POWER MAGNETICS @HIGH FREQUENCY WORKSHOP 2023

NANOCRYSTALLINE SOFT MAGNETIC MATERIAL (NSMM) APPLICATION DEVELOPMENT PROGRAM

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CBMM - Amsterdam: Technical Market Development Specialist (Global)-Nanomaterials

CBMM is the world leader in production and commercialization of Niobium products and has been in the market for over 60 years

Different products for unique applications

Infrastructure	Aerospace	Energy
Mobility	Health	Oil & Gas

More than 400 clients in 50 countries, in all continents

Production capacity that exceeds current global demand

Over 250M BRL per year invested in R&D

Partnership with the most renowned research centers

CBMM is present in all continents and has over 40 years of relationship with China

GUARANTEED BY A

GLOBAL COMPANY

Nanocrystalline Soft Magnetic Materials (NSMM) Development Program

FeNb

Nano Ribbon

Core

Magnetic Component

CMC, HFT, PFC, CT, ...

Power Component

Inverters, power converters, power supply units, rectifiers,...

Application

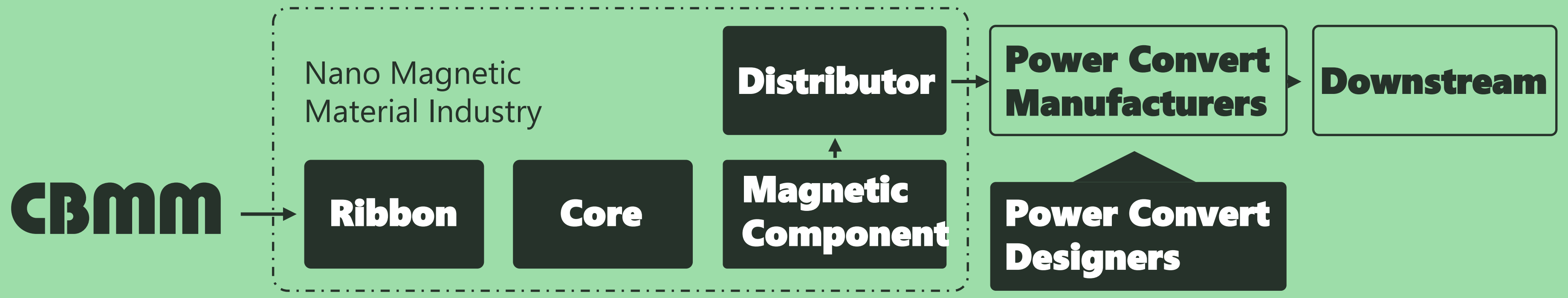
Ev's, HVAC, smart meters, solar power gen, data centers...

CBMM supplies essential raw material (Fe-Nb) to global nanocrystalline ribbon producers (90+)

100% of Nanocrystalline Soft magnetic Materials available in the market today contains Nb .

In a typical Nanocrystalline ribbons production, 5.6 % by weight of Niobium is used . Along with other elements like Fe, Si, B and Cu

CBMM focus is disseminating its application in emerging markets



NANOCRYSTALLINE PRODUCTION PROCESS

Produced as thin ribbons

Thickness of the sheet: 14-30µm
(↓ thickness - ↑ properties)

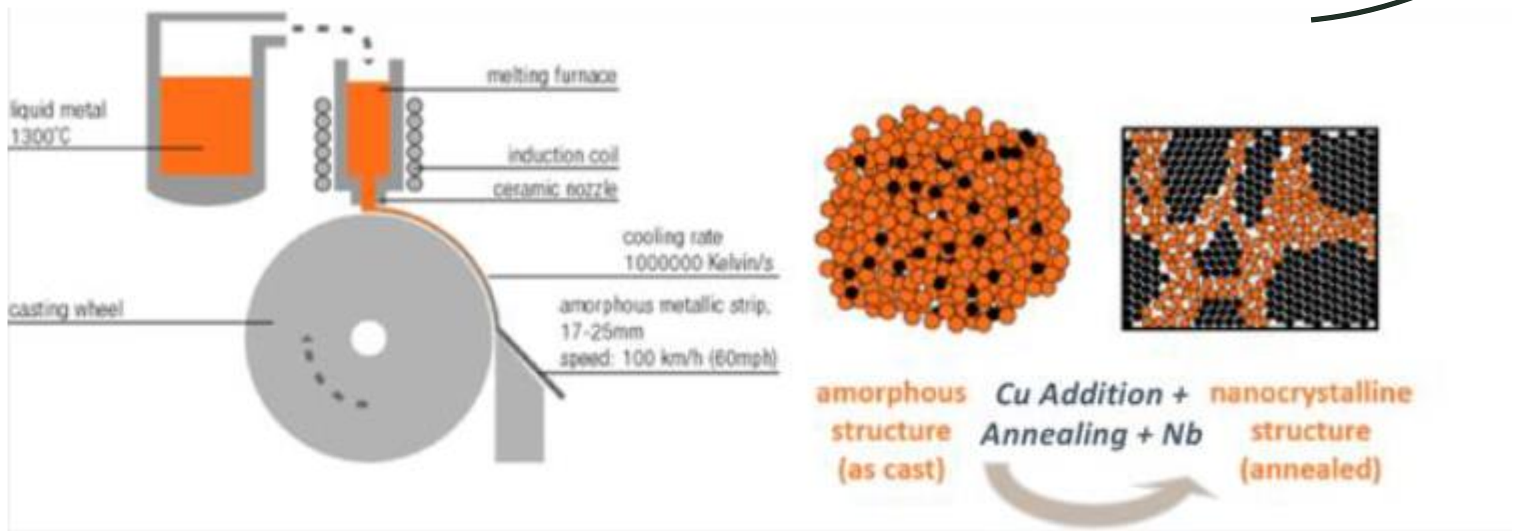
Ribbon width: usually 60-70mm

Firstly developed by Hitach in 1989 as FINEMET®

Production process

MELT SPINNING

ANNEALING



Standard chemical composition (small variations):
$[(Fe)]_{83.4}$ $[(Nb)]_{5.6}$ $[(Cu)]_{1.3}$ $[(Si)]_{7.7}$ $[(B)]_{2}$ – tradicional FINEMET® chemical composition

Usually 5.5 to 6% of Nb in Chemical composition

Grains extremely small (~10nm) and uniform distribution

Source : VAC and Proterial

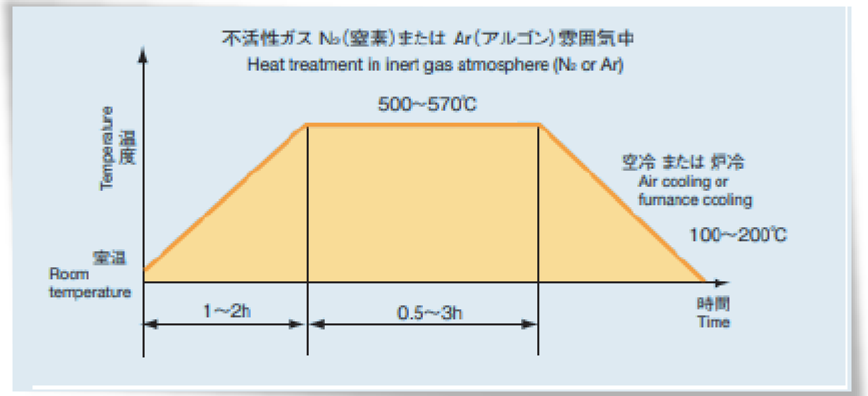
NANOCRYSTALLINE PROPERTIES

Ribbon thickness

14 - 18 µm
18 - 22 µm
22 - 26 µm
26 - 30 µm
> 30 µm

+

Annealing treatment



Ramp-up;

