporation

February 2013

Started business and capital partnership
with KEMET Corporation

- Material characteristics of FlakeComposite™ ,
  in comparison with existing magnetic materials.
  -Permeability, magnetic saturation, core loss, etc.

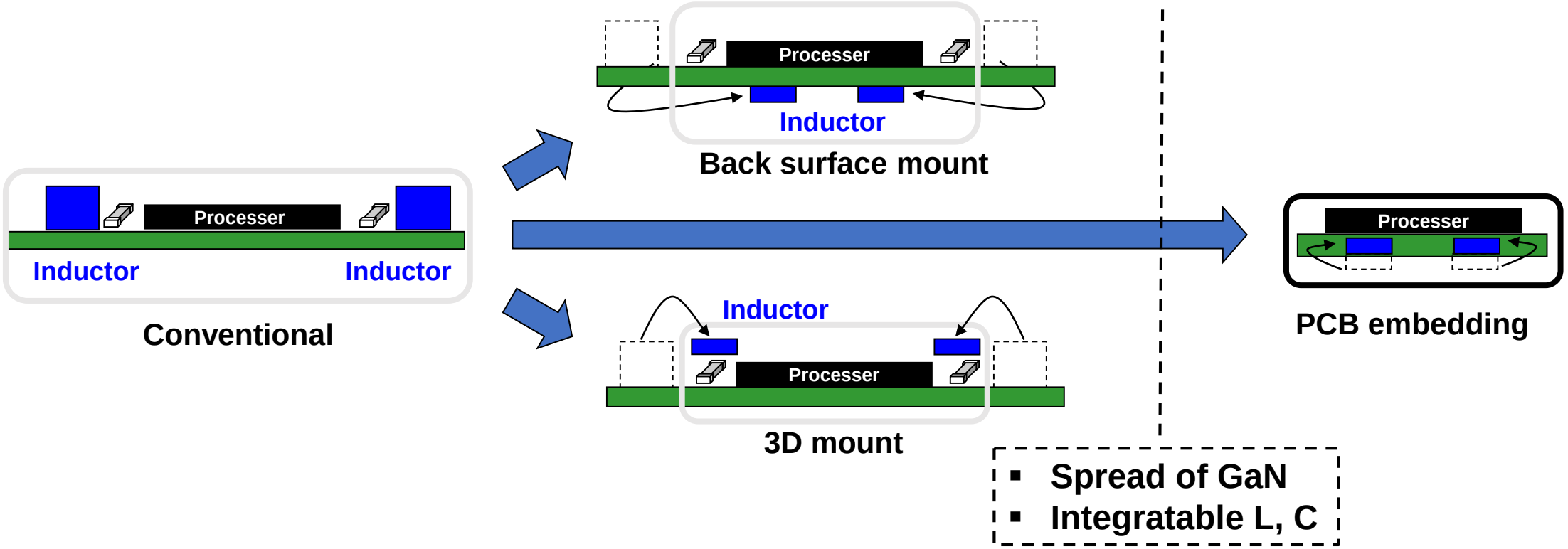
- Inductor performance benchmarking.

- PCB embedded inductor test fabrication result.

Motivation

Higher DC current / Higher switching frequency

Demands: Shorten the distance from DC/DC converter to the load.



- Low-profiled inductor for integrated DC/DC converter is required.
- PCB embed enabling magnetic material will also be required in future.

What is FlakeComposite™?

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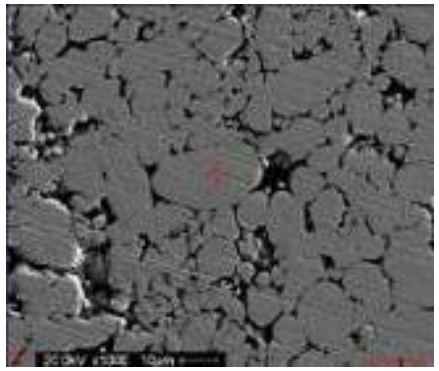
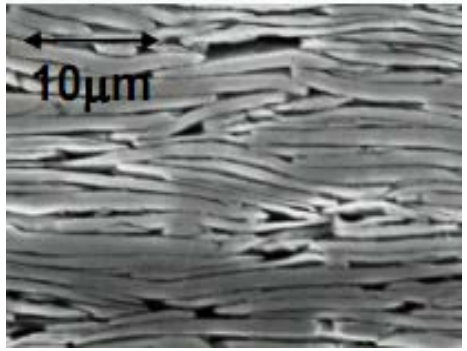
Conventional Metal composite



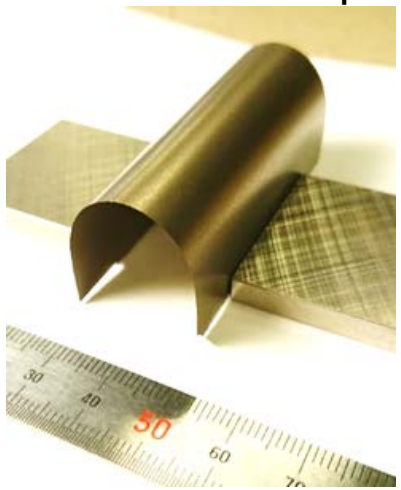
Metal-flake Compacting Technology

FlakeComposite



Permeability	**< 40**	**Smaller component's volume**	**>300** (Same as ferrites)
Thickness	**>0.5mm** Brittle	**Enable PCB Embedding**	**>50µm** Flexible
Heat durability	**<200℃** Organic binder	**Suitable for power modules**	**>200℃** Inorganic binder

t=50µm



Comparison of Magnetic Materials for PCB Embedding

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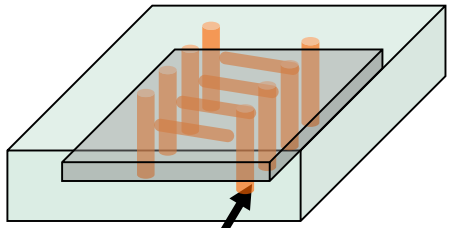
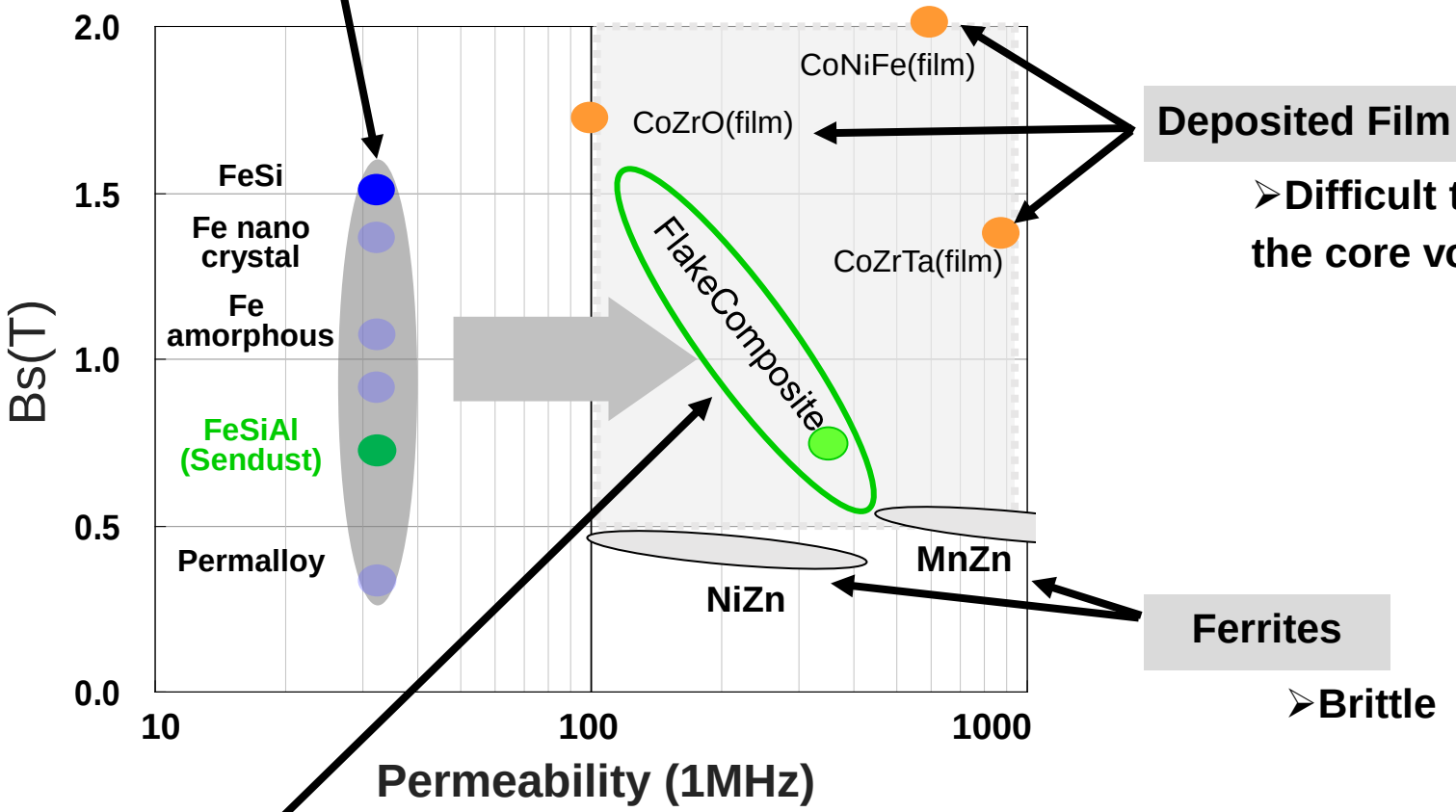


