Nanocrystalline, Amorphous and Powdered Amorphous Cores

APEC 2019

Mark Rine
Director Sales and Marketing
Hitachi Metals America, Ltd.
Mark Rine Bio

BS Electrical Engineering – Purdue University
MBA – University of Southern Indiana

Companies
Siemens 17 years
Spectronics, Inc. 7 years
VAC Magnetics USA (Vacuumschmelze GmbH) 9 years
Hitachi Metals USA, Llc 2 years

Current Position – Director Sales & Marketing, Hitachi Metals USA. Responsible for NAFTA Nanocrystalline materials and components sales and marketing.

Past responsibilities include – Design Engineering, Manufacturing Engineering, Operations Management, Product Management, International and Domestic Sales and Marketing

Resides in Dallas, Texas

Languages – English, German
Amorphous Metals - How Are They Unique?

Metglas® is Amorphous
Structure Randomized by Process

Metallic Solids Are Crystalline
Atomic Arrangement Is Regular & Periodic

- Absence Of Structure Helps Magnetization Process
- Simple Heat Treatment Changes Directional Properties of Material or Core

- Structural Anomalies in Atomic Arrangement Hinder Magnetization Process
- Structural Arrangement Modified By Thermo-mechanical (Hot Rolling) Grain Orientation

Infrared Photographs of (a) Metglas® Amorphous Metal Transformer / Inductor Core & (b) Grain Oriented Steel

Heat Spectrum Radiated in Grain Oriented Core is significant compared to Metglas® Amorphous Metal Transformer / Inductor Core due to its significant core losses

Random Structure Gives Enhanced Performance
Rapid Solidification Material Casting Process

Unique Process Allows For Enhanced Properties
FINEMET® Soft Magnetic Material Products

- 1.3 Microstructure of FINEMET®

- Material Comparison Table:
<table>
<thead>
<tr>
<th>Material</th>
<th>Chemical Composition</th>
<th>Crystal</th>
<th>Magnetic Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal</td>
<td>Big</td>
<td>Normal</td>
<td></td>
</tr>
<tr>
<td>Amorphous</td>
<td>Fe, Si, B</td>
<td>None</td>
<td>Good</td>
</tr>
<tr>
<td>Nano-crystal FINEMET®</td>
<td>Fe, Si, B, Cu, Nb</td>
<td>Small (≈10nm)</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

- Diagram:
  - Rapidly quenched amorphous phase
  - The early stage of annealing
  - The early stage of crystallization
  - Microstructure after proper annealing
Key Magnetic Core Design Criteria

- Size and Weight
- Efficiency (Core Loss)
- Solution Cost
## FINEMET versus Ferrite Material Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>FINEMET (Nanocrystalline)</th>
<th>Ferrite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Composition</td>
<td>Fe Si (75 / 25%)</td>
<td>MnZn</td>
</tr>
<tr>
<td>Permeability (max at 10Khz)</td>
<td>500 to 100,000</td>
<td>15,000</td>
</tr>
<tr>
<td>Saturation Induction Bsat</td>
<td>1.2 Tesla</td>
<td>0.4 Tesla</td>
</tr>
<tr>
<td>Core Loss W/Kg (100Khz, 0.2T)</td>
<td>20 (FT-3K50T) and 35 (FT-3KL)</td>
<td>120</td>
</tr>
<tr>
<td>Curie Temperature</td>
<td>550- 570 deg C</td>
<td>200-300 deg C</td>
</tr>
<tr>
<td>Max Continuous Operating</td>
<td>150 deg C</td>
<td>100 deg C</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FT-3K50T Impedance vs Frequency

- **Graph**
  - Frequency (kHz) on the x-axis.
  - Impedance (kΩ) on the y-axis.
  - Line graphs for FT-3KM, FT-3K50T, Mn-Zn Ferrite (μ' 5k), and Mn-Zn Ferrite (μ' 10k).
  - The graph indicates that FT-3K50T has a lower impedance than Mn-Zn Ferrite (μ' 10k).

- **Table**
  - Comparison of volume and weight between FT-3K50T and Mn-Zn ferrite.
  - Volume: 24 cm³ (55% of Mn-Zn) vs. 44 cm³
  - Weight: 55 g (53% of Mn-Zn) vs. 104 g

- **Core Size**
  - OD: 25mm, ID: 15mm, HT: 12.5mm
  - Cu wire: 1.5mm - 13ts

- **Specs**
  - Rated Current: 20A, 3mH at 100kHz

- **Images**
  - FINEMET®
  - Mn-Zn Ferrite
FINEMET Temperature Stability vs Ferrite
-40 deg C to +140 deg C

MnZn Ferrite CMC

FINEMET CMC
FINEMET Advantages

- Filter Order Reduction (excellent low frequency and high frequency performance)
- Core Size Reduction
- Core weight reduction
- Thin ribbon material offers high frequency higher permeability than competitive nanocrystalline tapes offering same L with less cross sectional area (lower cost, small size / weight)
- Energy efficiency (reduced core loss -transformers, lower DCR-CMC)
- Ease of design (constant u over temperature)
- Mechanical shock / vibration (no chip and crack specification)
- Improved conduction emissions performance can sometimes lead to reduced radiated emissions.
FINEMET Applications

- **Common Mode Chokes**
  - High frequency attenuation across FCC/CISPR range (150 kHz – 30 MHz)
  - Size / Weight reduction (high permeability material)
  - Can be cost reduction (Filter order reduction)
  - High temp capability / Consistent temp performance

- **Medium Frequency transformers**
  - High Bsat (1.2) = reduced core size
  - Low core loss compared to ferrite
  - Effective in 10 kHz – 80 kHz frequency range