Temperature;

Soaking time;

Number of heating steps;

Applied magnetic field (longitudinal, transversal, none)

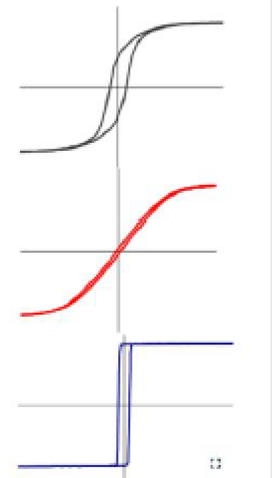
=

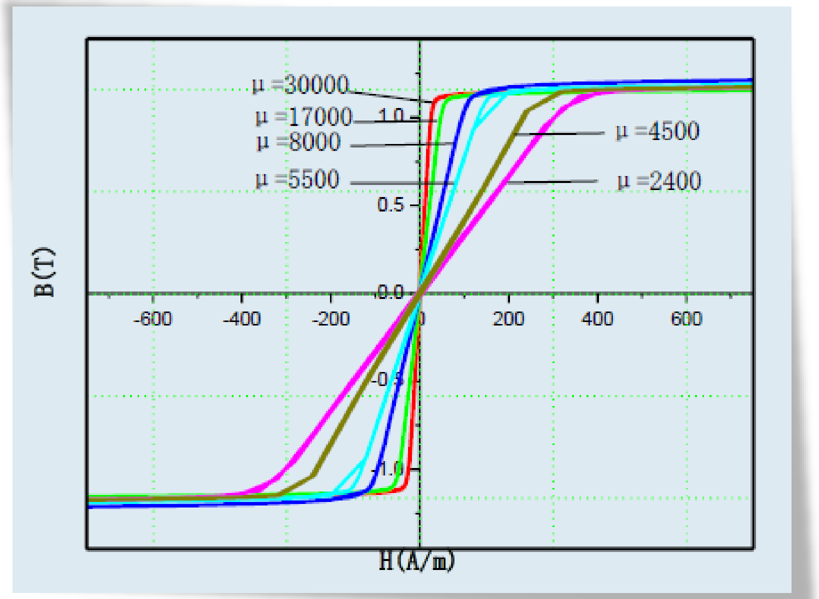
Hysteresis curve

Permeability

Frequency

Saturation





Source : VAC and Proterial

Nanocrystalline materials allow miniaturization while increasing performance of components

Systems

- Smart meter
- EV charging station
- Onboard chargers and Inverters for EV
- Power converters
- Data center - UPS
- Electric motors
- Solar PV Inverter

Components

- CMC filters
- EMI filters
- DC filters
- Current transformers
- RCD Type A (6mA DC)
- Dual active bridge transformers
- PFC & DC Inductors
- Motor stator...

Major benefits of nanocrystalline materials

Performance

- Accuracy & Efficiency: 99%
- Reduced core loss
- Higher filter attenuation
- Safety: fast response time

Size reduction

- Up to:
- 40% less copper windings
- 70% less weight
- 60% less volume

Properties shown in:
Smart meters; EV charging IC-CPD; On board charger; Solar energy; Energy grid

Comparisons with standard materials:
Ferrite; Permalloy; Amorphous; Sendust; MPP

GROWING APPLICATION TRENDS FOR THE USE OF NSMM*

CMC and EMC for EV:
On-board & Off-board applications

Current Transformers for: Smart metering, Revenue metering, Data center BCM**, Industrial metering

Differential Current Sensor for EV charging stations: RCD Type A + 6 mA DC sensor

Medium frequency Transformer applications for high power electronics and solid-state transformers

DC-DC inductors and PFC inductors using Nanocrystalline powder cores and stress annealed cores

Wireless charging shields for mobiles and EV charging

**NSMM=Nanocrystalline Soft Magnetic Materials*
***BCM= Branch Circuit Monitoring*

MAJOR CHALLENGES FOR APPLICATION OF NSMM*

Low awareness about material properties, its potential applications and the connection between producers and end users

Negative perception from the market that NSMM is expensive and very hard to source

Shape limitation as they are tape wound cores

Lower Bs (1.2T) compared to electrical steel (1.8T)

Lack of standardization protocols for testing and characterization of materials & cores

Present NSMM* technology is not suitable for power applications (transformers and inductors) > 100KHz

**NSMM=Nanocrystalline Soft Magnetic Materials*
***BCM= Branch Circuit Monitoring*

CBMM DEVELOPMENT STRATEGY FOR NSMM*

Investing in pilot studies/case studies with universities and industrial players to prove the benefits of using NSMM in emerging applications.

- High power density electric motors using NSMM* stator
- NSMM testing and characterization
- Current transformers for energy metering
- Electronic components for charging stations (filters, RCD's, transformers)
- High power density EV Onboard Chargers
- Wireless Charging

**NSMM=Nanocrystalline Soft Magnetic Materials*

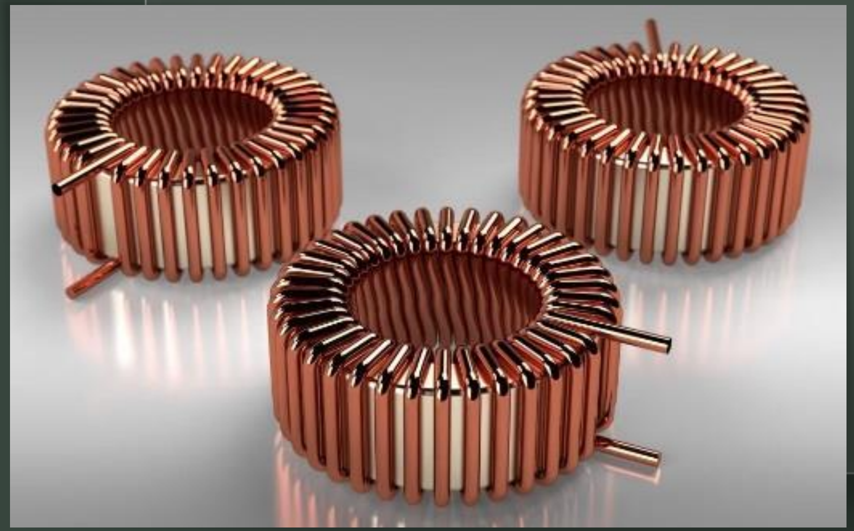
PARTNERSHIP WITH AMPED & PITTSBURGH UNIVERSITY

University of Pittsburgh

CBMM

Standardized Testing of Materials and Electromagnetic Components

Benchmarking of Nanocrystalline Soft Magnetic Cores vs. Industry Standard



Three Applications:

High Frequency Transformer

Harmonic Filter / Line Filter

Current Transformer

Two Core Types:

Industry Standard

Nanocrystalline

PARTNERSHIP WITH AMPED & PITTSBURGH UNIVERSITY

IEEE 393: 1991 – IEEE Standard for Test Procedures of Magnetic Cores

- **Section 5** – Analytical terminology definition (core loss, apparent core loss, permeability, etc.)
- **Section 6** – Test procedures including two-winding method, bridge measurements, etc.