PCB embedded Magnetic Material

Conventional metal composite

➢Low permeability



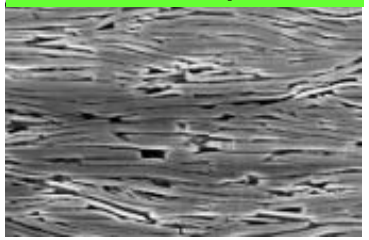
Deposited Film

➢Difficult to increase the core volume.

Ferrites

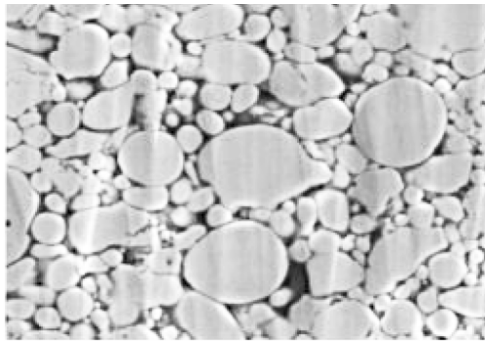
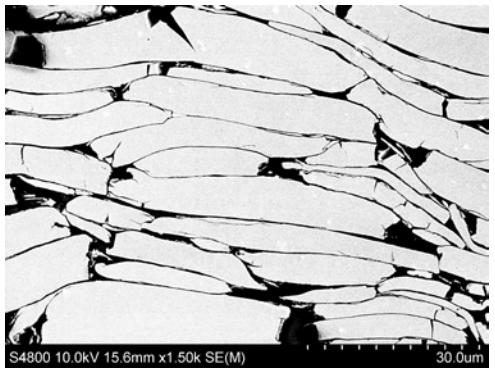
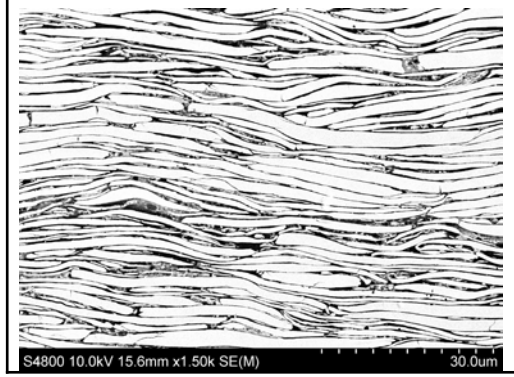
➢Brittle

FlakeComposite



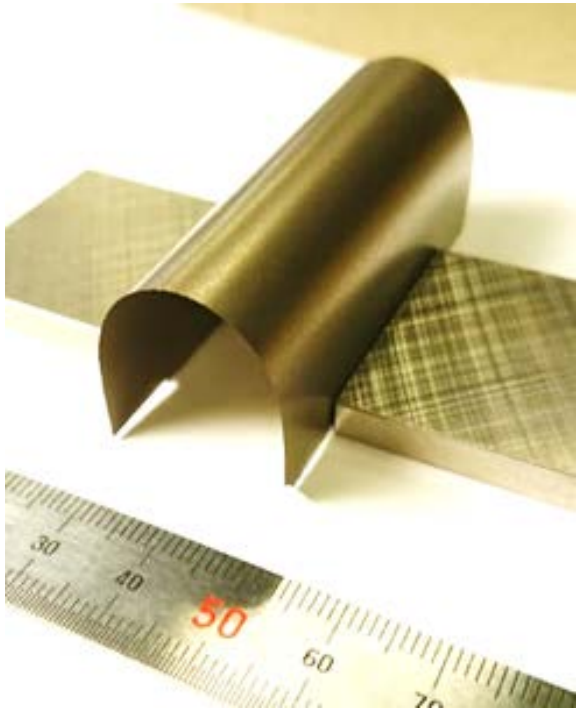
➢High permeability (300 at 1 MHz.)
➢50μm to 2mm thickness
➢Thin, Flexible(Rigid)

Effect of Powder Shape on Permeability and Flexibility

Powder Shape	Permeability	Min. bend radius (Arb. unit)
	35	10
	160	4
	300	1

30μm

t=50μm



➢10 times improvement in permeability and flexibility

Permeability vs Frequency

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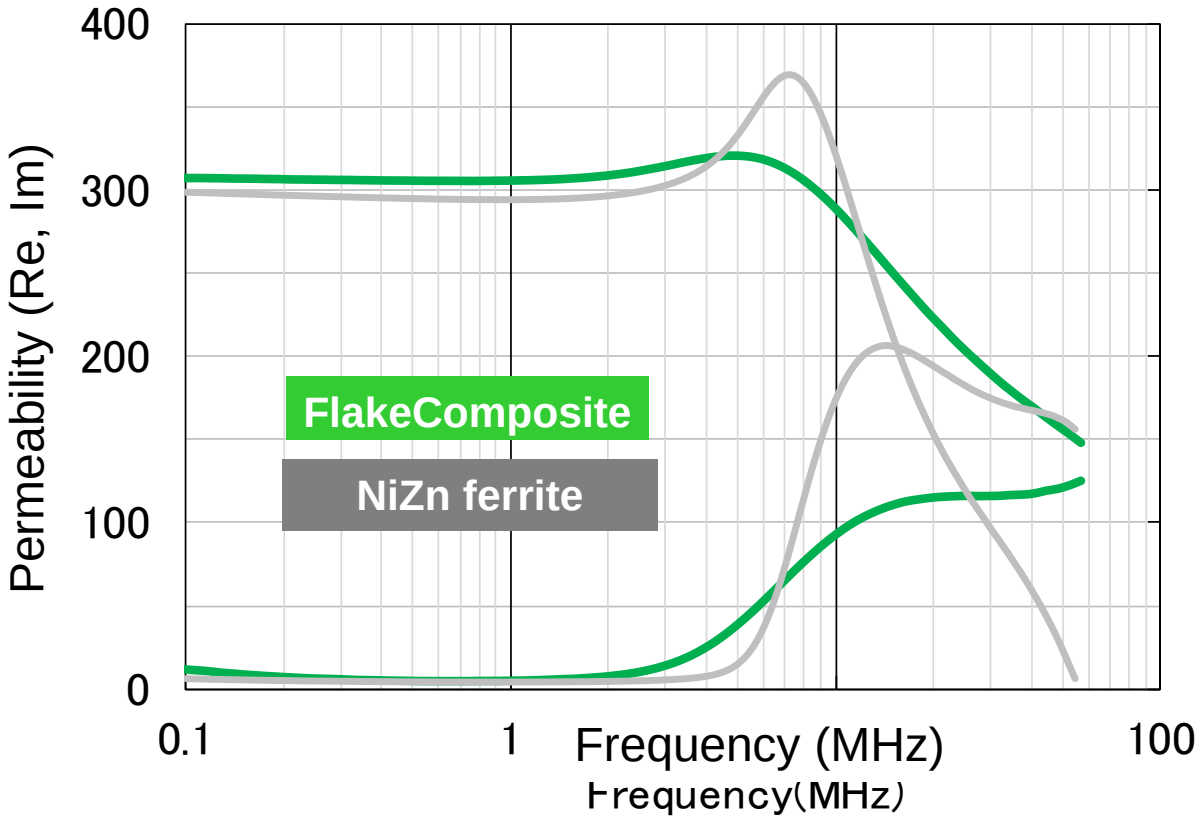
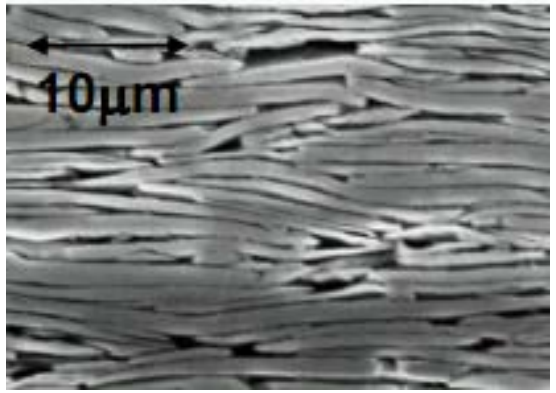
Frequency dispersion of complex permeability