- **Wireless Charging Receiver / Transmitter Core (Qi standard)**
  - High Bsat (1.2) = less magnetic material required. Thin package profile.
  - Thin tape construction / packaged in laminated sheet form

- **Current Transformer**
  - High permeability and low core loss = low amplitude error and low phase angle error so can meet ANSI / IEC 0.2 / 0.5 accuracy standards for energy metering with calibration.
  - Capable of <1% uncalibrated accuracy for datacenter monitoring.
Metglas® Amorphous Metal – 2605HB1M Alloy

**Metglas® Amorphous Metal**

Soft Magnetic Materials with:
- Extremely Low Core Loss, 35% of M3-Grade GOES core loss in finished cores
- High Permeability
- High Efficiency
- Smaller Size and Weight

**Electromagnetic Properties for 2605HB1M Alloy**

<table>
<thead>
<tr>
<th>Property</th>
<th>2605HB1M</th>
<th>M3 SiFe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation Induction (T)</td>
<td>1.63</td>
<td></td>
</tr>
<tr>
<td>Electrical Resistivity (μΩm)</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Magnetostriction (x10-6)</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Curie Temperature (°C)</td>
<td>364</td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing electromagnetic properties](image)
POWERLITE® - Amorphous Metal Cut Cores

Physical Properties METGLAS Alloy 2605SA1

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ribbon Thickness (µm)</td>
<td>.25</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>7.18</td>
</tr>
<tr>
<td>Thermal Expansion (ppm/°C)</td>
<td>7.6</td>
</tr>
<tr>
<td>Crystallization Temperature (°C)</td>
<td>505</td>
</tr>
<tr>
<td>Curie Temperature (°C)</td>
<td>392</td>
</tr>
<tr>
<td>Continuous Service Temperature (°C)</td>
<td>150</td>
</tr>
<tr>
<td>Tensile Strength (MN/m²)</td>
<td>1k-1.7k</td>
</tr>
<tr>
<td>Elastic Modulus (GN/m²)</td>
<td>100-110</td>
</tr>
<tr>
<td>Vicker’s Hardness (50g load)</td>
<td>860</td>
</tr>
</tbody>
</table>

Magnetic Properties METGLAS Powerlite Cores

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation Flux Density (Tesla)</td>
<td>1.56</td>
</tr>
<tr>
<td>Permeability (depending on gap size)</td>
<td>VARIABLE</td>
</tr>
<tr>
<td>Saturation Magnetostriction (ppm)</td>
<td>27</td>
</tr>
<tr>
<td>Electrical Resistivity (µΩ cm)</td>
<td>137</td>
</tr>
</tbody>
</table>

Application - Differential Mode Chokes / Transformer

- Alternative Energy Power Supplies
- UPS system magnetic components
- Electric Vehicle
- Welding and Plasma cutting
- Medical
Microlite Distributed Gap Cores

Unique combination of high saturation flux density & low loss make Microlite the first choice for all energy storage applications while their distributed gap format renders a distinct RFI advantage to conventional air gap cores enabling the designer to achieve both size & system cost reduction.

- Higher Bsat for smaller component size
  - $B_{sat} = 1.56$ Tesla
- High permeability
  - $\mu \sim 250$ Less turns, lower Cu loss
- Extended Bias property
  - Better retention ( %L vs. DC bias )
- Lower Magnetic Losses
  - 85 W / kg @ 100kHz, 1000 Gauss
- Higher thermal conductivity
  - Ensures good heat dissipation
- Higher Curie temperature
  - 395 C
- Excellent permeability @ high frequency
  - 95% @ 1000kHz
- High continuous Service Temperature
  - 150 C

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Microlite</th>
<th>Iron Powder</th>
<th>MPP</th>
<th>Kool Mu</th>
<th>Ferrite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bsat</td>
<td>1.56</td>
<td>1.0-1.4</td>
<td>0.75</td>
<td>1.1</td>
<td>0.35</td>
</tr>
<tr>
<td>Permeability</td>
<td>245/380</td>
<td>75</td>
<td>125</td>
<td>125</td>
<td>Gap Based</td>
</tr>
<tr>
<td>Core Loss (W/kg)</td>
<td>&lt;80/60</td>
<td>680</td>
<td>65</td>
<td>140</td>
<td>&lt;65</td>
</tr>
<tr>
<td>% Perm</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>&lt;25</td>
</tr>
<tr>
<td>Turns</td>
<td>1</td>
<td>1.8</td>
<td>1.1</td>
<td>1.1</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Applications
- Output Inductor
- Input Differential Mode Inductor
- Flyback Transformer
- Power Factor Correction Boost Inductor
Powdered Amorphous Cores

HLM50 series have low loss, high magnetic flux density, and high reliability using our uniquely processed amorphous powder. This series is suited to coils for higher switching power electronics applications. (Power Factor Correction)

- High Saturation Flux Density Bs
  Higher saturation flux density compared to Sendust powder core.
- Low Core Loss.
  Lower core loss than Sendust powder core.
- Suitable for PFC Circuit and Boost/Buck Converter.
- Three Types of Core are in Production Lineup
  Bare core, cased core and over-coated core can be applied depending on customer requirement.
Tech Roadmap – Electrical and Mechanical

- Road Map (High Impedance) for Noise Attenuation
  => High Performance and/or Size Reduction
- Saturation Induction Increase
  => Transformer size reduction
- Low permeability
  => Low core loss, non cut core DM choke
  => DC tolerant current transformer

FT-3KM
μrz = 34k

FT-3K50T
μrz = 35k
Thinner Ribbon

FT-3K50T
μrz = 40k
Process Optimization

FT-3K10Q (NEW!)

FT-3W
Low U

1.2T
1.8T

Mechanical Packaging of Amorphous and FINEMET material for applications such as motor stators and wireless charging