POWER MAGNETICS @HIGH FREQUENCY WORKSHOP 2023

NANOCRYSTALLINE SOFT MAGNETIC MATERIAL (NSMM) APPLICATION DEVELOPMENT PROGRAM

Bharadwaj Reddy Andapally
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
- Mobility
- Health
- Energy
- 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
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.
Produced as thin ribbons

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

Ribbons 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...

**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
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

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

*NSMM=Nanocrystalline Soft Magnetic Materials
PARTNERSHIP WITH AMPED & PITTSBURGH UNIVERSITY

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

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)

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

- Magnetic properties at high excitation levels
- Annex A and section 6: show the two-winding method, Annex B shows RMS method
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 7.7 kW and 11 kW at 85 kHz for EV charging
PARTNERSHIP WITH UNIVERSITY OF CAMBRIDGE: EV WIRELESS CHARGING (Prof Teng Long)

A novel magnetic core for wireless charging coils

- FeCuNiSiB 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 to use in high power IPT as a high frequency electromagnetic device could be feasible
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)

- More than 2.5% efficiency higher than the ferrite counterpart with the same iron and number of turns
- Easy current loss of nanocrystalline core is reduced, but still dominates its total core loss
- Hysteretic 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
PARTNERSHIP WITH UNIVERSITY OF CAMBRIDGE: EV WIRELESS CHARGING (Prof Teng Long)

Higher power density (high saturation point)

- The same coil design, ferrite core saturates at about 134 W but nanocrystalline researches 328 W (lab test) and still non-saturation
- Superior performance \(\rightarrow\) higher power density, same coil size, higher power

Better thermal performance

- 6 pieces 3.5x3.5cm nanocrystalline ribbon cores (Hitachi Metals: Green Patent)
- Nanocrystalline ribbon cores show lower temperature rise and better heat distribution \(\rightarrow\) lower core loss, higher thermal conductivity, monolithic structure (no gap)
**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 → 3D building materials
- Geometry of the core is adjustable: wound, stacked, hybrid
- Stacking factor can be adjusted → control core loss and overall permeability

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

**Core loss density comparison between NFR and ferrite**

- **Design parameters**
  - Core size (mm)
  - Inner diameter (mm)
  - Outer diameter (mm)
  - Height of core (mm)
  - Number of layers of the coating

<table>
<thead>
<tr>
<th>Design</th>
<th>Core size (mm)</th>
<th>Inner diameter (mm)</th>
<th>Outer diameter (mm)</th>
<th>Height of core (mm)</th>
<th>Number of layers of the coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>NFR</td>
<td>10x10</td>
<td>10x10</td>
<td>12x12</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Ferrite</td>
<td>12x12</td>
<td>12x12</td>
<td>14x14</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

- **Higher thermal conductivity of NFR**
- **Lower loss density of NFR than ferrite**
- **Similar loss density of NFR when thin**

**Core loss comparison between NFR and Ferrite**

- **NFR**
  - Core size: 30x30 mm
  - Inner diameter: 18 mm
  - Outer diameter: 23 mm
  - Height: 5 mm
  - Permeability: 3000µH
  - 1.5µH inductors with 5 turns by both NFR and Ferrite core above

- **Ferrite**
  - Core size: 35x35 mm
  - Inner diameter: 20 mm
  - Outer diameter: 25 mm
  - Height: 6 mm
  - Permeability: 2500µH

- **NFR permeability can be adjusted by processing process**
- **Stacking factor can be adjusted by number of layers and 40% ferrites**
- **Stacked permeability can be achieved by adjusting NFR and stacking**

- **Lower core loss by stepped core and more uniform flux**
- **High saturation point than ferrite**
PARTNERSHIP WITH INNOLECTRIC (GERMANY) FOR ONBOARD CHARGER 22KW – Pilot case study

SOME PROJECTS:

Magnetic components in testing:
- PFC Grid Filters
- PFC Main inductor
- Input 4phase CMC
- Output DC CMC chokes

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

**Comparison of AC Common Mode Chokes**

<table>
<thead>
<tr>
<th>Core material</th>
<th>Nanocrystalline</th>
<th>Ferrite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier</td>
<td>Europe; of the shelf product</td>
<td>North America; Prototyping to Series Production; Custom built</td>
</tr>
<tr>
<td>Dimensions</td>
<td>50 mm *, 18 mm **</td>
<td>62 mm *, 26 mm **</td>
</tr>
<tr>
<td>Weight</td>
<td>165 g</td>
<td>430 g</td>
</tr>
</tbody>
</table>

**Comparison of DC Common Mode Chokes**

<table>
<thead>
<tr>
<th>Core material</th>
<th>Ferrite</th>
<th>Nanocrystalline (laminated)</th>
<th>Nanocrystalline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier</td>
<td>Europe; of the shelf product</td>
<td>North America; Prototyping to Series Production; Custom built</td>
<td>Asia; Mass producer; Custom built</td>
</tr>
<tr>
<td>Dimensions</td>
<td>45 mm *, 20 mm **</td>
<td>34 mm *, 13 mm **</td>
<td>34 mm *, 18 mm **</td>
</tr>
<tr>
<td>Weight</td>
<td>182 g</td>
<td>50 g</td>
<td>60 g</td>
</tr>
</tbody>
</table>

* 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

- 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
FAST CHARGING 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. 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, EDAT, Schurter, 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
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
Thank you!

LEARN MORE AT
www.niobium.tech