$\mu_{\perp} \leqq 5$

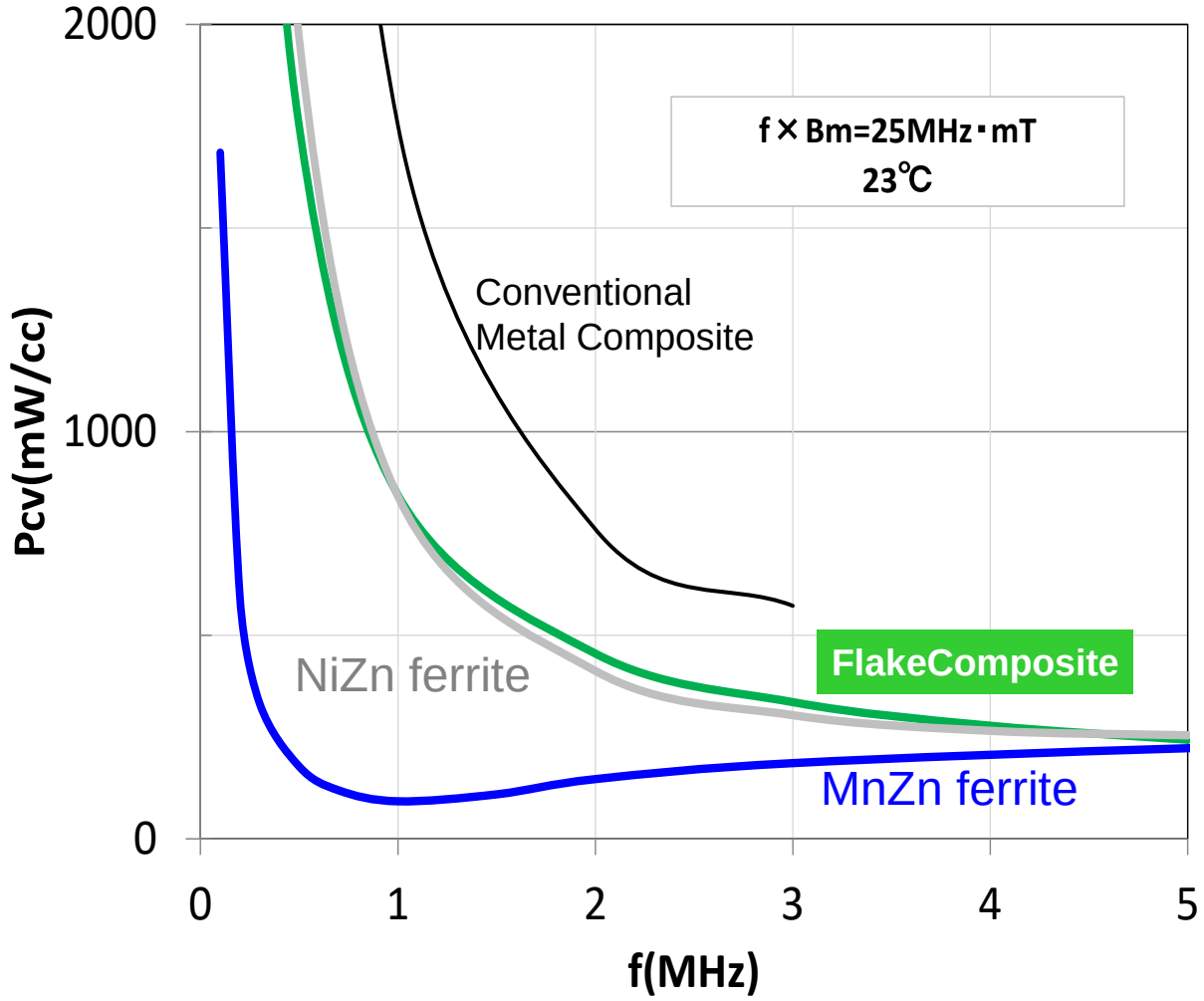
$\mu'_{//} = 300$

➢ Comparable to NiZn ferrite for MHz power application.

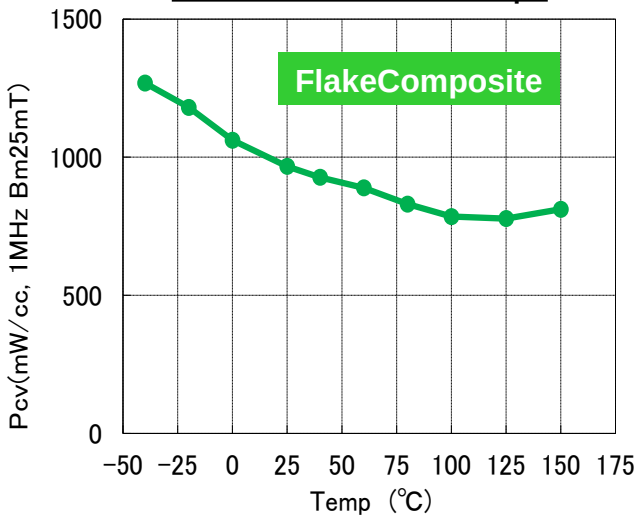
Limitation

Lower Out-plane permeability.

Core Loss

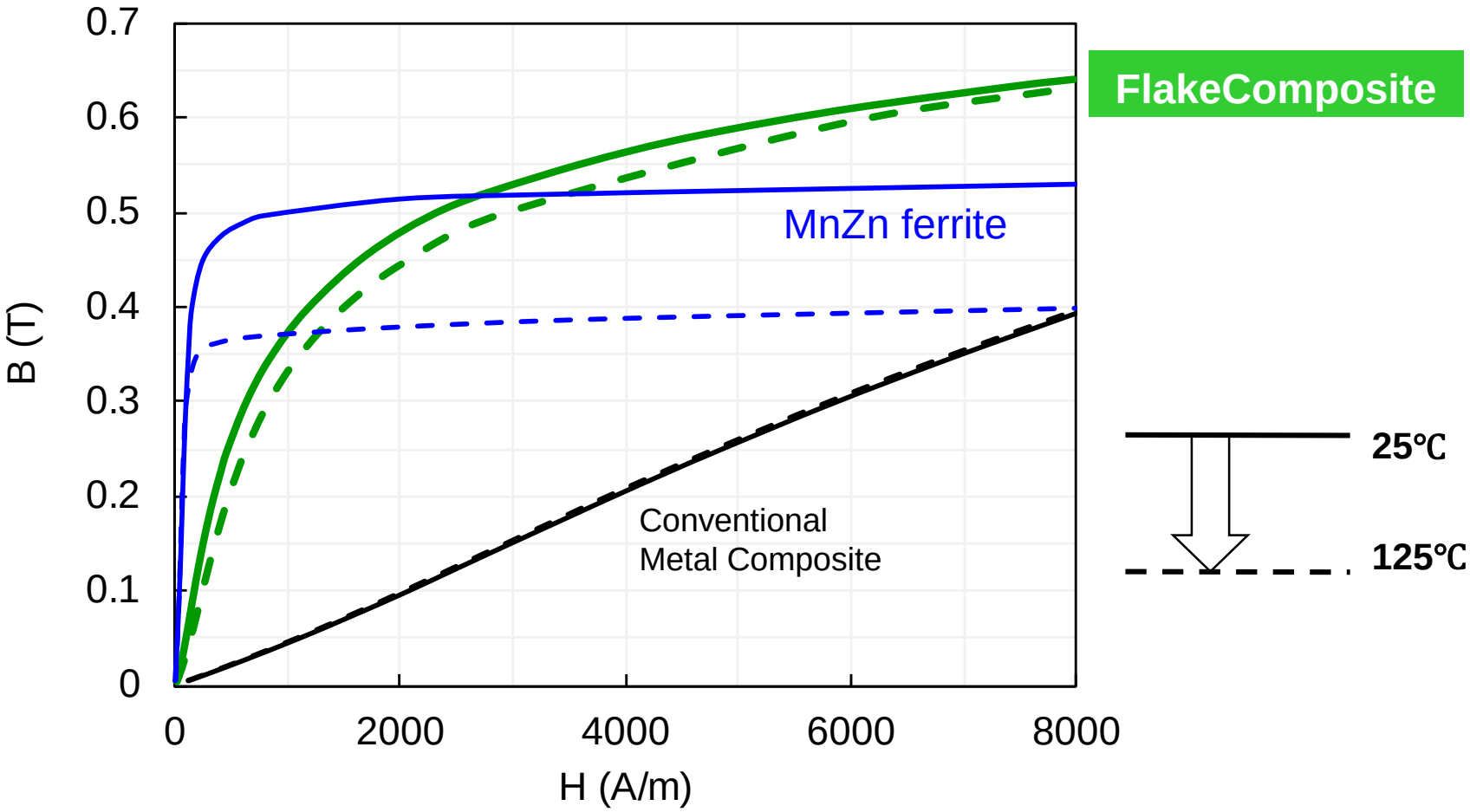


Core Loss vs Temp.



