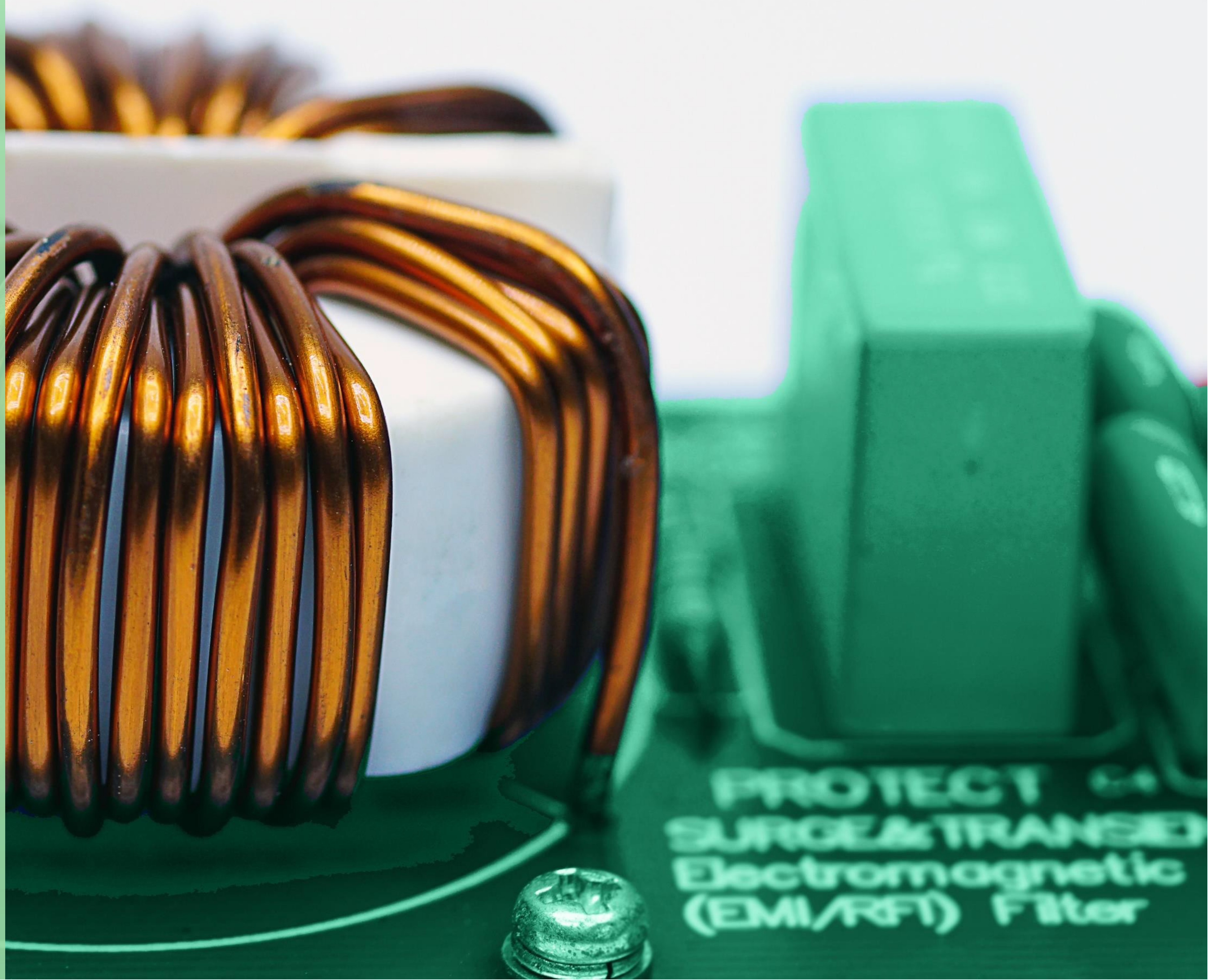
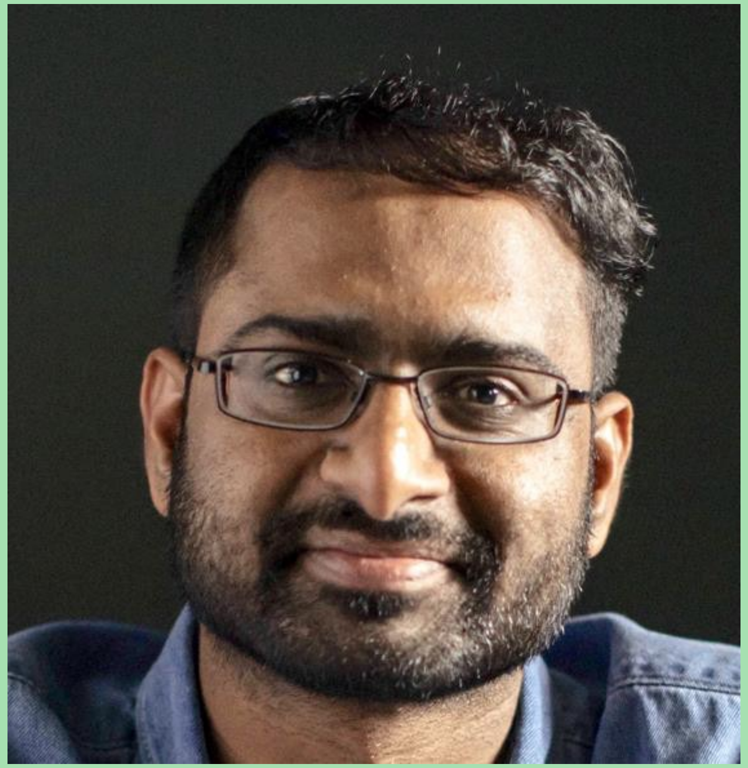
OVERVIEW OF PERSPECTIVE ON NANOCRYSTALLINE SOFT MAGNETIC MATERIAL (NSMM)

Bharadwaj Reddy Andapally

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



Biography



BHARADWAJ REDDY

2022- Present: Technical Market Development at CBMM -Amsterdam for Global Nanocrystalline Soft Magnetic Materials

2020-2022: Technical Advisor at CBMM -Amsterdam for Nanocrystalline Soft Magnetic Materials

2015-2021: R&D Engineer High Frequency Magnetic Components at ISE Magnetics- Netherlands (Spinoff -Philips & Aperam alloys)

2013-2015 Msc- Electrical Power Engineering- Power Electronics &Magnetics at TUDelft -Netherlands

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 60M USD per year invested in R&D

Partnership with the most renowned research centers

CBMM WORLDWIDE

CBMM is able to support your needs quickly and efficiently, guaranteed by a global presence and robust logistics

Nanocrystalline Soft Magnetic Materials (NSMM) Development Program

FeNb → Nano Ribbon → Core → Magnetic Component → Power Component → Application

FeNb

Nano Ribbon

Core

Magnetic Component

CMC, HFT, PFC, CT, ...