IEC 62044

IEC 62044-1:2000: Cores made of soft magnetic materials – Measurement Methods Part 1

- Generic specifications
- Defines basic testing principles, selection of coils, magnetic conditioning (electrical / thermal)

IEC 62044-2:2000: Cores made of soft magnetic materials – Measurement Methods Part 2

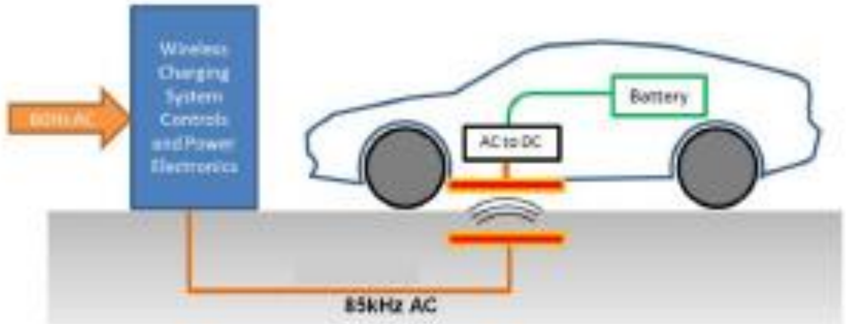
- Magnetic properties at low excitation levels
- Includes terminology and parameters for test setups using impedance analyzer / LCR meter

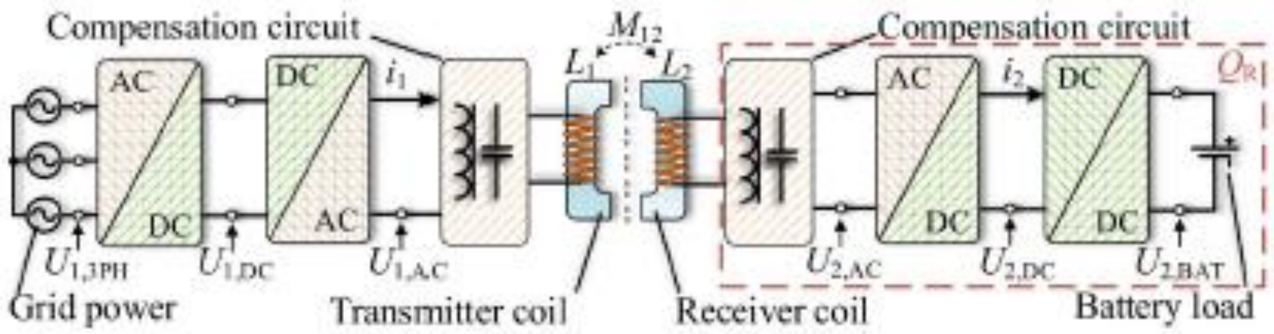
IEC 62044-3:2000: Cores made of soft magnetic materials – Measurement Methods Part 3

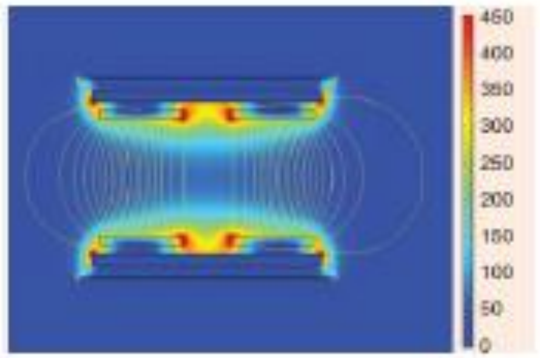
- Magnetic properties at high excitation levels
- Annex A and section 6: show the two-winding method, Annex B shows RMS method

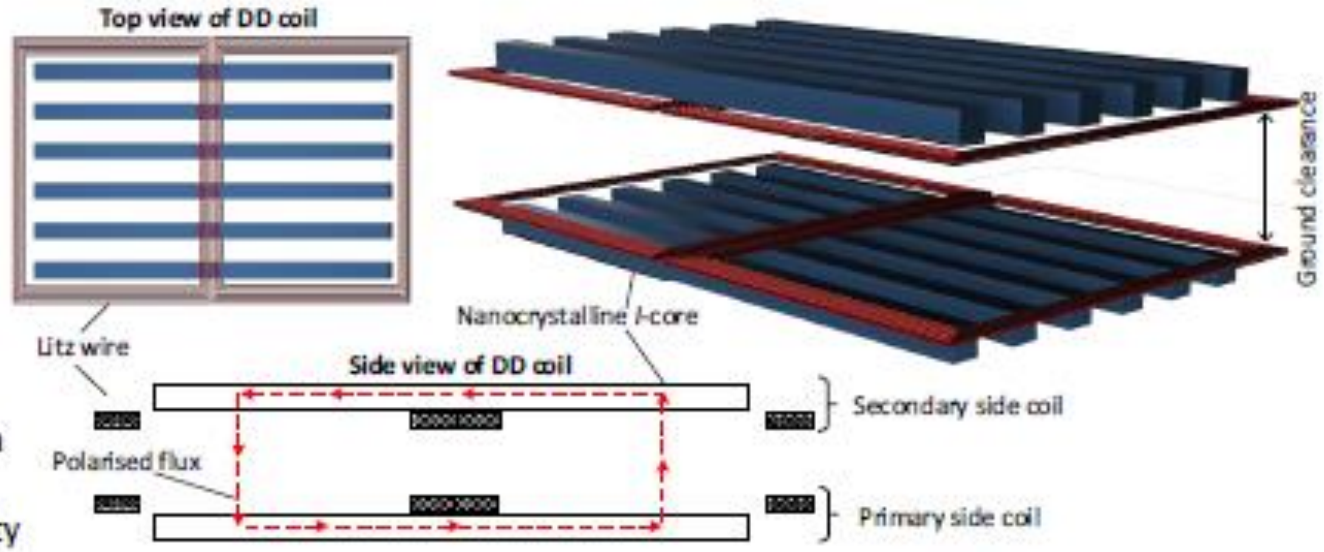
PARTNERSHIP WITH UNIVERSITY OF CAMBRIDGE : EV WIRELESS CHARGING (Prof Teng Long)

Basic concept of inductive power transfer (IPT)









- 50/60 Hz electricity to 85 kHz magnetic field
- 85 kHz magnetic field transfer energy via 10 to 30 cm free space
- Receiver converts magnetic field back to DC electricity
- SEA 2954 defines 7.7kW and 11 kW at 85 kHz for EV charging

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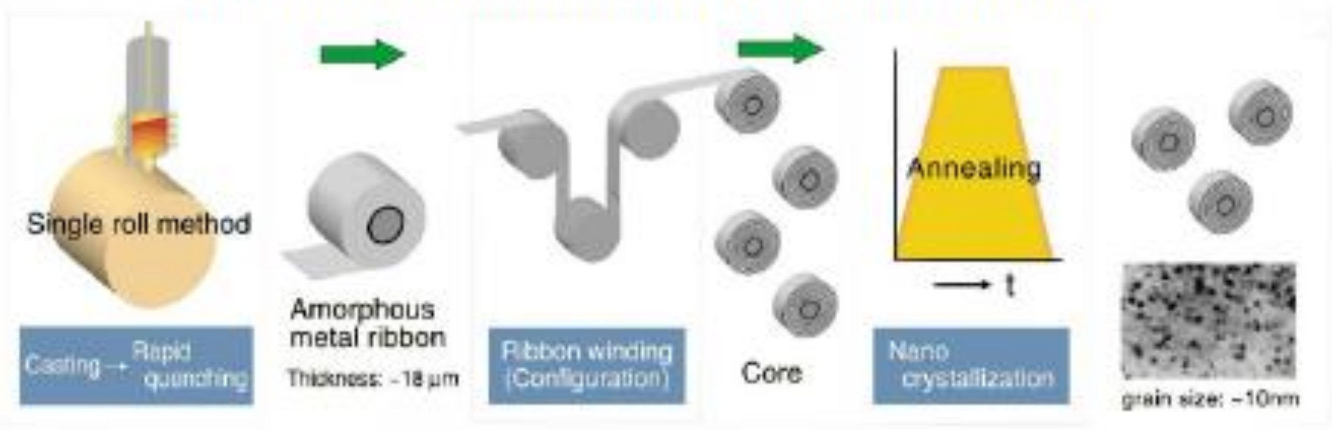
A novel magnetic core for wireless charging coils