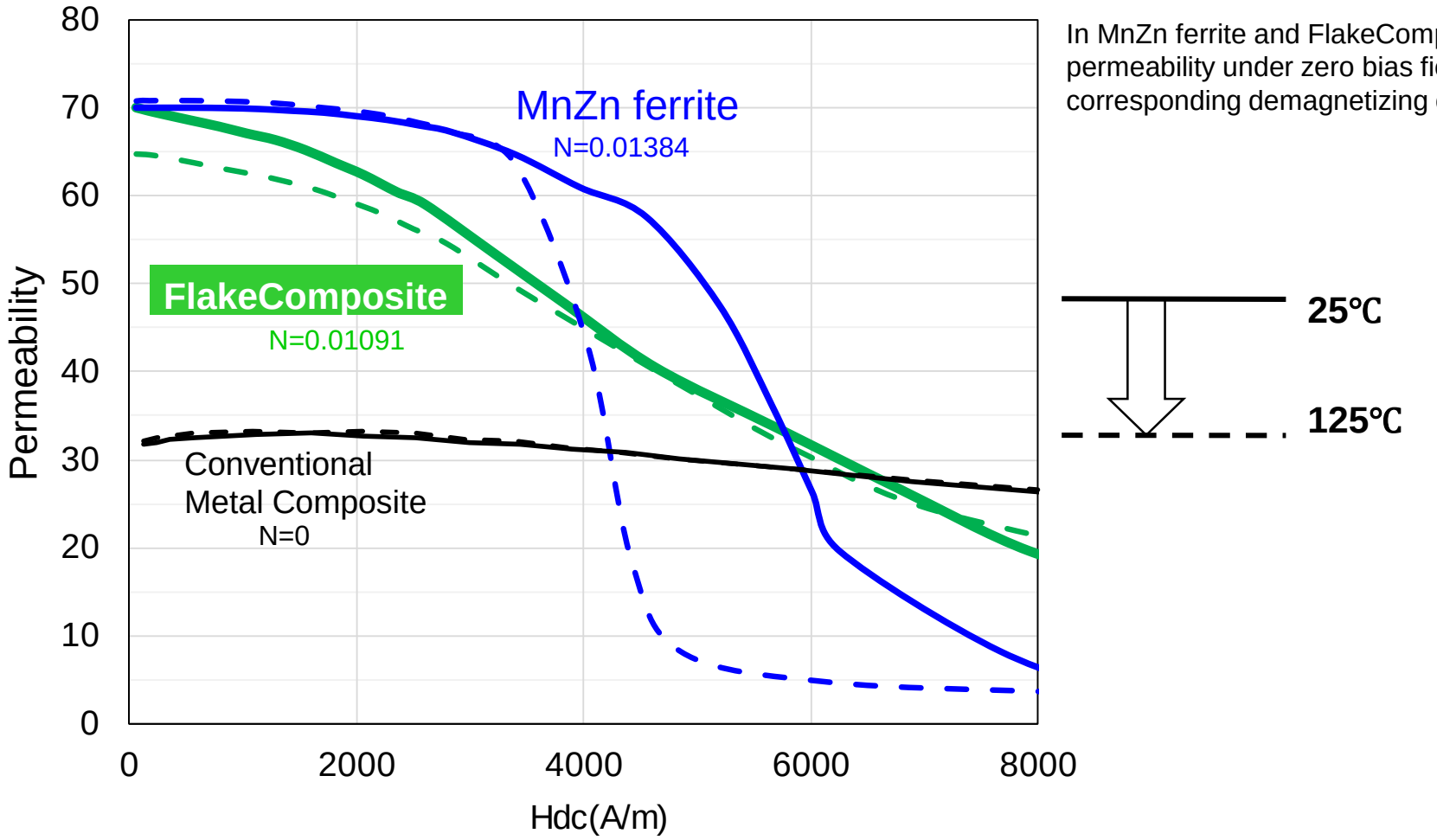
- Core loss of FlakeComposite is comparable to NiZn ferrite, but much larger than MnZn ferrite at few MHz.

Magnetic Saturation (BH curve)



- Soft-saturation in FlakeComposite.
- Smaller drop of saturated magnetic moment against temperature, comparing to MnZn ferrite.

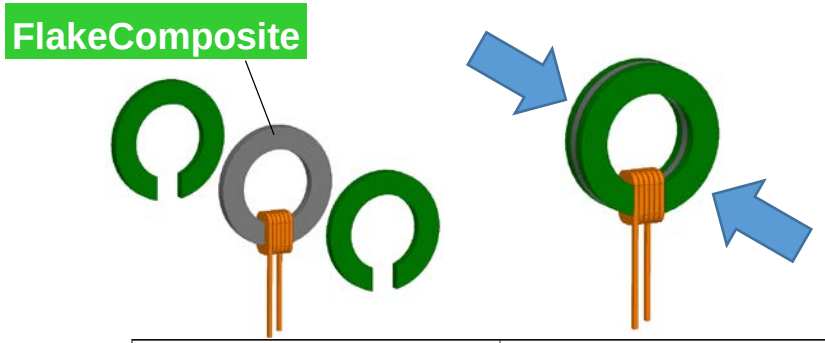
Permeability under DC-bias Field



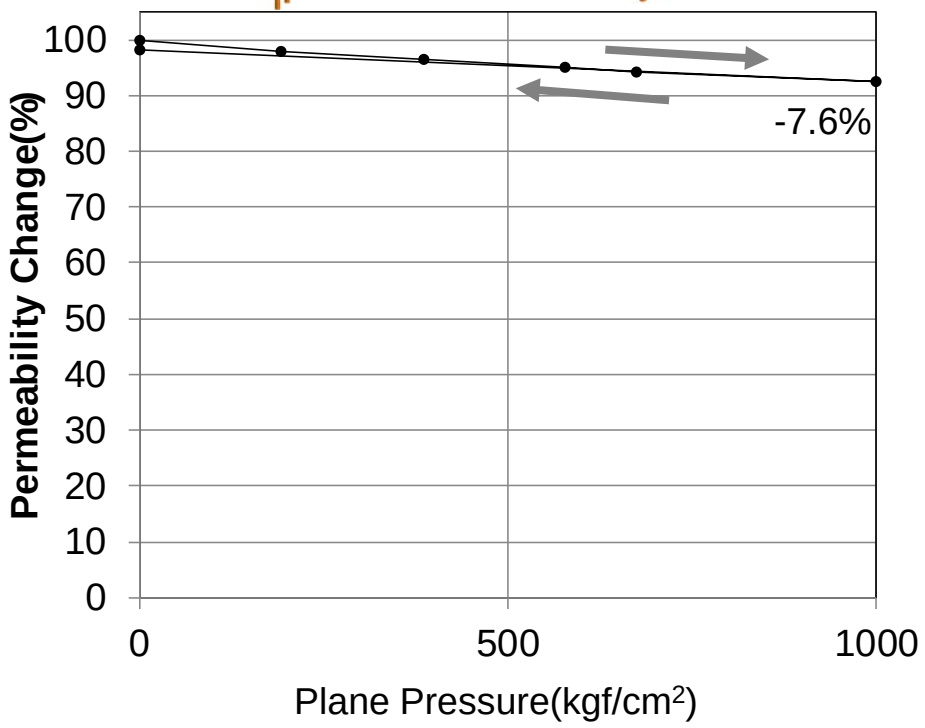
In MnZn ferrite and FlakeComposite, effective permeability under zero bias field is tuned to be 70 by corresponding demagnetizing coefficient, i.e, air-gap.

