This brochure describes characteristics of FINEMET® and gives examples of applications made of FINEMET®.
FINEMET® Nanocrystalline Fe-based Soft Magnetic Material with High Saturation Flux Density and Low Core Loss

FINEMET® is the product of Material’s Magic.
The best solution for energy saving, electromagnetic noise reduction and size reduction.

Superior to Conventional Material

Relationship between relative permeability and saturation flux density of various soft magnetic materials

Features

1) Satisfy both high saturation magnetic flux density and high permeability
High saturation magnetic flux density comparable to Fe-based amorphous metal. High permeability comparable to Co-based amorphous metal.

2) Low core loss
1/5th the core loss of Fe based amorphous metal and approximately the same core loss as Co-based amorphous metal.

3) Low magnetostriction
Less affected by mechanical stress. Very low audio noise emission.

4) Excellent temperature characteristics and small aging effects
Small permeability variation (less than ±10%) at a temperature range of -50°C~150°C. Unlike Co-based amorphous metals, aging effects are very small.

5) Excellent high frequency characteristics
High permeability and low core loss over wide frequency range, which is equivalent to Co-based amorphous metal.

6) Flexibility to control magnetic properties “B-H curve shape” during annealing
Three types of B-H curve squareness, high, middle and low remanence ratio, corresponding to various applications.

B-H Curve Control for FINEMET®

FINEMET® core’s magnetic properties, “B-H curve” can be controlled by applying a magnetic field during annealing. There are three types of B-H curves. 1) H type: a magnetic field is applied in a circumferential direction during annealing, 2) M type: no magnetic field is applied during annealing, 3) L type: a magnetic field is applied vertically to the core plane during annealing.

Examples of DC B-H curve

What is FINEMET®?

The precursor of FINEMET® is amorphous ribbon (non-crystalline) obtained by rapid quenching at one million °C/second from the molten metal consisting of Fe, Si, B and small amounts of Cu and Nb. These crystallized alloys have grains which are extremely uniform and small, “about ten nanometers in size”. Amorphous metals which contain certain alloy elements show superior soft magnetic properties through crystallization. It was commonly known that the characteristics of soft magnetic materials are “larger crystal grains yield better soft magnetic properties”. Contrary to this common belief, soft magnetic material consisting of a small, “nano-order”, crystal grains have excellent soft magnetic properties.

For safety and the proper usage, you are requested to approve our product specifications or to transact the approval sheet for product specifications before ordering. This catalog and its contents are subject to change without notice.
Hitachi Metals Ltd. produces various types of soft magnetic materials, such as Permalloy, soft ferrite, amorphous metal, and FINEMET®, and we use these materials in our product's applications. We continually improve our material technology and develop new applications by taking advantage of the unique characteristics these materials provide. FINEMET® is a good example. It is our hope, FINEMET® will be the best solution for your application.
**Major Application of FINEMET®**

The followings are examples of FINEMET® application by taking advantage of high permeability, high saturation flux density and low core loss.

**Common Mode Chokes for *EMI filters***

FINEMET® has higher impedance permeability ($\mu_{rz}$) and much smaller temperature dependence of permeability over a wider frequency range than Mn-Zn ferrite. Consequently, the volume of FINEMET® core can be reduced to 1/2 the size of a Mn-Zn ferrite core while maintaining the same performance at operating temperature of 0°C~100°C. Also, it has approximately three times higher saturation flux density than Mn-Zn ferrite and as a result it is hardly saturated by pulse noise.

*EMI: Electro Magnetic Interference

**Comparison of magnetic and physical properties among FT-3M and conventional materials**

<table>
<thead>
<tr>
<th>Material</th>
<th>FT-3M</th>
<th>Co-based amorphous</th>
<th>Ni-Zn ferrite</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Saturation flux density $B_s$ (T)</td>
<td>20°C</td>
<td>1.23</td>
<td>0.60</td>
</tr>
<tr>
<td>100°C</td>
<td>1.20</td>
<td>0.53</td>
<td>0.29</td>
</tr>
<tr>
<td>*Squareness ratio $R_{B_s}$</td>
<td>20°C</td>
<td>0.50</td>
<td>0.80</td>
</tr>
<tr>
<td>100°C</td>
<td>0.48</td>
<td>0.78</td>
<td>0.60</td>
</tr>
<tr>
<td>*Coercive force $H_c$ (A/m)</td>
<td>20°C</td>
<td>2.5</td>
<td>0.30</td>
</tr>
<tr>
<td>100°C</td>
<td>2.7</td>
<td>0.29</td>
<td>20</td>
</tr>
<tr>
<td><strong>Pulse permeability $\mu_{rz}$</strong></td>
<td></td>
<td>3,500</td>
<td>4,500</td>
</tr>
<tr>
<td><strong>Core loss $P_{cv}$ (J/m³)</strong></td>
<td></td>
<td>7.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Curo temperature $T_c$ (°C)</td>
<td>570</td>
<td>210</td>
<td>200</td>
</tr>
<tr>
<td>Saturation magnetostriction $k_h$ ($\times 10^{-5}$)</td>
<td></td>
<td>7.6</td>
<td>0</td>
</tr>
<tr>
<td>Electrical resistivity $\rho$ ($\mu\Omega\cdot m$)</td>
<td></td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Density $d$ (kg/m³)</td>
<td>7.3 $\times 10^3$</td>
<td>7.7 $\times 10^3$</td>
<td>5.2 $\times 10^3$</td>
</tr>
</tbody>
</table>