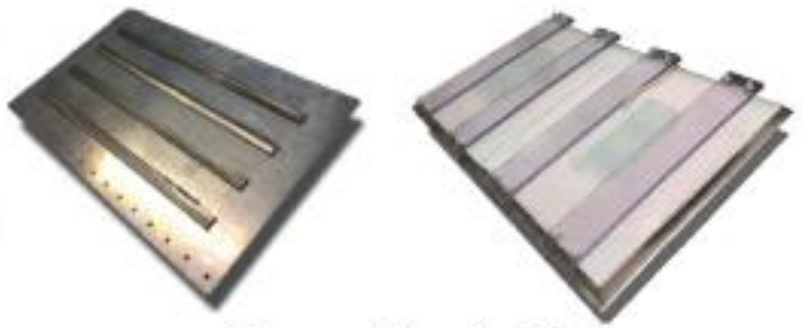
Manufacturing process of nanocrystalline alloy ribbon



(a)

Nanocrystalline alloy ribbon reel

(b)



Nanocrystalline alloy ribbon cores (magnetic strip cores in IPT coils)

- FeCuNbSiB nanocrystalline alloy ribbon is used for magnetic cores
- Nanocrystalline ribbon is inherently thin (less than 20 μm) due to quenching technique in manufacturing
- Ribbons are stacked and insulated by resin and special coating for lower eddy current loss.
- Nanocrystalline ribbon cores have been used in common mode chokes and high frequency transformers → **use in high power IPT as a high frequency electromagnetic device could be feasible**

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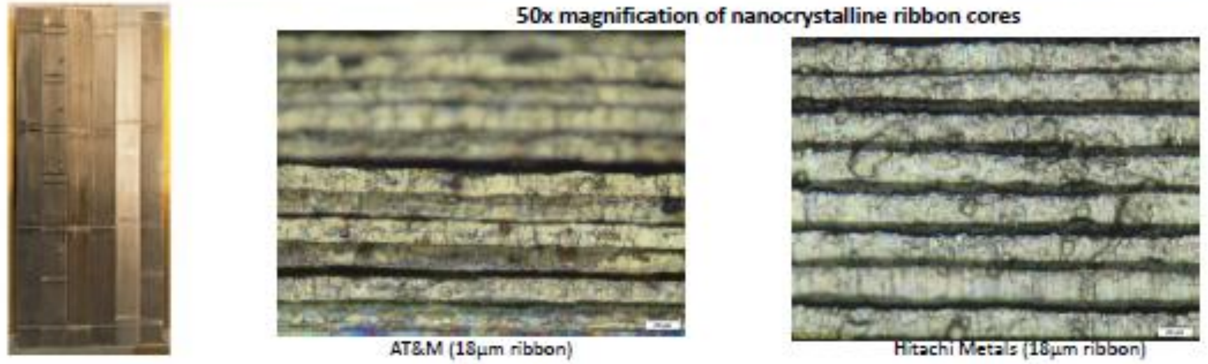
IPT Design 2 | Better nanocrystalline lamination

50x magnification of nanocrystalline ribbon cores



➢ Better segregation between nanocrystalline ribbons from Hitachi also improves performance

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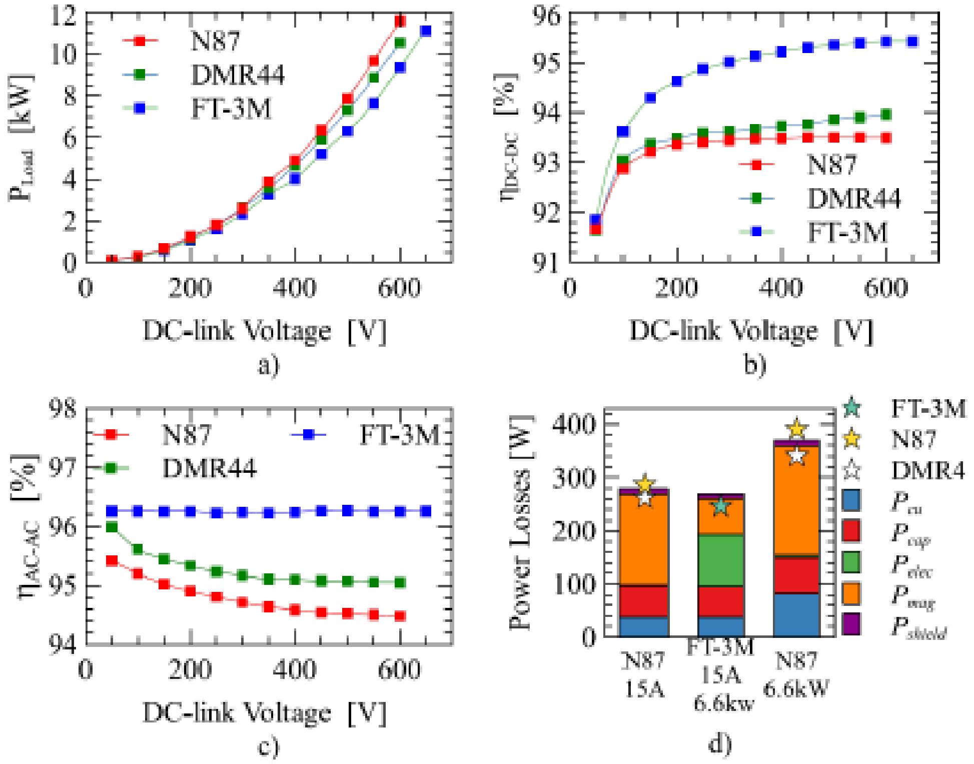
Performance of nanocrystalline core IPT Design 2 (11kW)



- More than 2.5% efficiency higher than the ferrite counterpart with the demission and number of turns
- Eddy current loss of nanocrystalline core is reduced, but still dominants its total core loss
- Hysteresis loss of nanocrystalline cores is much smaller than that of ferrite cores
- Superior performance ➔ **nanocrystalline cores are more efficient than ferrite cores for high power IPT**