Power Component

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

Application

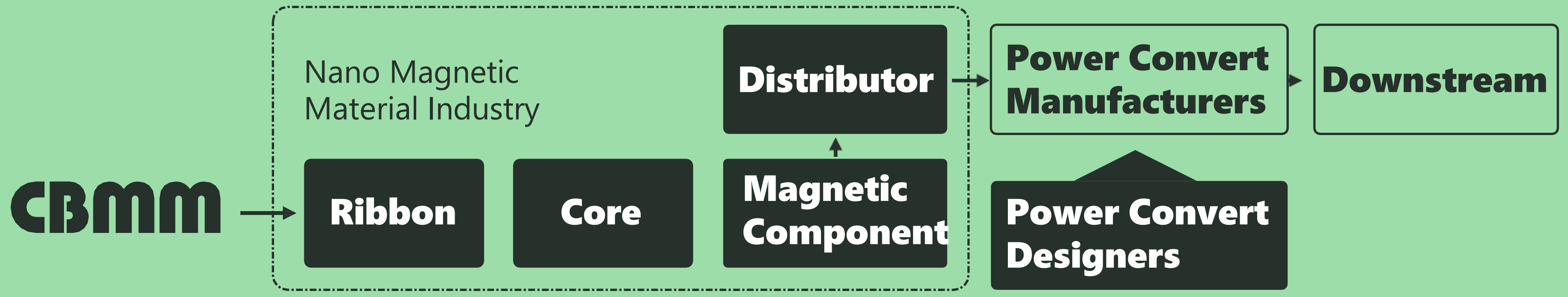
Ev's, HVAC, smart meters, solar power gen, data centers...

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)

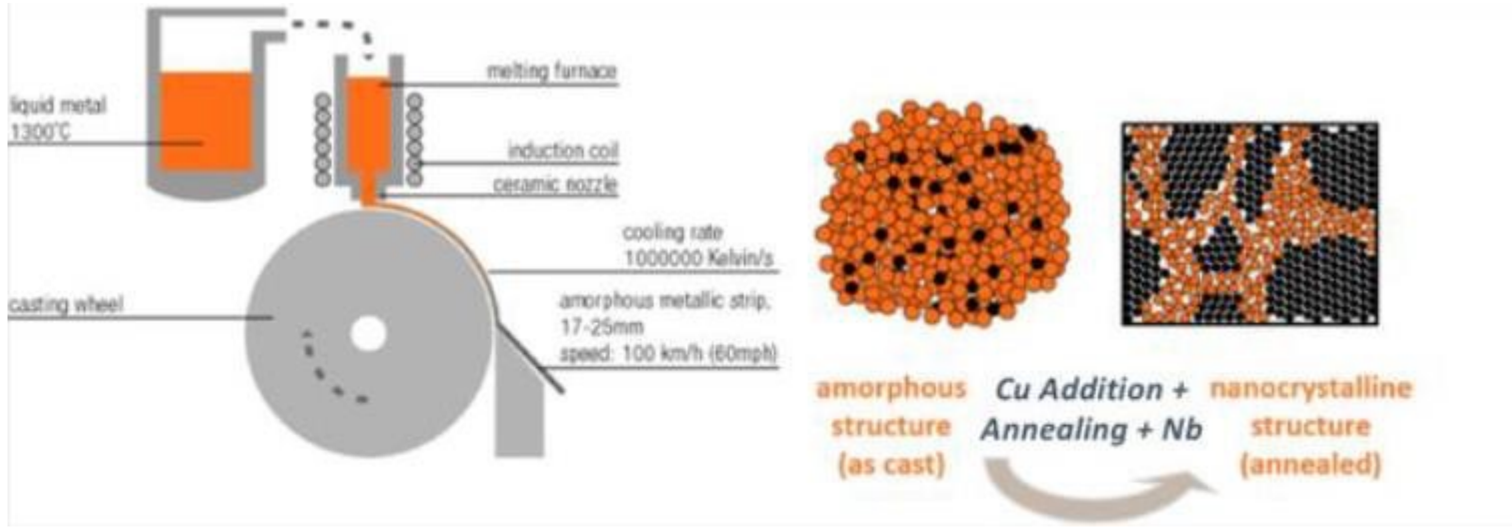
Ribbon width: usually 60-70mm

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

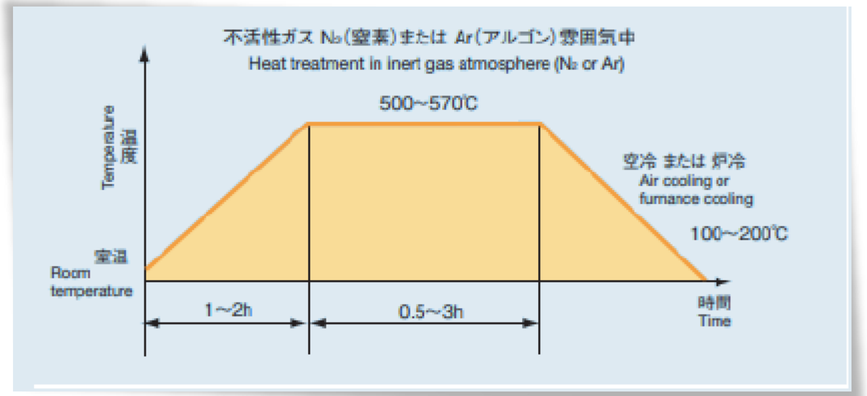
Grains extremely small (~10nm) and uniform distribution

Source : VAC and Proterial

NANOCRYSTALLINE PROPERTIES

Ribbon thickness + Annealing treatment = Hysteresis curve

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



Ramp-up;

Temperature;

Soaking time;

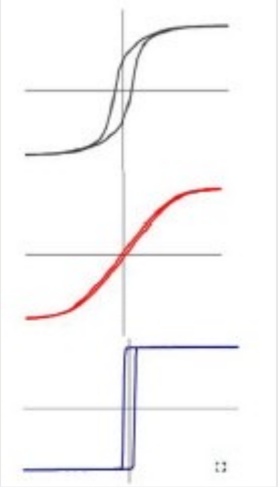
Number of heating steps;