- In metals, permeability under DC-bias field is insensitive to temperature.
- In metals, permeability survives under high DC-bias field.

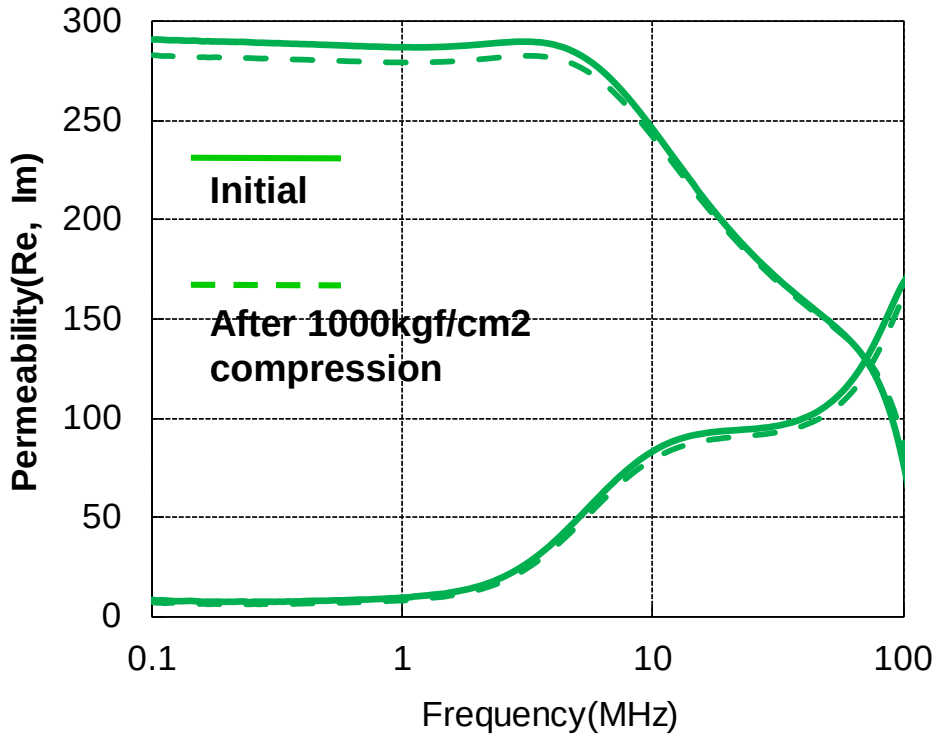
Effect of Plane Compression



- Apply 1000kgf/cm^2 plane pressure on the toroidal core.



- Only 7.6% permeability decrease under 1000kgf/cm^2 compression.



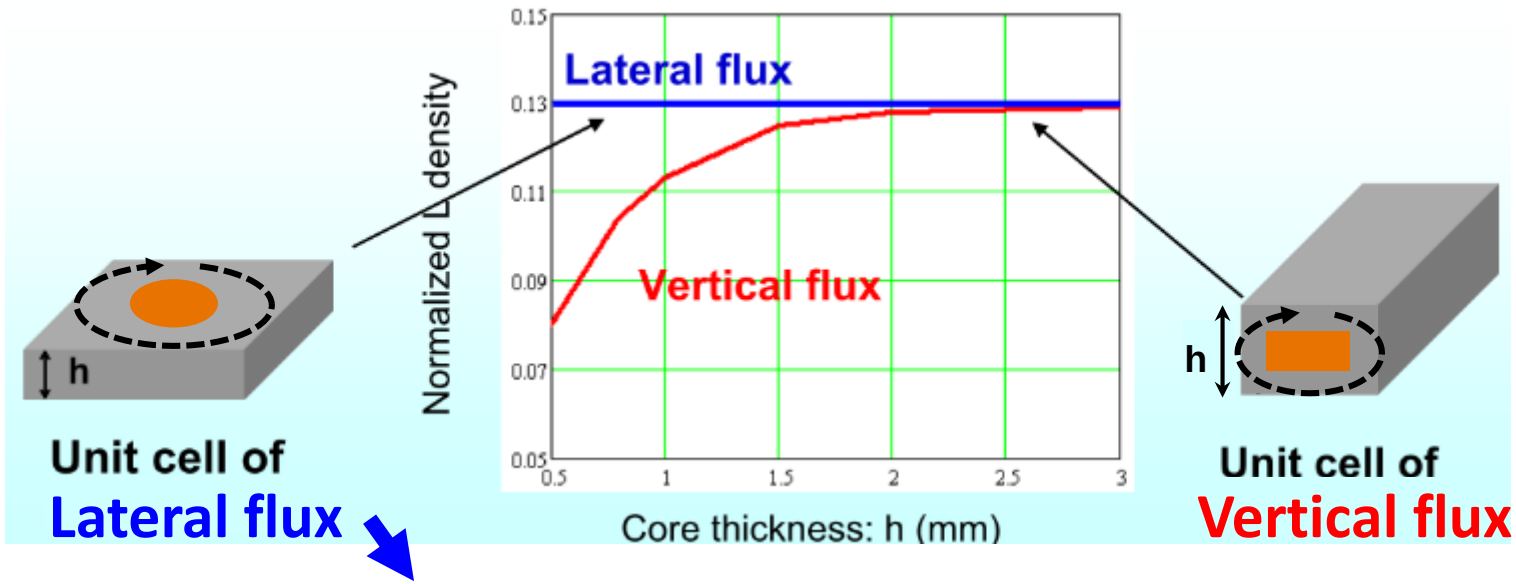
- Only 2.7% permeability decrease after 1000kgf/cm^2 compression.
- No apparent damage was found.

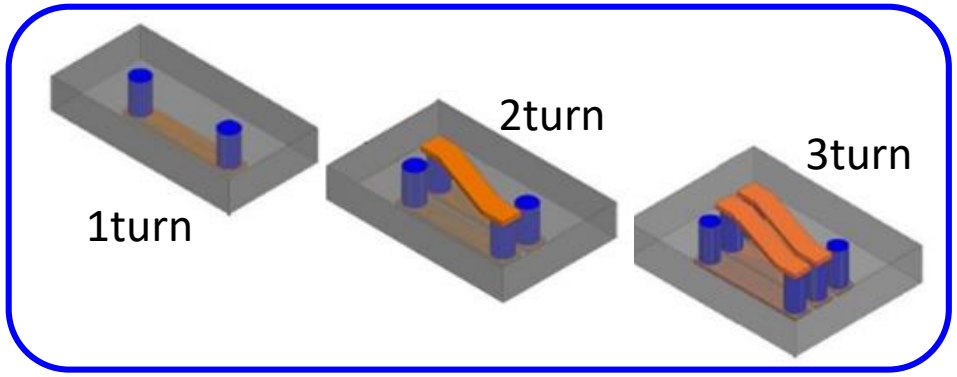
- Material characteristics of FlakeComposite™ ,
  in comparison with existing magnetic materials.
  -Permeability, magnetic saturation, core loss, etc.

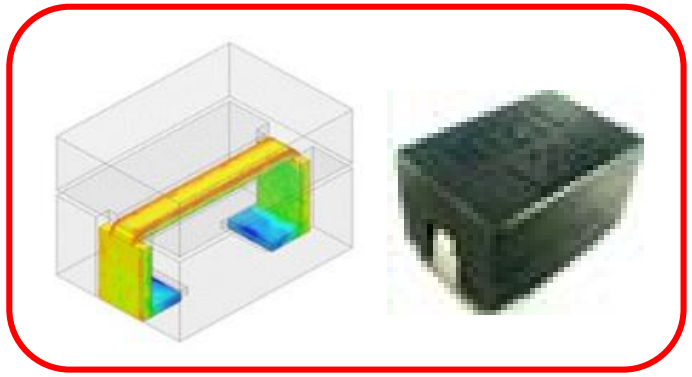
- Inductor performance benchmarking.

- PCB embedded inductor test fabrication result.