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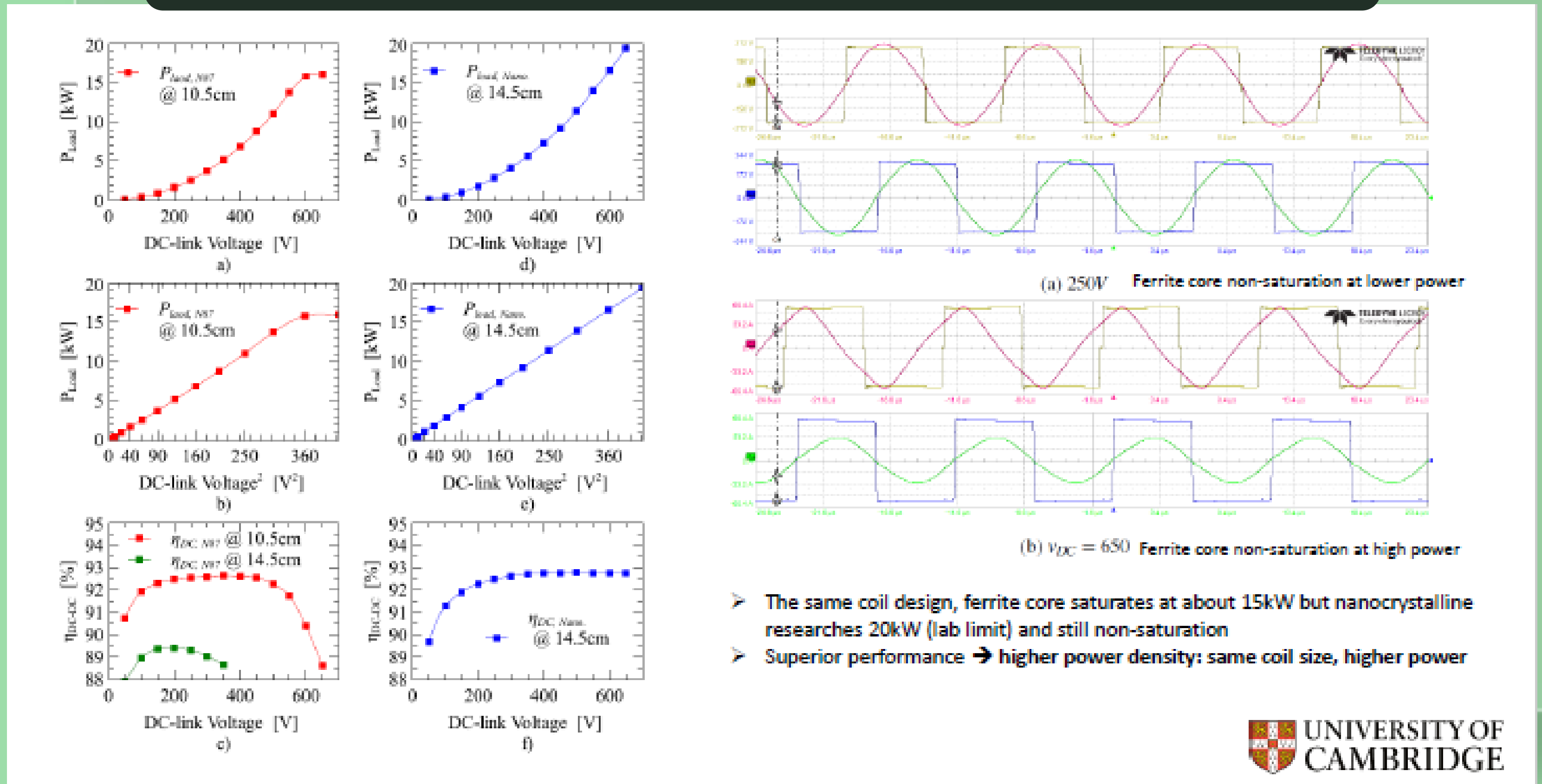
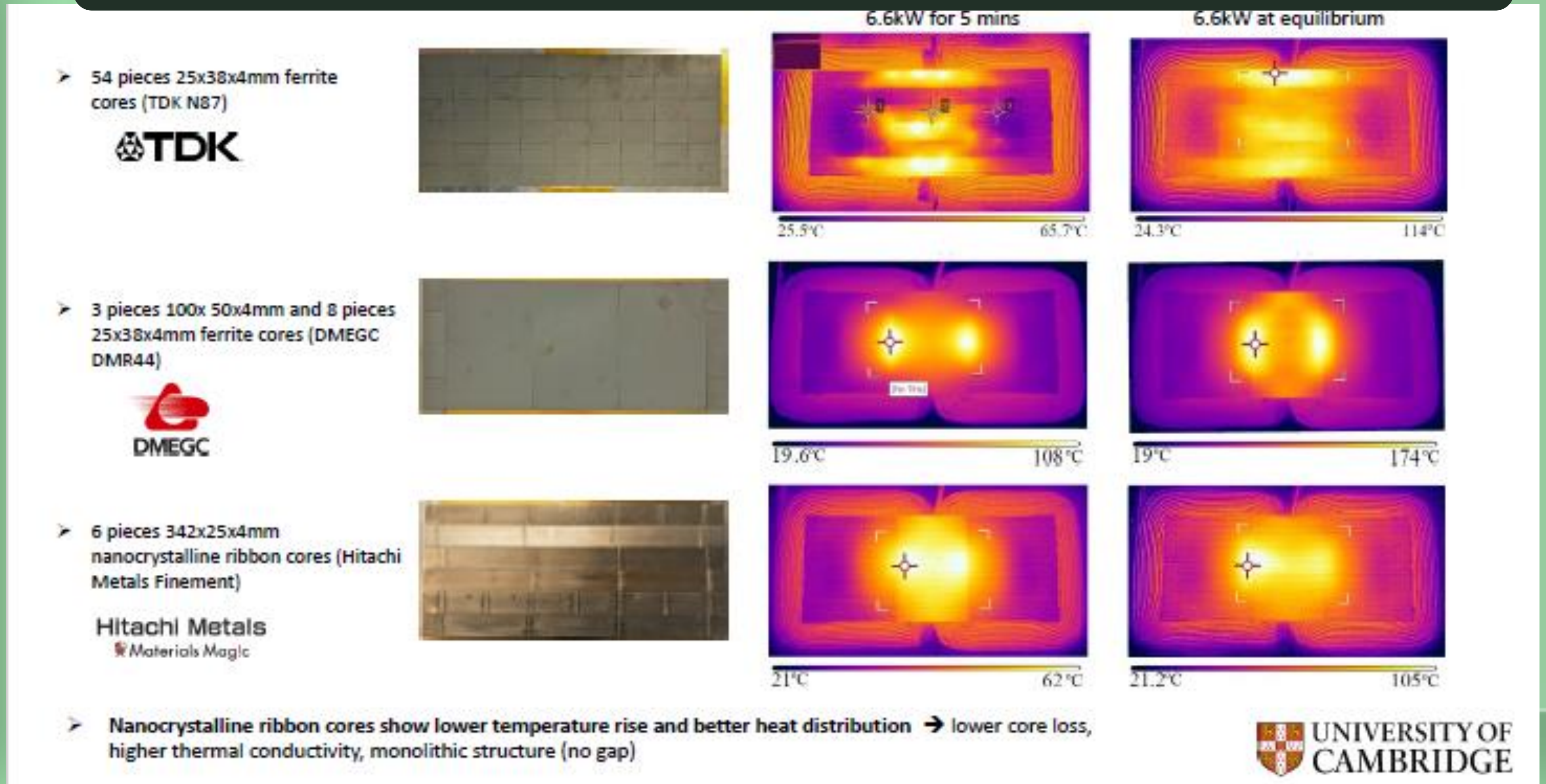
Higher power density (high saturation point)