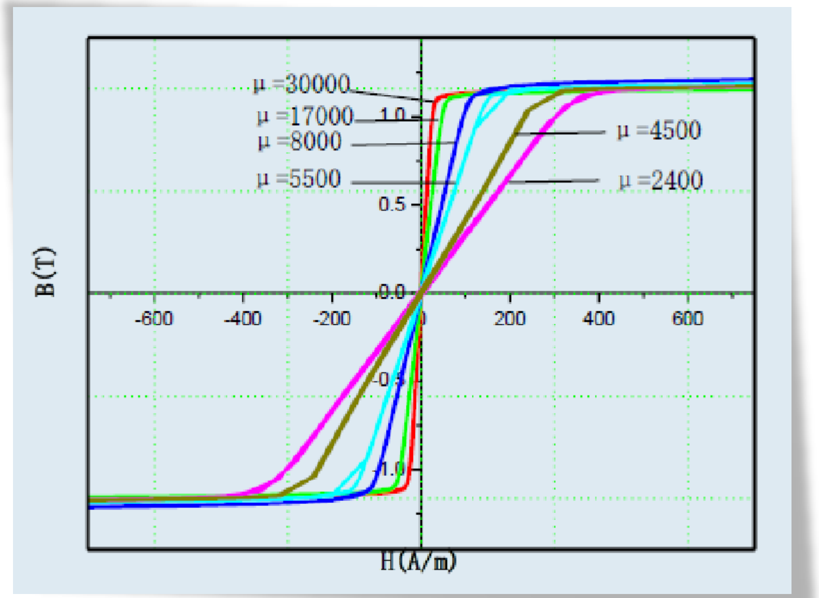
Applied magnetic field (longitudinal, transversal, none)

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*

MARKET NEEDS FOR POWER ELECTRONIC MAGNETIC COMPONENTS

- Very low core loss at higher frequencies (Transformers and Inductors)
- Low eddy current and fringing losses in windings
- Better thermal management (lower thermal resistance)
- High power density (lower weight and volume)
- High permeability at wider frequencies (CMC and EMC filters)
- Stable performance at wider temperatures
- Different core shapes
- High voltage isolation
- Higher reliability

MAJOR CHALLENGES FOR APPLICATION OF NSMM* (MARKET FEEDBACK)

There's a significant gap in information sharing between power electronic designers and NSMM producers

Shape limitations restrict NSMM to only toroidal and C/U core shapes

There is lack of commercially available NSMM with High frequency (>100KHz) and High Bs(1.5T) for applications in transformer, inductors and motors

There's a lack of precise testing data and simulation models from suppliers, which is crucial for power electronic designers when selecting specific magnetic components

There's no dedicated digital hub for sharing information on global NSMM developments

**NSMM=Nanocrystalline Soft Magnetic Materials*

CBMM PROSPECTIVE FOR OVERCOMING THE CHALLNGES

Co-development between NSMM producers and power electronic companies is crucial

NSMM producers should aim to become comprehensive magnetic component solution providers, meeting market needs for complex power electronic topologies

Projects that support innovative manufacturing of new shapes need to be developed

Projects that support commercialization of high frequency and high Bs NSMM manufacturing

NSMM producers must provide users with precise test data and assist global power electronic simulation software by sharing appropriate simulation models

A digital hub should be created to facilitate the sharing of NSMM developments, involving all stakeholders in the NSMM field

NSMM=Nanocrystalline Soft Magnetic Materials

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

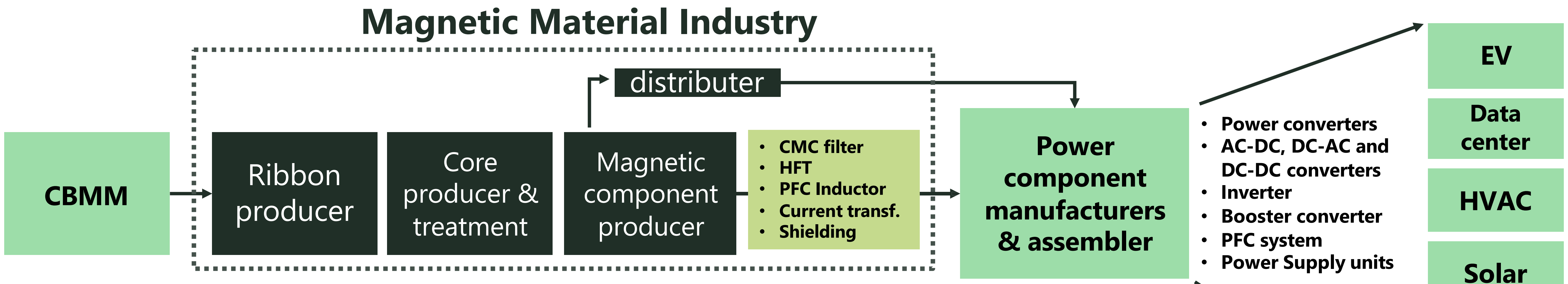
Magnetic components for EV charging stations (Filters, RCD's, Transformers , PFC)

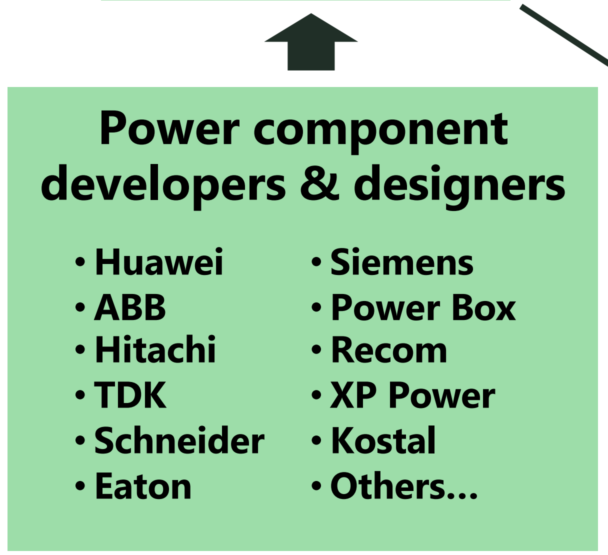
High power density EV Onboard Chargers

Wireless Charging

**NSMM=Nanocrystalline Soft Magnetic Materials*

HOW A PARTNERSHIP WITH CBMM CAN BENEFIT PLAYERS ACROSS THE WHOLE VALUE CHAIN:





CBMM could offer:

- Contact with all the top players of the supply chain involving nanocrystalline solutions
- Supply chain diversification and transparency
- Bring in strategic partnerships with universities and companies for developing advanced magnetic solutions with nano
- Contact with potential end-users of power electronics systems

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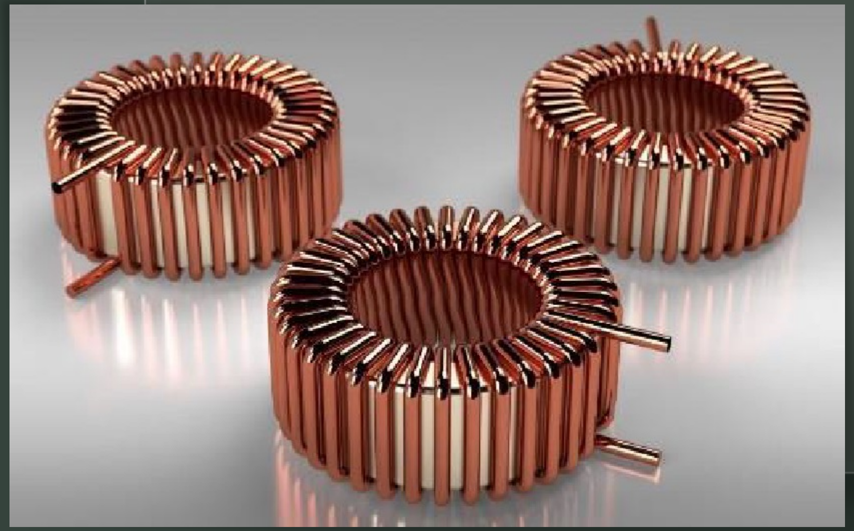
Standardized Testing of Materials and Electromagnetic Components