Lateral Flux Inductor Structure





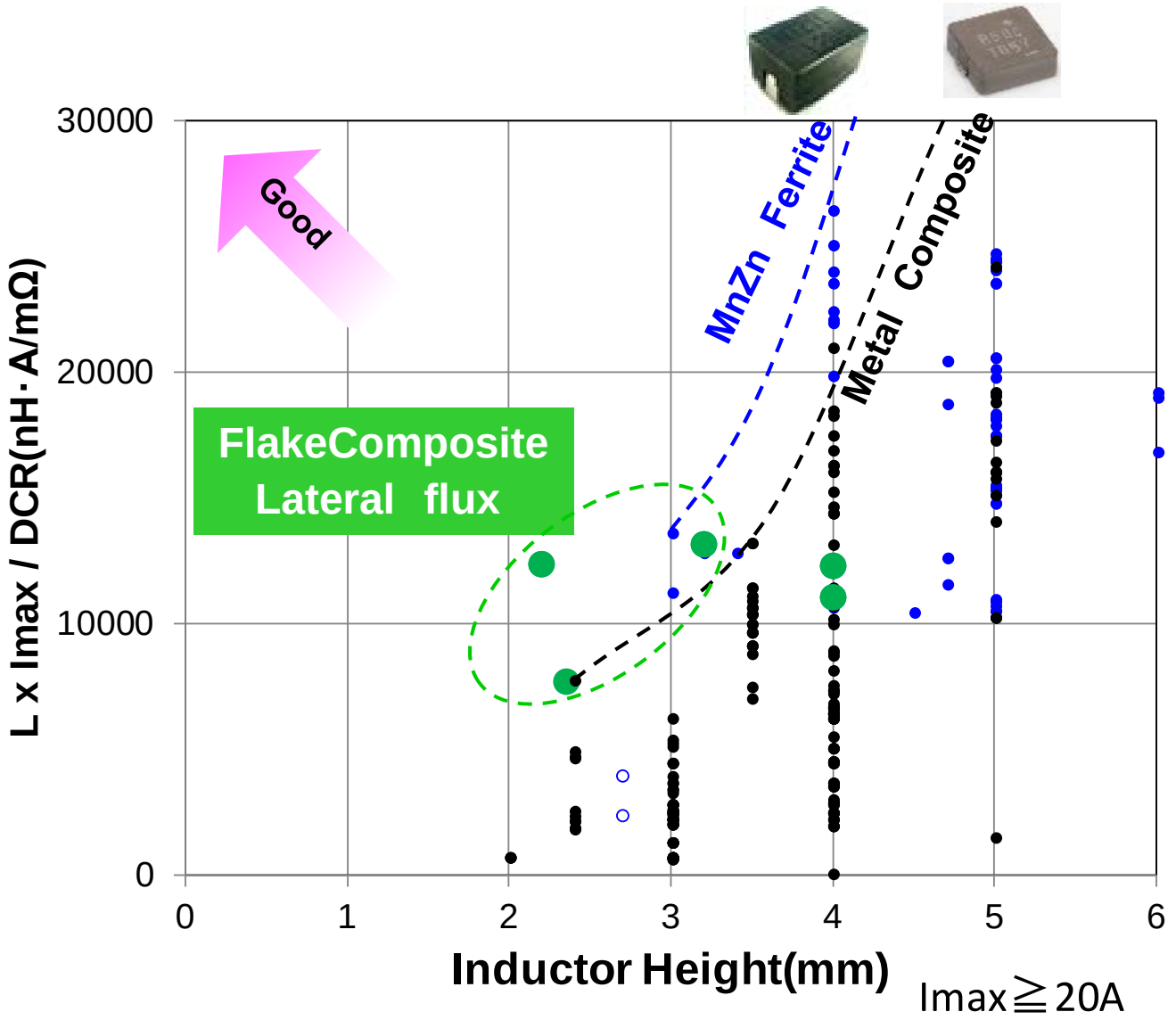


- FlakeComposite is suitable to demonstrate the proposed advantage of “Lateral flux” inductor design.
- As inductor goes thinner, the advantage of “Lateral flux” inductor structure should be more prominent.

Qiang Li, Fred C. Lee, “High Inductance Density Low-Profile Inductor Structure for Integrated Point-of-Load Converter”, 2009 IEEE Applied Power Electronics Conference and Exposition (APEC), Washington, District of Columbia, Feb. 15 – 19, 2009, pp. 1011 – 1017.

Dongbin Hou, Yipeng Su, Qiang Li, Fred C. Lee, “Improving the Efficiency and Dynamics of 3D Integrated POL”, IEEE Applied Power Electronics Conference and Exposition (APEC), 2015, pp. 1011 – 1017.

Benchmarking Result



- The advantage of FlakeComposite Lateral flux inductor becomes prominent as the inductor height goes lower.

Reliability Test Example (On samples to CPES)

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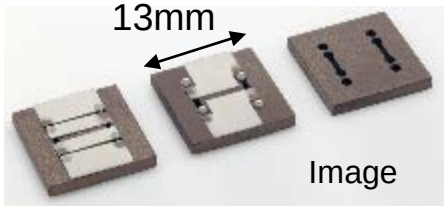
Sample Structure

・Tin plated lead frame and Cu pins (without insulation coating) are attached on the FlakeComposite core.



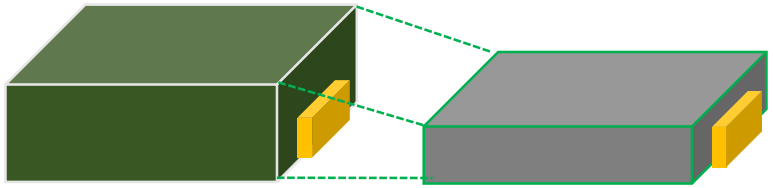
- Acceptance Criteria:
  - ・ Change of Ls, Rs and DCR<10% pre-test to post-test.
  - ・ No cracks, chips or discoloration

Storage	JESD22-A119 JESD22-A103 Condition B		**Result** (N=22)
	-50℃	1000h	Pass
	150℃	1000h	Pass
Heat Cycle	JESD22-A104 Condition C Soak Mode 4		
	-65⇔150℃	500cycle	Pass
Hi Temp and Humidity	MIL-STD-202 Method 103		
	85℃85%	1000h	Pass
Unbiased Hast	JESD22-A118		
With MSL 3 Pre-Conditioning	130℃85%	96h	Pass
	33.3psia(2.3atm)		
MSL test (Level 1)	J-STD-020E		
Pre-bake	125℃	24h	Pass
Moisture Soak	85℃85%RH	192h	
Reflow	260℃ x 3		

➢ AEC-Q200 compatible. (RoHS2.0, Halogen free, REACH compliant.)

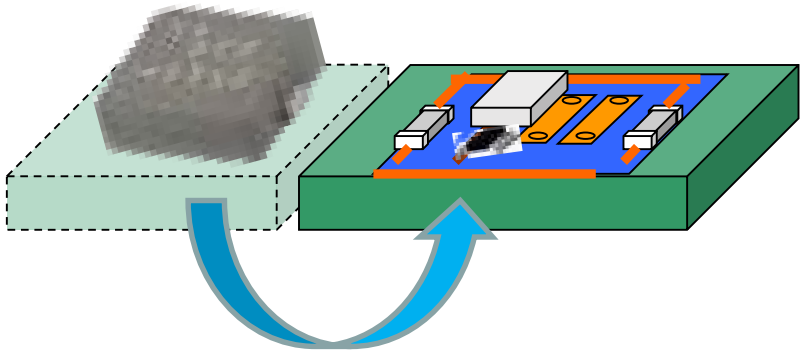
Application Target

Power Inductors



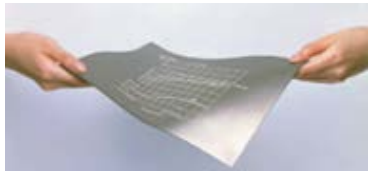
Ferrite ➡ **FlakeComposite™**

40% height reduction with FlakeComposite inductor.

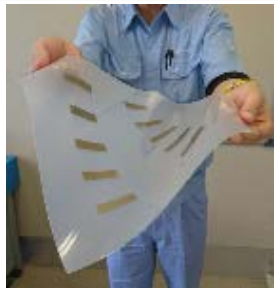


PCB embedded inductor to minimize:
- PCB board area.
- parasitic inductance of Cu trace.