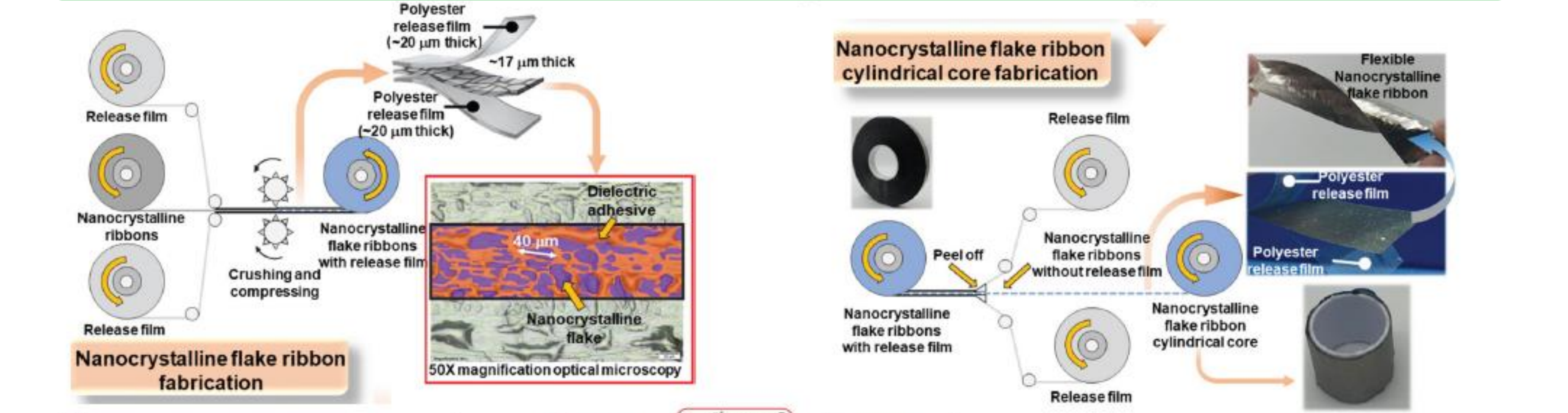


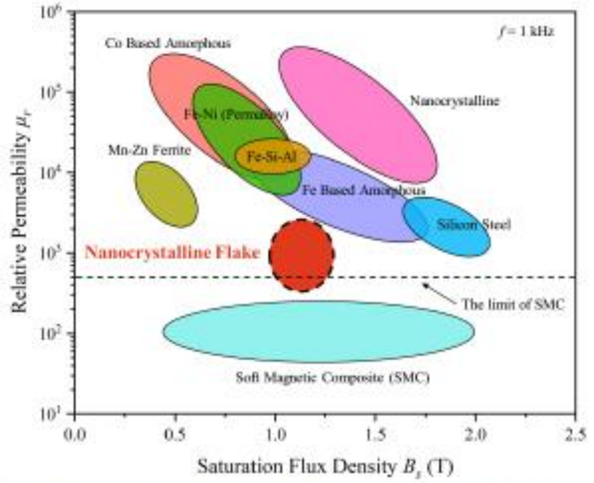
Better thermal performance

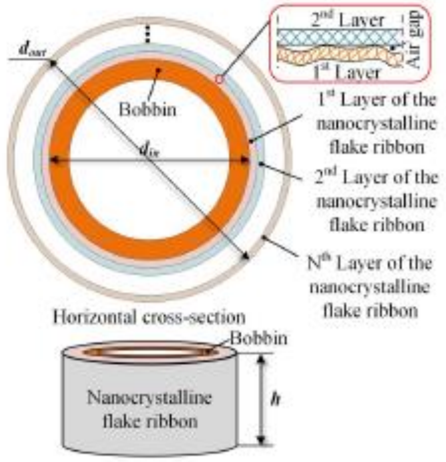


SOME PROJECTS: Partnership with University of Cambridge: Nanocrystalline Flake Ribbons for Inductors and Transformers

Flexible magnetic sheet – enabling self-made magnetic cores







- Nanocrystalline Flake Ribbon (NFR) magnetic sheets
- Permeability of NFR can be adjusted by pressing process
- Magnetic core is formed NFR sheets ➔ 2D building materials
- Geometry of the core is adjustable ➔ wound, stacked, hybrid
- Stacking factor can be adjusted ➔ control core loss and overall permeability

Z. Luo, X. Li, C. Jiang and T. Long, "Characterization of Nanocrystalline Flake Ribbon for High Frequency Magnetic Cores," in IEEE Transactions on Power Electronics, vol. 37, no. 12, pp. 14011-14016, Dec. 2022, doi: 10.1109/TPEL.2022.3189575.