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

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Core Testing Standards:

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

INNOLECTRIC CASE

With 1/3 of size and weight of a ferrite core, nano meets the efficiency and performance requirements for AC and DC Filters

Advantages proved in showcase with Innolectric:

Up to 80%
Reduction in the cost with quotes for large quantities

Up to 60%
Reduction in the weight of the CMC

Up to 70%
Reduction in the size of the core

Up to 25%
Improvement in the efficiency with reduced thermal losses

Up to 20%
Improvement in the performance with higher attenuation

Comparison of DC Common Mode Chokes

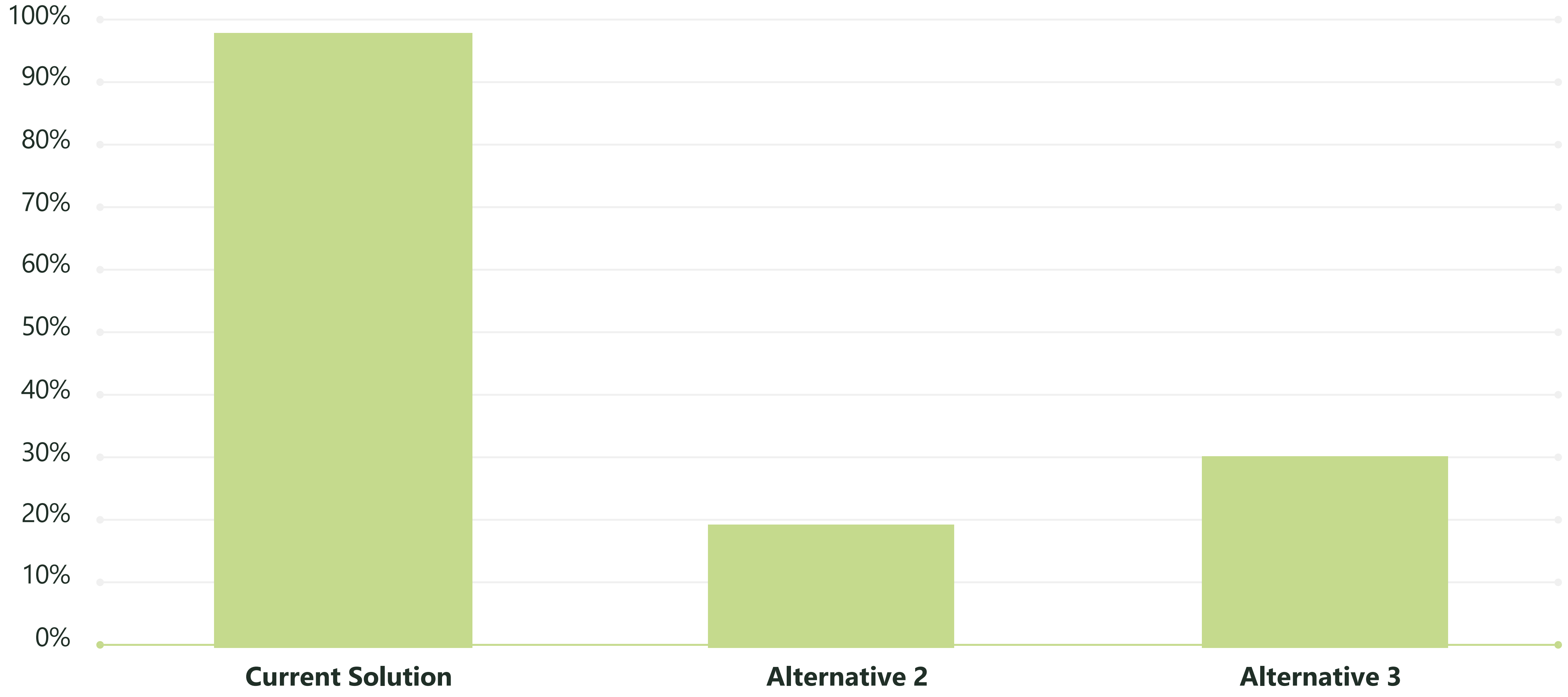
	DC CMC: Windely used vesion	**DC CMC**: Alternative 1	**DC CMC**: Alternative 2	**DC CMC**: Alternative 3
Realistic size comartion				
Core material	Ferrite	Nanocrystalline		
Supplier	Europe; off the shelf product	North America, Prototyping to Series Production; Custom built	Asia; Mass producer; Custom 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

Source: Innolectric paper, to be published in Q3/2023.

DC COMMON MODE FILTERS WITH NANOCRYSTALLINE WERE SHOWN TO BE 70 TO 80% CHEAPER THAN CURRENT SOLUTION WITH FERRITE

Economic analysis of DC common mode filters with ferrite (current solution) versus nanocrystalline (alternatives 2 and 3)



Prices were quoted with leading Chinese component producer;

Main reasons for price reduction of the component using nanocrystalline:

Use of less magnetic material for the core (approximately 1/3 of the magnetic material is needed when using nanocrystalline, compared to ferrite)

Less copper windings

INNOLECTRIC CASE

Nanocrystalline powder cores outperformed Sendust cores for PFC Grid Filter in performance and efficiency

Advantages proved in showcase with Innolectric:

Up to 13%
Reduction in the number of copper turns

Up to 40%
Reduction in the weight of the PFC

Up to 65%
Reduction in the size of the PFC

Up to 19%
Reduction in the operating temperature

Up to 93%
Reduction in the core resistance

Up to 10%
Reduction in the parasitic capacitance

Core material	PFGA- 20W1C	PFGC	Deviation*
manufacturer	Nanoamor	Ro-Lo	-
modell	N-D57H15U90	CS572060 WEE 05880	-
Inductance	85 цH	92 цH	**-7.6%**
Resonance frequency	8 MHz	7.3 MHz	**+9.5%**
Resistance	0.04 ohm	0.52 ohm	**-92.3%**
Parasitic capacitance	4.66 pF	5.17 pF	**-9.8%**
Core Saturation temp. @ op 1 (510V-41A), (Power loss)	175 °C. 126 W	88 °C, 131.56 W	**-14.7%**
Core Saturation temp. @ op 2 (315V-65A), (Power loss)	68 °C, 90.46 W	84 °C, 103.54 W	**-19%**
Winding diameter (WD)(mm)	2x1.91 22,92	2 × 1.91 22,92	**0%**
Outer core diameter OD(mm)	57.15	57.15	**0%**
Numbr of Turns	20	23	**-13%**
Consumed surface A=ODX(Height+2*WD)(mm^2)	870.96	1903.56	**-54.2%**
Height(mm)	15.24	2 × 13.97	**-45,4%**
Volume(mm^2)	39093.74	110406.48	**-64,5%**
Weight(g)	219 (2.5g/1W)	362	**-39,5%**
EMI			-

PFGA - Nanocrystalline cores

PFGC - Send Dust cores

Source: Innolectric paper, to be published in Q3/2023.