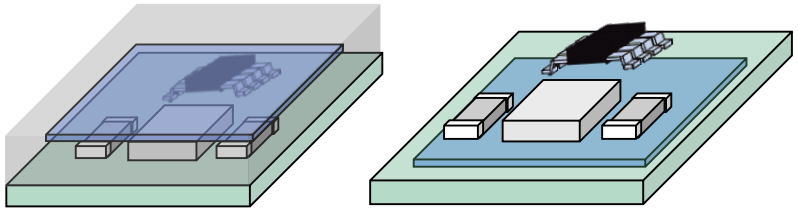
Magnetic Sheets



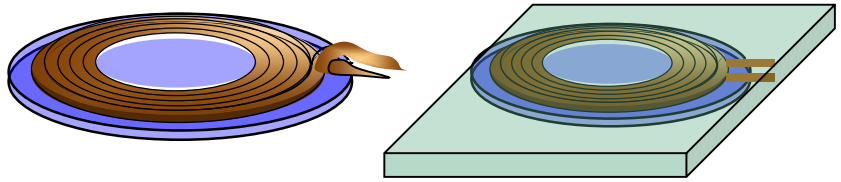
FlexSuppressor® ➡



Flex "Embedded" Suppressor



Embedded noise shielding layer



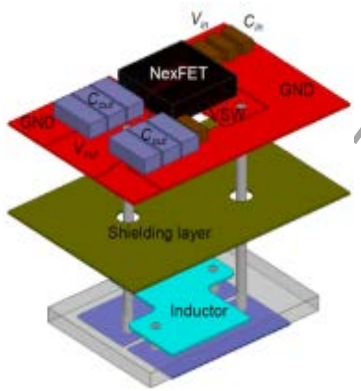
Flexible shielding layer (for WPT)
- Combined with PCB embedding technology.

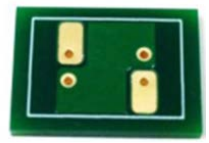
- Material characteristics of FlakeComposite™ ,
  in comparison with existing magnetic materials.
  -Permeability, magnetic saturation, core loss, etc.

- Inductor performance benchmarking.

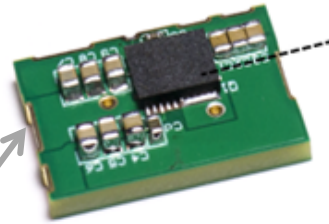
- PCB embedded inductor test fabrication result.

PCB Embedded Inductor Demonstrated by CPES



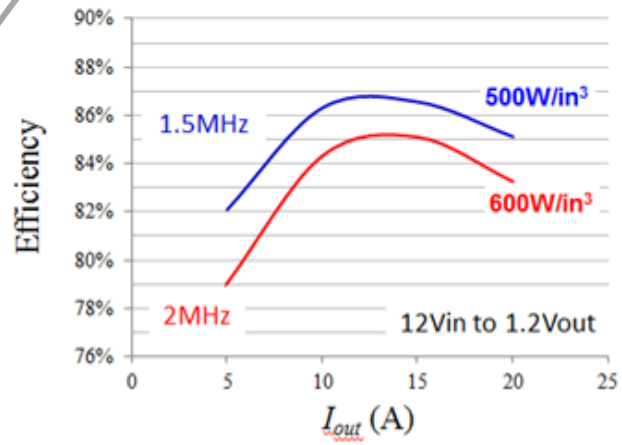


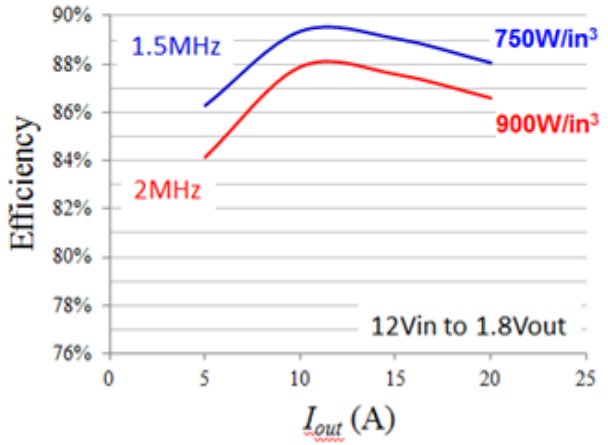
Efficiency Testing of PCB Integrated POL Module



TI's NexFET PowerStage
CSD97370 ($30V_{ds}$)

f_s	core size (mm)	module thickness
1.5M	15*10*1.3	3.8 mm
2M	15*10*1.0	3.5 mm





Y. Su, W. Zhang, Q. Li, F. C. Lee, and M. Mu, "High frequency integrated Point of Load (POL) module with PCB embedded inductor substrate," in *Energy Conversion Congress and Exposition (ECCE), 2013 IEEE*, 2013, pp. 1243-1250.

- Similar prototypes were fabricated.

PCB Embedded Inductor Prototype

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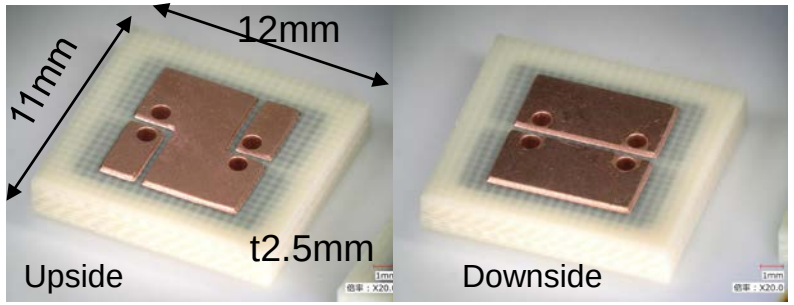
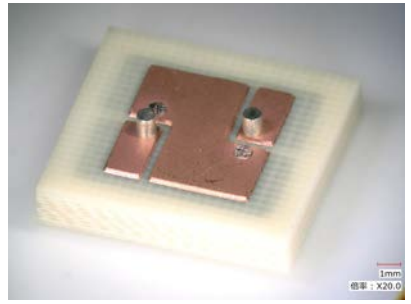
2 turn