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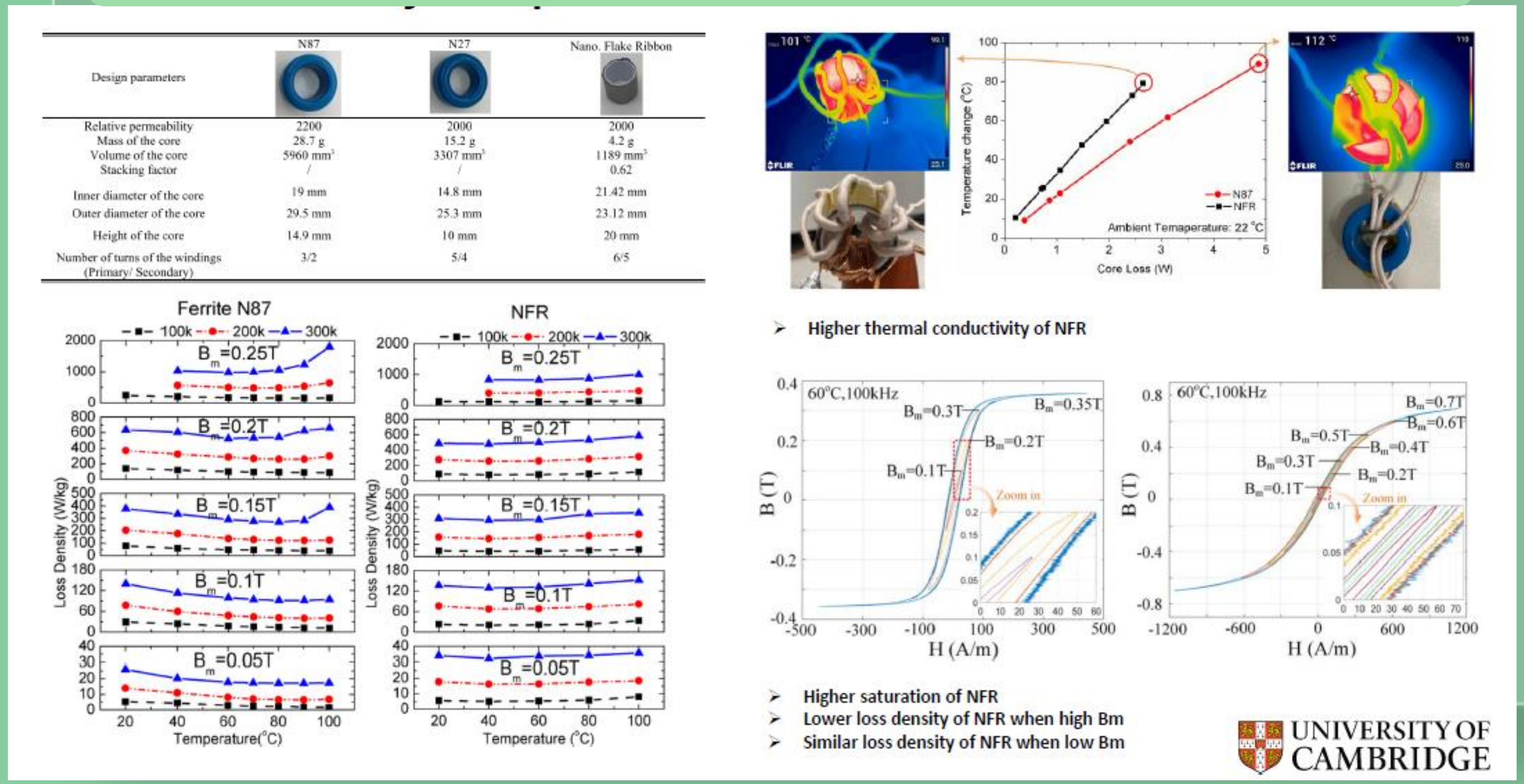
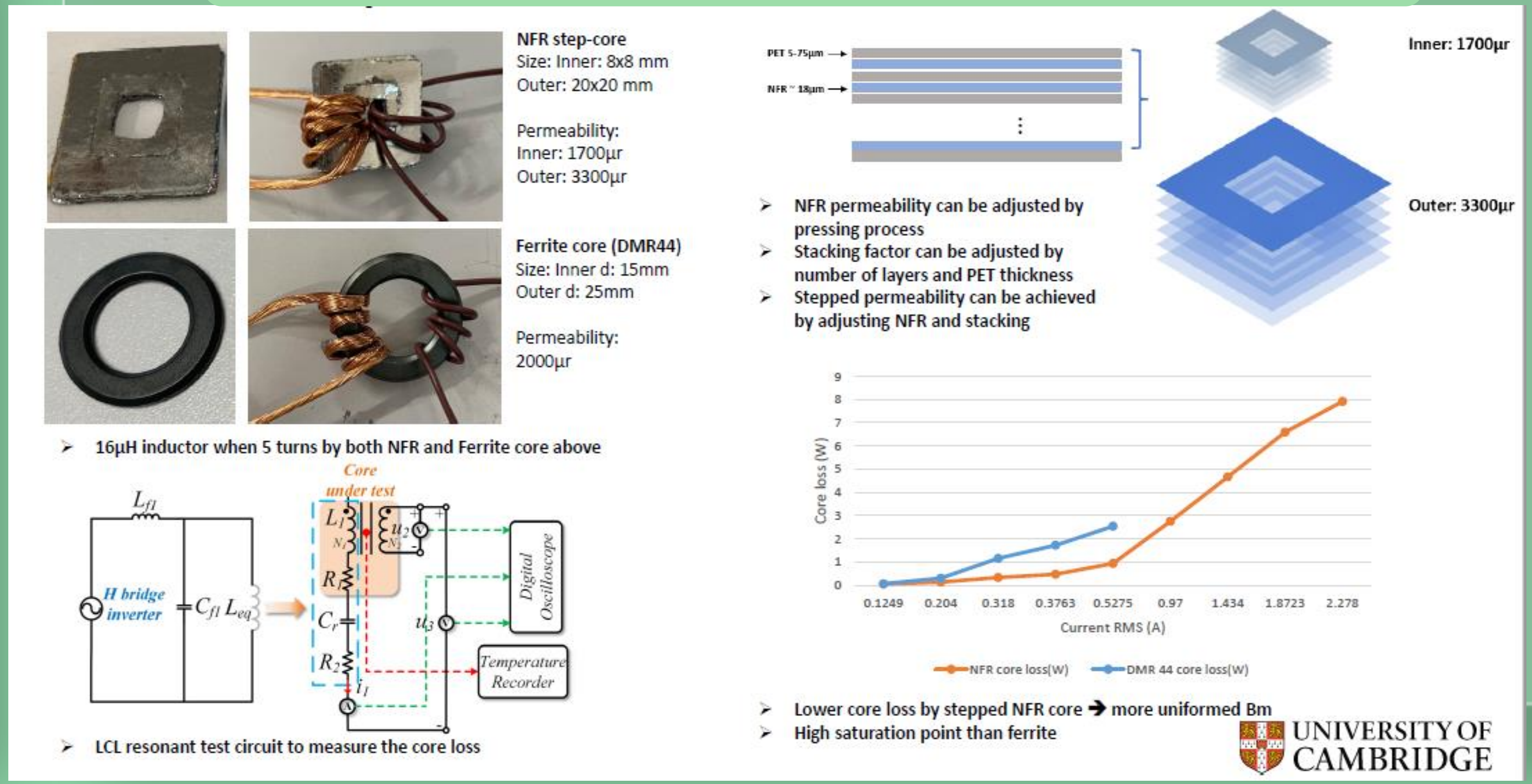
SOME PROJECTS: Partnership with University of Cambridge: Nanocrystalline Flake Ribbons for Inductors and Transformers

Core loss density comparison between NFR and ferrite



Design parameters	N87	N27	Nano. Flake Ribbon
Relative permeability	2200	2000	2000
Mass of the core	28.7 g	15.2 g	4.2 g
Volume of the core	5960 mm³	3307 mm³	1189 mm³
Stacking factor	/	/	0.62
Inner diameter of the core	19 mm	14.8 mm	21.42 mm
Outer diameter of the core	29.5 mm	25.3 mm	23.12 mm
Height of the core	14.9 mm	10 mm	20 mm
Number of turns of the windings (Primary/ Secondary)	3/2	5/4	6/5

Core loss comparison between NFR and Ferrite



SOME PROJECTS:
PARTNERSHIP WITH INNOLECTRIC (GERMANY) FOR ONBOARD CHARGER 22KW – Pilot case study

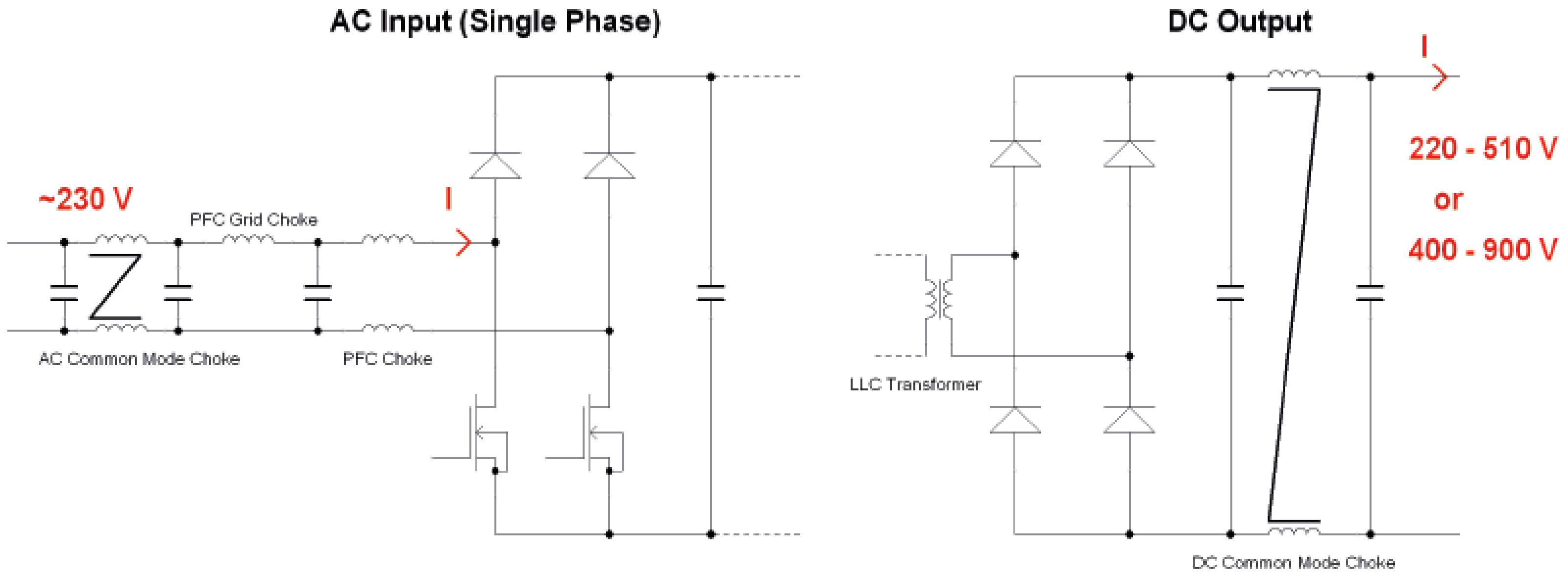


Figure 2 Simplified Schematic of a single phase OBC

Magnetic components in testing :