CBMM partnership with Lightning Motorcycles(USA) for Nanocrystalline powder cores pilot case study

Motorcycle with Nanocrystalline magnetic components

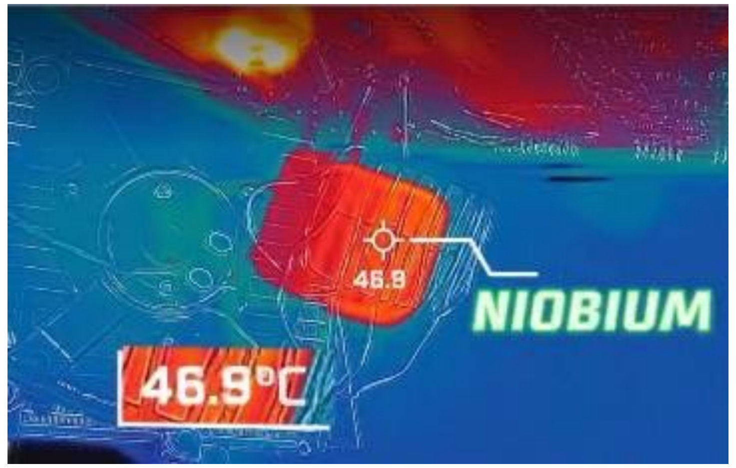
Advantages proved in showcase with Lightning