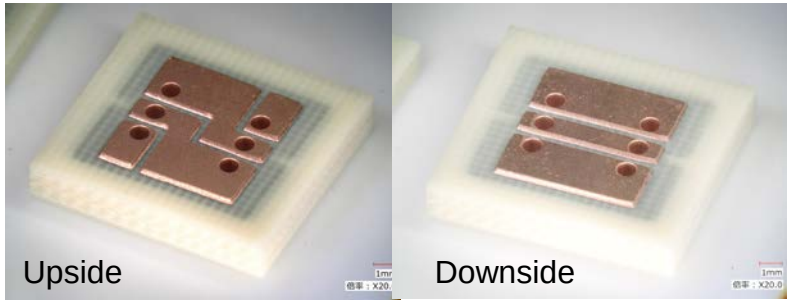


DCR
2.8mΩ

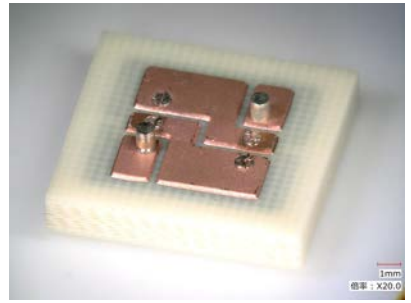


With inserted pins
0.8mΩ

3 turn

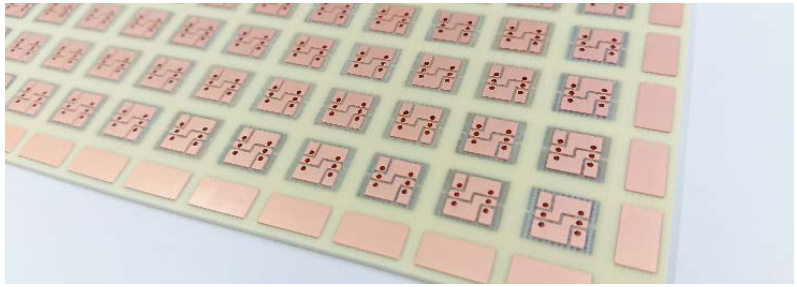


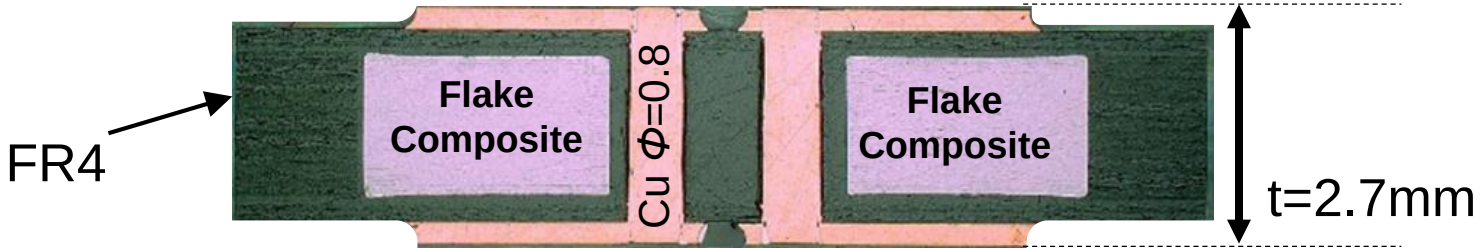
DCR
4.4mΩ

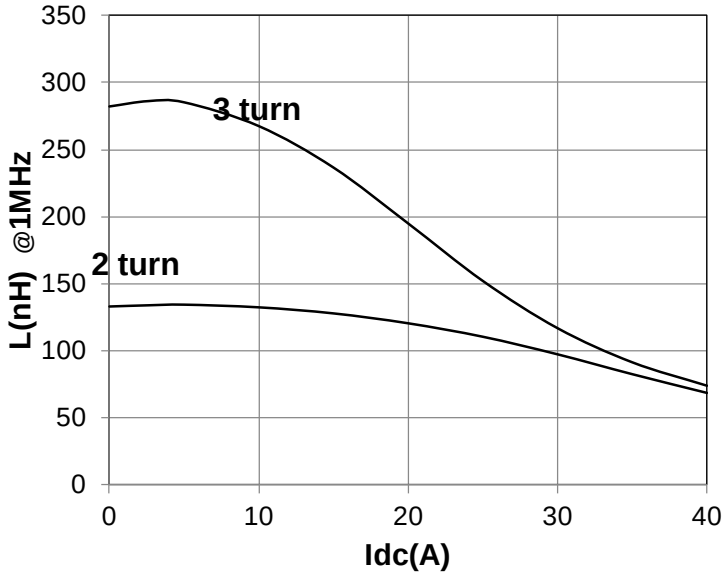


With inserted pins
2.1mΩ

Embedded core size
9 x 8 x t1.5mm

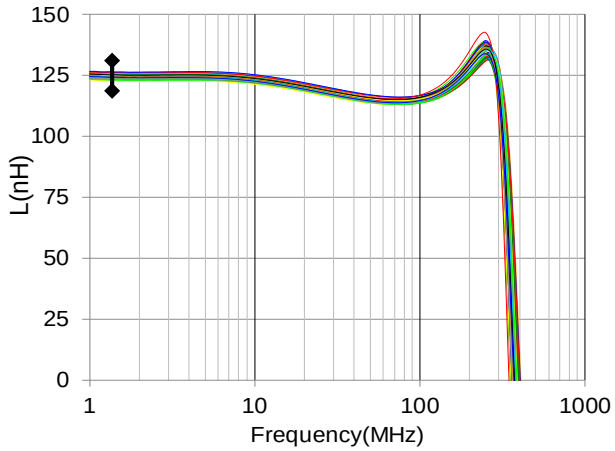


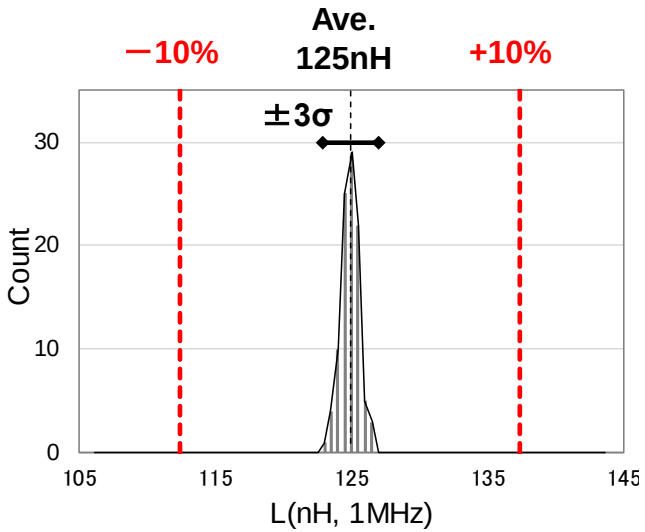


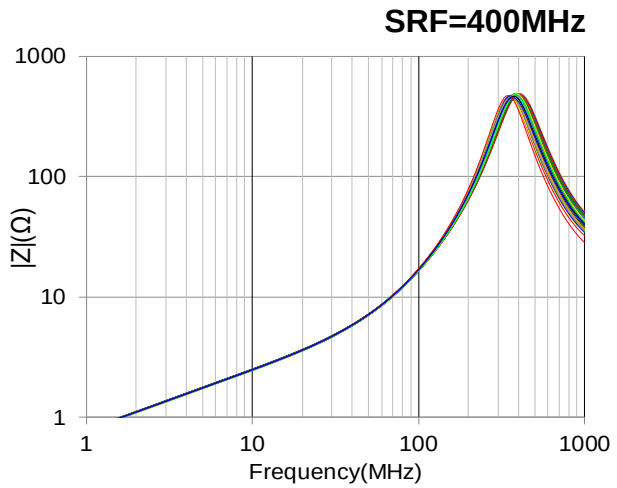


Dispersion of Inductance , |Z|

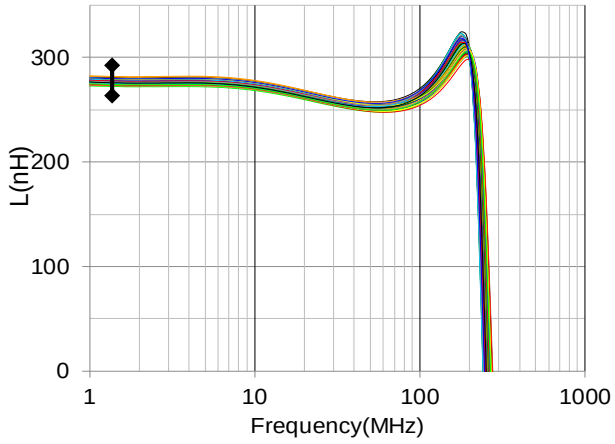
2 turn (n=100)

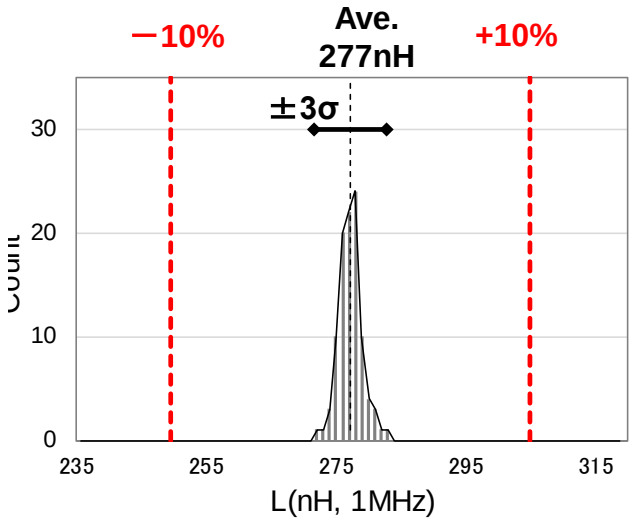


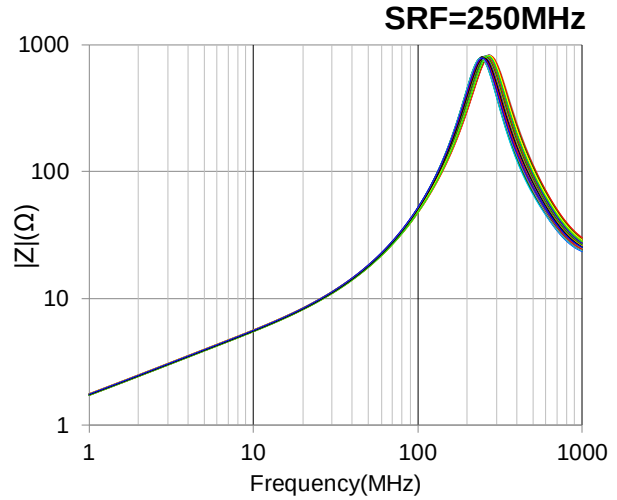




3 turn (n=100)







➢ Tight tolerance of inductance is readily achieved in prototypes.

Summary

- FlakeComposite™ is:
  - -Thin, Flexible, PCB-embed-enabling,
  - -High permeability at multi-MHz swithcing frequency,
  - -High-saturated magnetic moment than ferrite,
  - -High temperature tolerant

  soft magnetic material for power supply application.

- We believe this material will contribute to the miniturization of electronic circuits, especially in:
  - - DC/DC converters,
  - - Wireless Power Transfer system.

- We are continuing to scale-up this technology for use in several applications.

Thank you very much for your attention.