PFC Grid Filters
PFC Main inductor
Input 4phase CMC
Output DC CMC chokes

Source Image :https://innolectric.ag/innolectric-and-cbmm-test-new-magnetic-materials

SOME PROJECTS:
PARTNERSHIP WITH INNOLECTRIC (GERMANY) FOR ONBOARD CHARGER 22KW – Pilot case study

Comparison of AC Common Mode Chokes

	AC CMC: Widely used version with nanocrystalline core	AC CMC: Ferrite based solution
Realistic size comparison		
Core material	Nanocrystalline	Ferrite
Supplier	Europe; of the shelf product	North America; Prototyping to Series Production; Custom built
Dimensions	50 mm * 18 mm **	62 mm * 26 mm **
Weight	165 g	430 g

** outer core diameter* *** height*

Comparison of DC Common Mode Chokes

	DC CMC: Widely used version	DC CMC: Alternative 1	DC CMC: Alternative 2	DC CMC: Alternative 3
Realistic size comparison				
Core material	Ferrite	Nanocrystalline (laminated)	Nanocrystalline	
Supplier	Europe; of the shelf product	North America; Prototyping to Series Production; Custom built	Asia; Mass producer; Custom built	
Dimensions	45 mm * 20 mm **	34 mm * 13 mm **	34 mm * 13 mm **	45 mm * 18 mm **
Weight	182 g	50 g	60 g	102 g

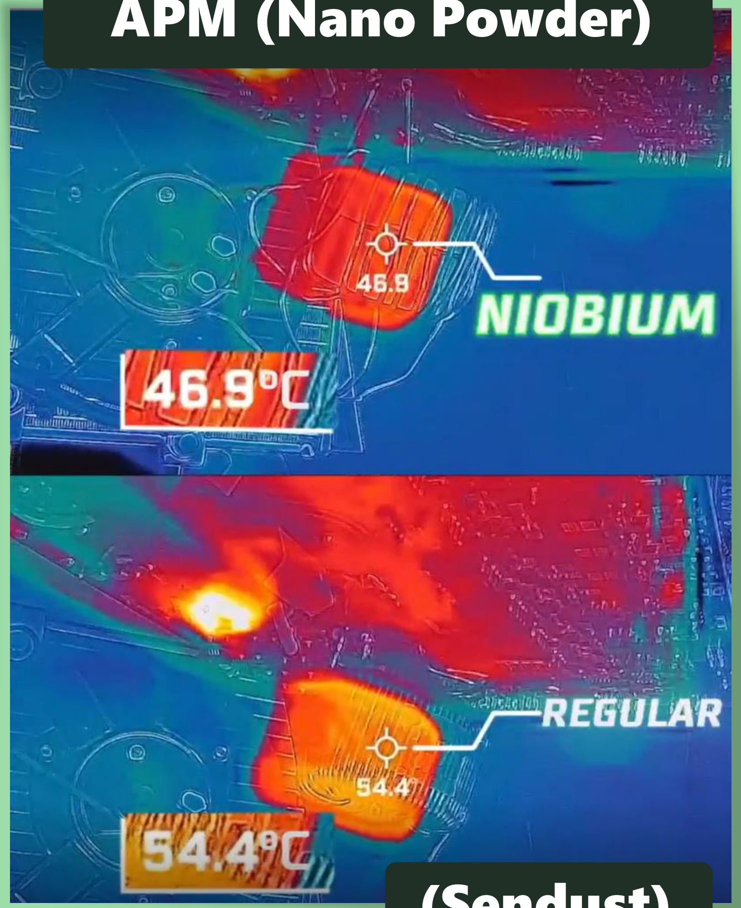
** outer core diameter* *** height*

More technical details : CBMM and Innolectric to launch Whitepaper March 2023

SOME PROJECTS: CBMM partnership with Lightning Motorcycles(USA) and Amogreentech (South Korea) for Nanocrystalline powder cores pilot case study

Motorcycle with Nanocrystalline magnetic components

APM (Nano Powder)



(Sendust)

Nanocrystalline magnetic components

- 40% less volume for common mode chokes
- PFC inductor using Nanocrystalline powder cores (Amogreentech) with low core loss: Reduced operating temperature (-7,5°C) leads to longer lifetime

Powder Core

AMO AMOGREENTECH

PFC & DC Output Choke core

Basic characteristics

Product	APH series	APM series	AGH Series	APD series	APK series
Material Alloy	Fe-Amorphous	Nanocrystalline	Fe-based metal	Fe-based metal	Fe-Si based metal
Composition	Fe-Si-B	Fe-Si-B-Nb-Cu	Fe-Ni	Fe-Si-Al	Fe-Si
Permeability(μ)	60, 90μ	26, 60, 90μ	26, 40, 60μ	26, 60, 90μ	26, 40, 60, 75, 90μ
Size(mm)	Ø13~57	Ø13~57	Ø13~57	Ø13~57	Ø13~57
Core Loss (mW/cm³) @50kHz, 0.1T	300 ~ 350	150 ~ 200	200 ~ 250	250 ~300	600 ~ 650
DC Bias @100Oe	70%	48 %	85%	60%	70%
Shape Avail.	-	-	-	EE/EQ/EQI	Cylinder & EE
Part Color					

APM (Nano Powder)

PARTNER T.B.D IN 2023

FAST CHARING EV CHARGING STATIONS

In the pipeline: EV DC Fast Charger with nano could be smaller, safer, more efficient and have reduced C footprint

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Potential Use of Nano EV DC fast charger

1. Current transformers
2. Residual Current Detector
3. Common Mode filter
4. EMC Filters
5. AC Common mode choke
6. DAB Transformer (DC-DC)
7. Medium Frequency Transformer
8. PFC Inductors

Properties shown in following applications
Smart meters; EV charging IC-CPD; On board charger; Solar energy; Energy grid

Sources: VAC, Magnetec, KEMET, Schaffner, Innoelectric, Amogreentech
*Comparisons with standard materials: ferrite, permalloy, amorphous, sendust, MPP.

Possible gains with Nano*

Performance

- Accuracy 99%
- Efficiency 99%
- Reduction in core loss
- Higher filter attenuation at broad band frequencies
- Safety: fast response time

Size reduction

Up to:

- 40% less copper windings
- 70% less weight
- 60% less volume

Reduced C footprint

- Dematerialization
- Up to 50% less C footprint

CBMM FUTURE DEVELOPMENT STRATEGY FOR NSMM*

Investing in pilot studies/case studies with universities and industrial players to develop new materials and applications of NSMM :

- NSMM based powder development using gas atomization process
- High Bs (> 1.5T) NSMM ribbon development
- NSMM thin ribbon development (<16 μm) for high frequency transformers and inductors

**NSMM=Nanocrystalline Soft Magnetic Materials*

LEARN MORE AT
www.niobium.tech

Thank you!

CBMM | Niobium Nb