Common Mode Choke

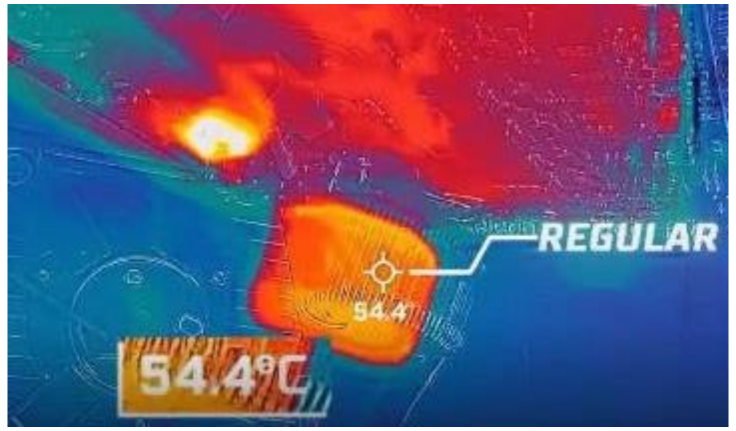
Miniaturization
40% less volume

PFC Inductor

Longer Lifetime
Reduction of 7,5°C in the operating temperature

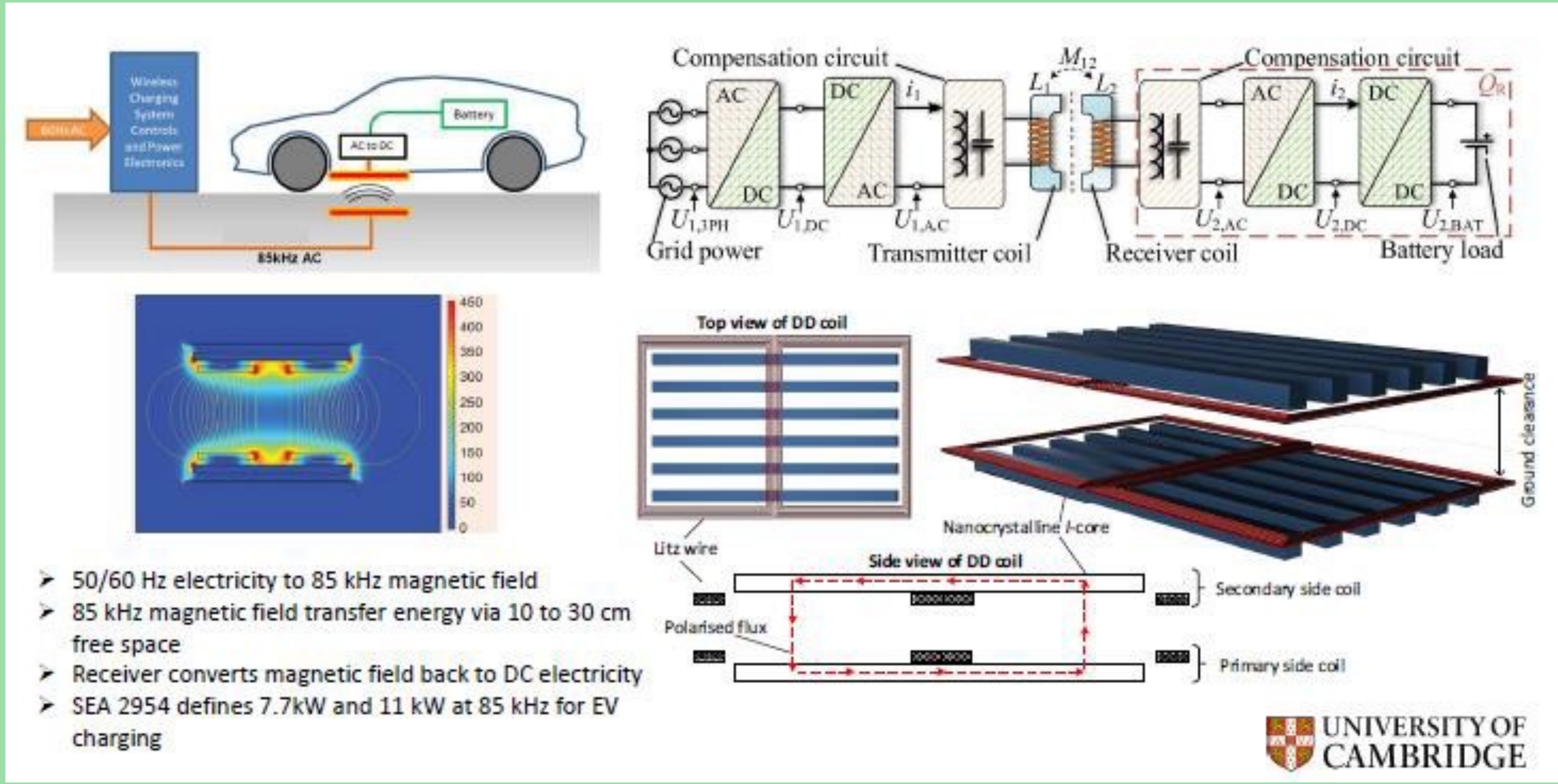


Nano Powder



Sendust

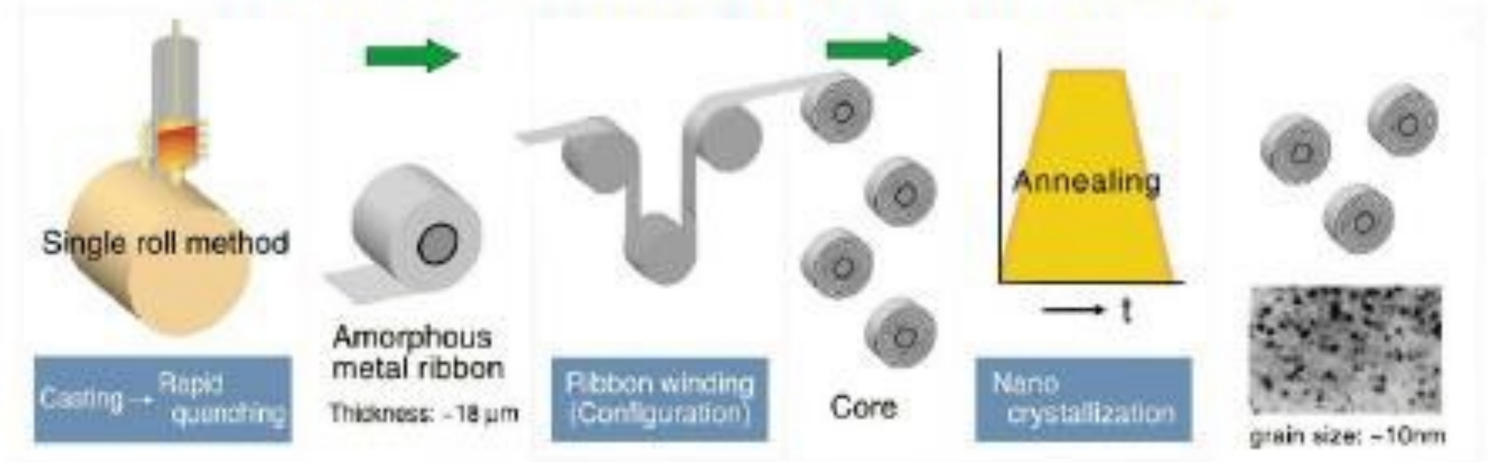
PARTNERSHIP WITH UNIVERSITY OF CAMBRIDGE: EV WIRELESS CHARGING (Prof Teng Long)



Basic concept of inductive power transfer (IPT)

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

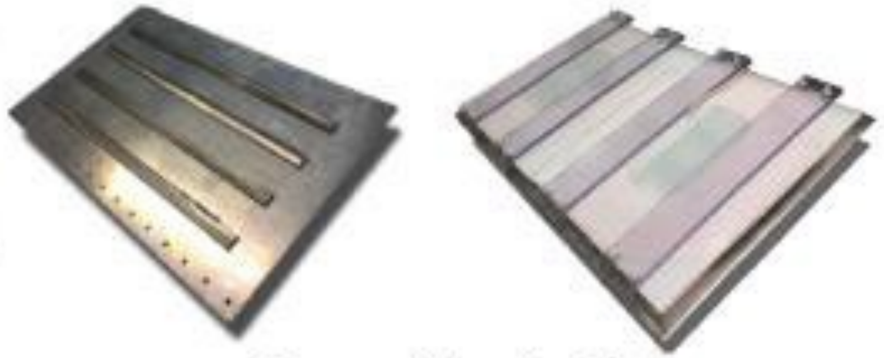
Manufacturing process of nanocrystalline alloy ribbon



(a)

Nanocrystalline alloy ribbon reel

(b)



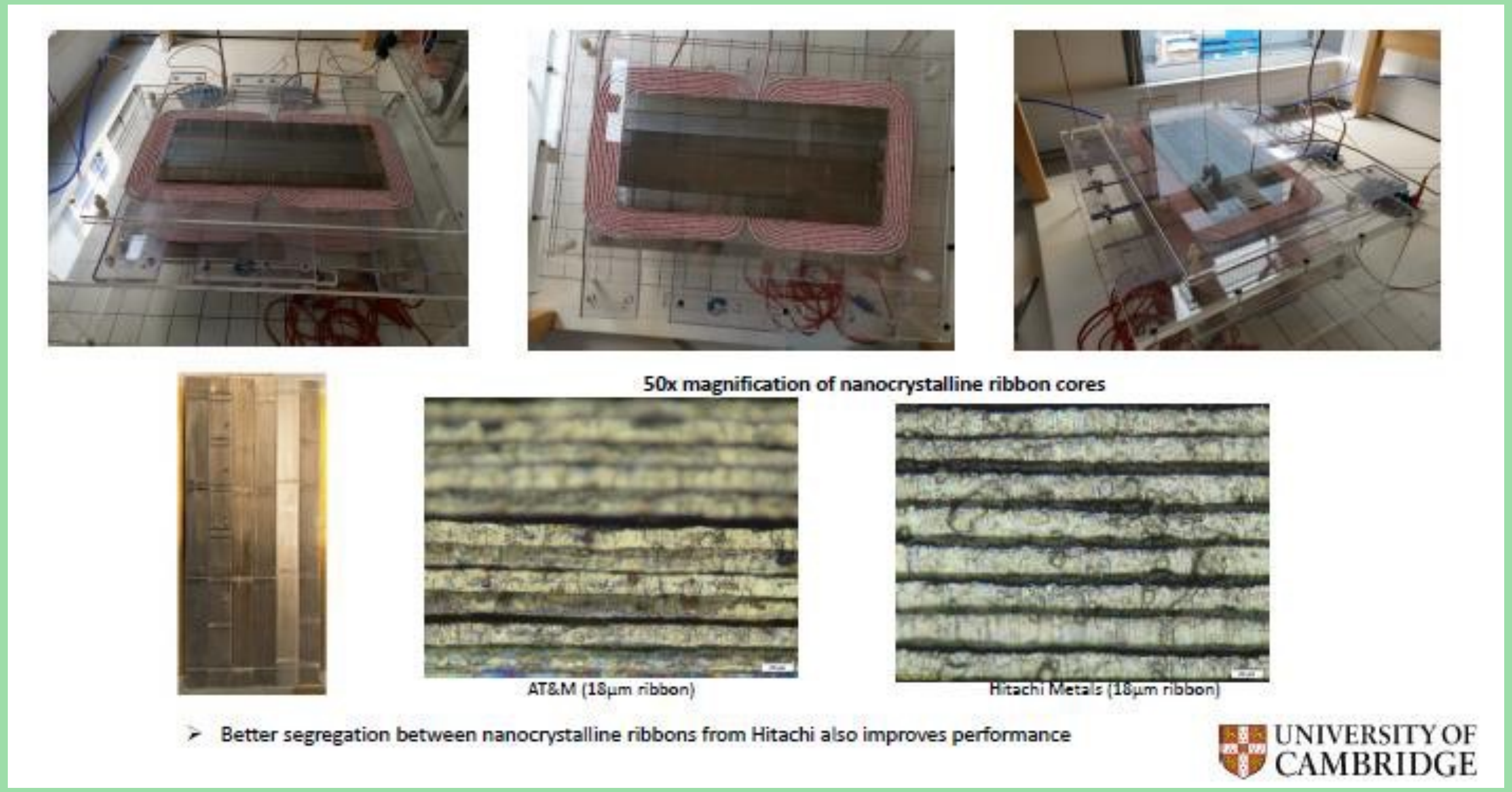
Nanocrystalline alloy ribbon cores (magnetic strip cores in IPT coils)

- 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

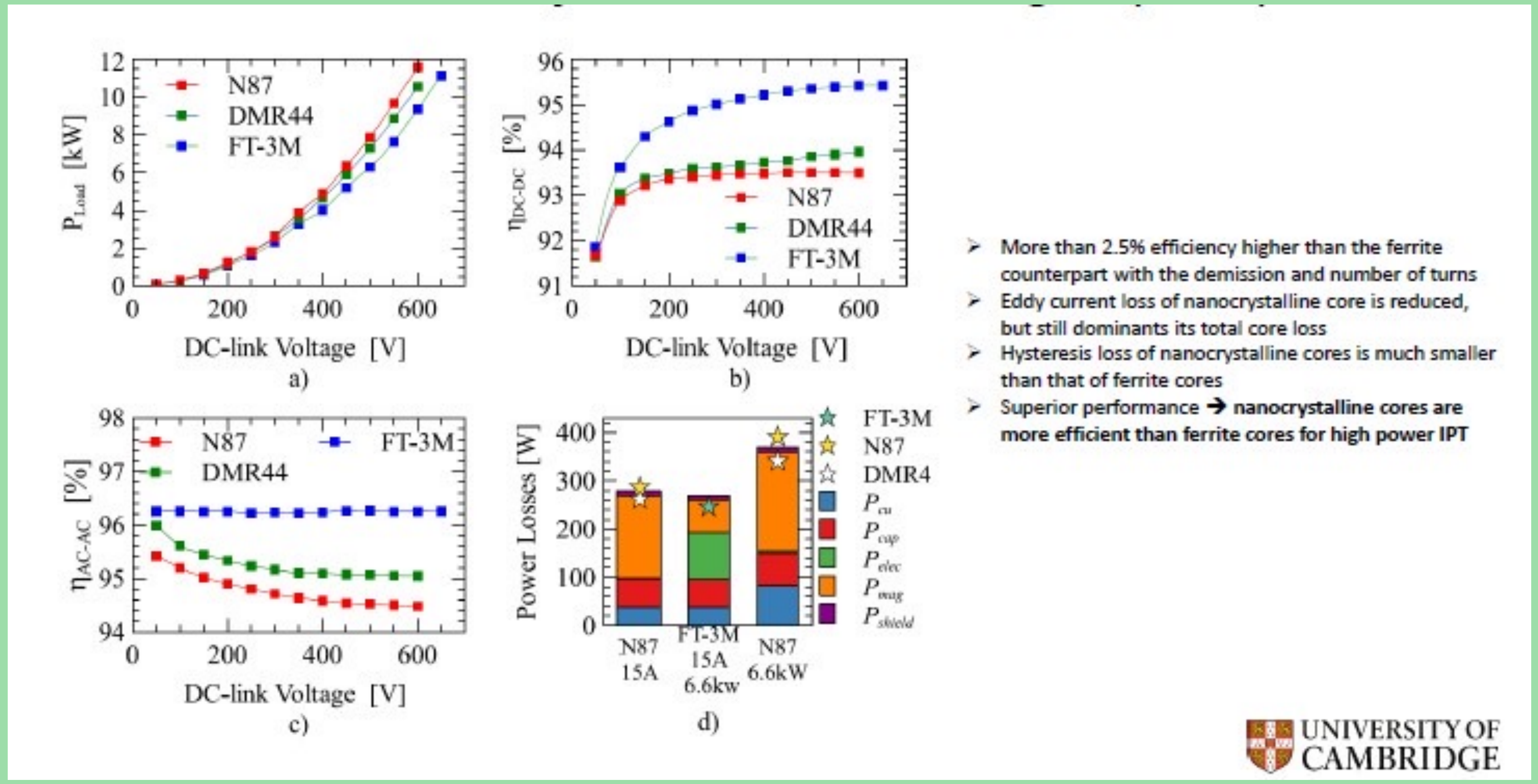
UNIVERSITY OF CAMBRIDGE

A novel magnetic core for wireless charging coils

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

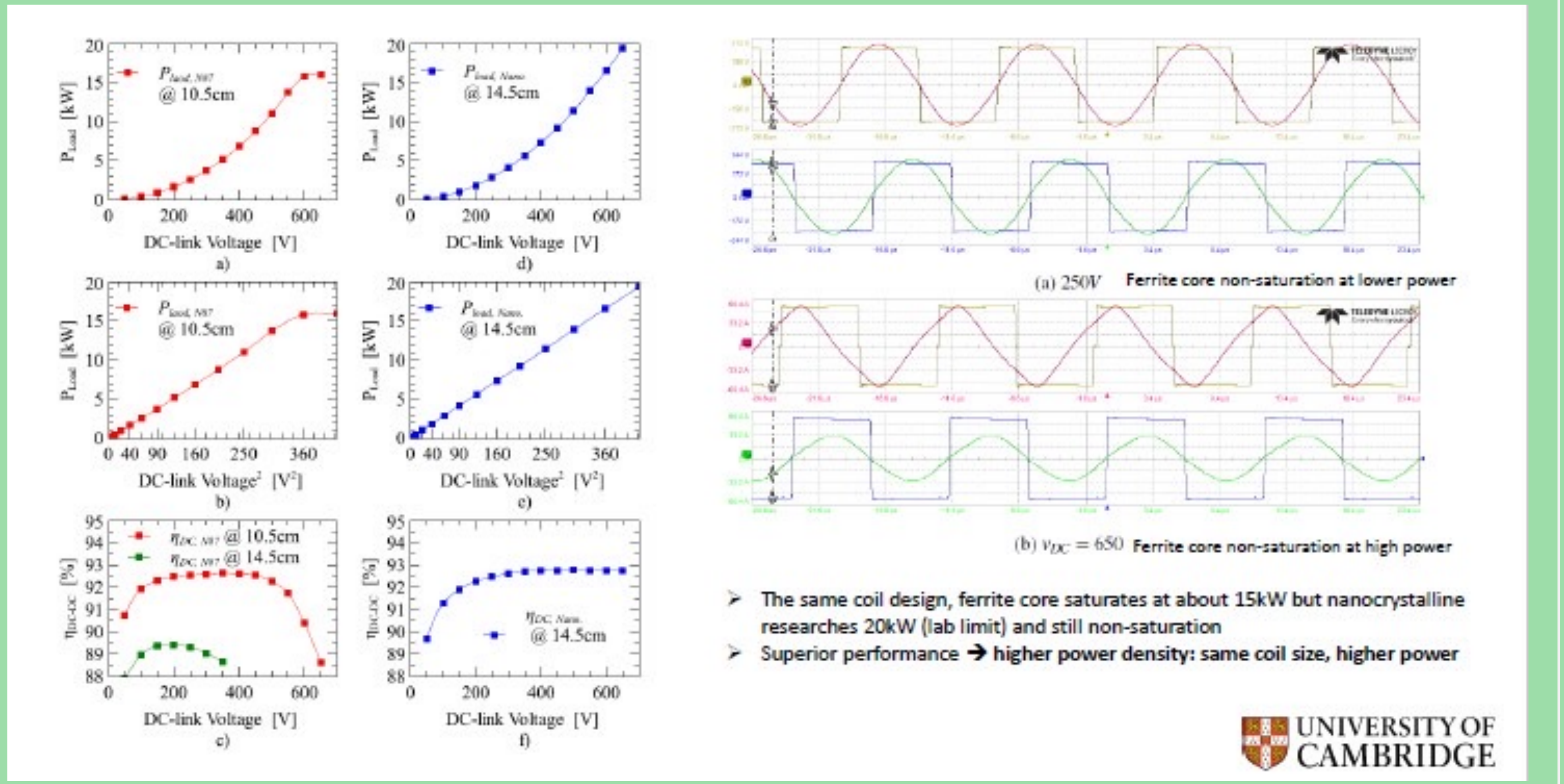


IPT Design 2 | Better nanocrystalline lamination

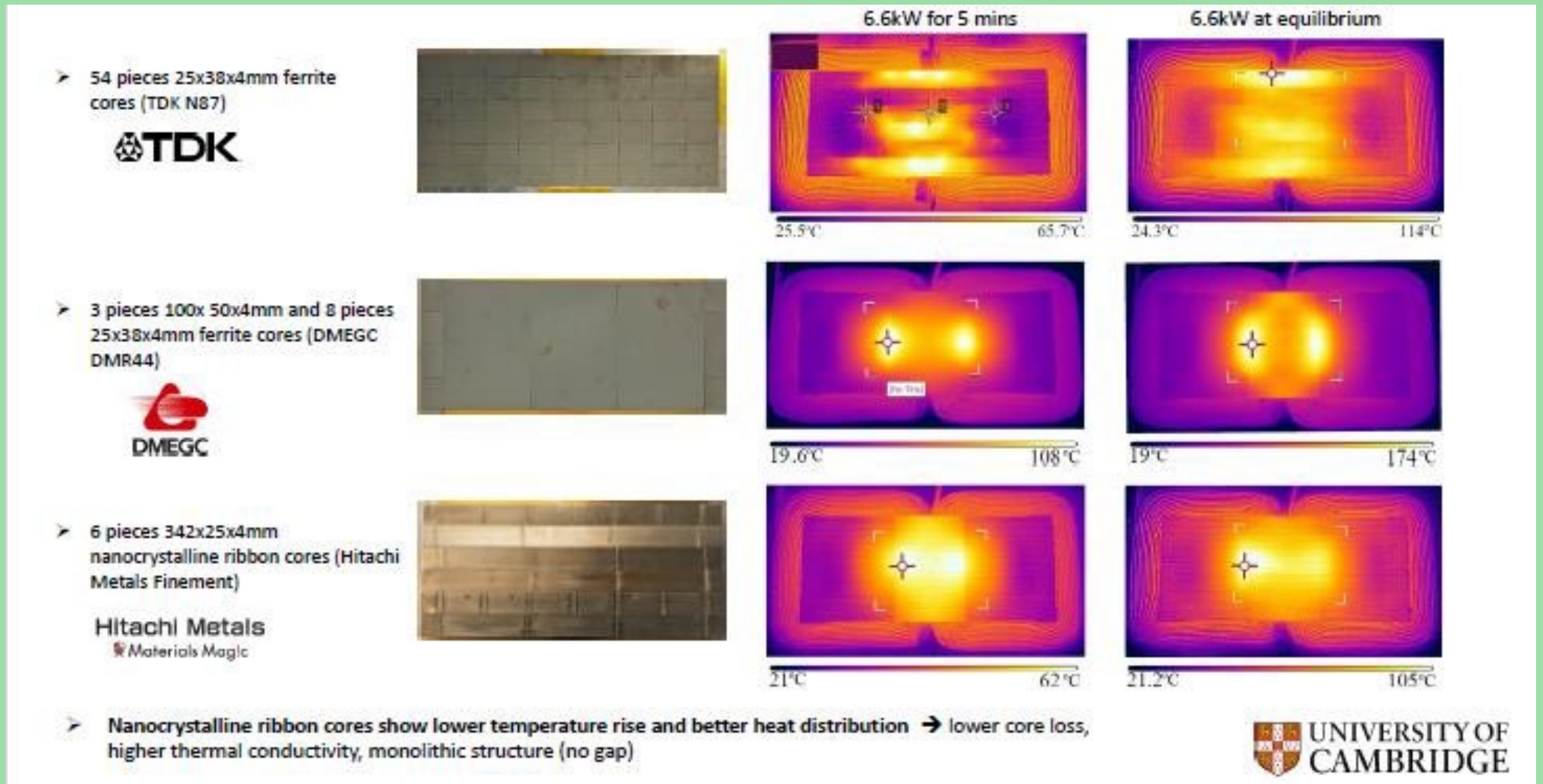


Performance of nanocrystalline core IPT Design 2 (11kW)

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



Higher power density (high saturation point)



Better thermal Performance

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

Potential Use of Nano EV DC fast charger

1. Current transformers
2. Residual Current Detector
3. EMC Filters
4. EMI /EMC Filters
5. AC and DC 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

ReducedC 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 based high frequency motors for EV and industrial applications

**NSMM=Nanocrystalline Soft Magnetic Materials*

LEARN MORE AT
www.niobium.tech

Thank you!

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