* DC magnetic properties at 800A/m ** Pulse width 0.1 μs, operating magnetic flux density $\Delta B = 0.2T$

**FINEMET® Beads**

FINEMET® Beads are made of FINEMET® FT-3M material. As below table describes, the saturation magnetic flux density is twice as high as that of Co-based amorphous metal and Ni-Zn ferrite, and the pulse permeability and the core loss are comparable to Co-based amorphous metal. Because of the high curie temperature (570°C), FINEMET® Beads shows excellent performance at high temperature. These cores are suitable for suppression of reverse recovery current from the diode and ringing or surge current from switching circuit.

**High voltage surge suppression with high saturation flux density**

FINEMET® has higher impedance permeability ($\mu_{rz}$) and much smaller temperature dependence of permeability over a wider frequency range than Mn-Zn ferrite. Consequently, the volume of FINEMET® core can be reduced to 1/2 the size of a Mn-Zn ferrite core while maintaining the same performance at operating temperature of 0°C~100°C. Also, it has approximately three times higher saturation flux density than Mn-Zn ferrite and as a result it is hardly saturated by pulse noise.

For safety and the proper usage, you are requested to approve our product specifications or to transact the approval sheet for product specifications before ordering. This catalog and its contents are subject to change without notice.
Size reduction with low core loss

**High Frequency Power Transformer**

The core loss of FINEMET® (FT-3M) cut core has less than 1/5th the core loss of Fe based amorphous metal and Mn-Zn ferrite, and less than 1/10th the core loss of silicon steel at 10kHz, Bm=0.2T. FINEMET® has significantly lower core loss and thus makes it possible to reduce the size of the core for high frequency power transformer. Also, the magnetostriction of FT-3M is $10^{-7}$ order and, as a result, cores made from this material will make very little audible noise when compared to cut cores made from Fe based amorphous metal and silicon steel.

Size reduction and lower core loss

**Pulsed Power Cores**

FINEMET® pulsed power cores use a thin ceramic insulation which has a high break down voltage. FINEMET® pulsed power cores are suitable for saturable cores and step-up pulse transformer cores that are used in high voltage pulsed power supplies for Excimer lasers and accelerators, and for cavity cores used in induction linacs and RF accelerators.

### Comparison of core materials applied in saturable cores for magnetic pulse compression circuit

<table>
<thead>
<tr>
<th>Core material</th>
<th>FINEMET® FT-3H</th>
<th>Fe-based amorphous metal</th>
<th>Co-based amorphous metal</th>
<th>Ni-Zn ferrite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation</td>
<td>Ceramic</td>
<td>PET film</td>
<td>PET film</td>
<td>–</td>
</tr>
<tr>
<td>Effective induction swing $K_{aB_{m}}$ (T)</td>
<td>1.54</td>
<td>2.04</td>
<td>0.78</td>
<td>0.65</td>
</tr>
<tr>
<td>Half-cycle core loss $Pc$ (J/m³)</td>
<td>710</td>
<td>1680</td>
<td>180</td>
<td>70</td>
</tr>
<tr>
<td>Relative permeability at saturation range $H_{(reset)}$</td>
<td>$\leq 1$</td>
<td>$\leq 1.3$</td>
<td>$\leq 1$</td>
<td>$\leq 3$</td>
</tr>
<tr>
<td>Reset magnetizing force $H_{(reset)}$ (A/m)</td>
<td>8</td>
<td>40</td>
<td>8</td>
<td>160</td>
</tr>
<tr>
<td>Volume ratio of saturable cores</td>
<td>1</td>
<td>0.74</td>
<td>3.95</td>
<td>16.8</td>
</tr>
<tr>
<td>Total core loss ratio of saturable cores</td>
<td>1</td>
<td>1.75</td>
<td>1.0</td>
<td>1.66</td>
</tr>
</tbody>
</table>

Pulse duration compression ratio: 5:0 (input pulse duration 0.5µs, output pulse duration 0.1µs)

K: Packing factor \( \Delta_{Pmax} \): Maximum operation flux density

---

**For safety and the proper usage, you are requested to approve our product specifications or to transact the approval sheet for product specifications before ordering. This catalog and its contents are subject to change without notice.**
Manufacturing Process and Microstructure of FINEMET®

Overview of manufacturing process, crystallization process and annealing conditions

Manufacturing Process of FINEMET®

A below diagram shows the process for the creation of amorphous ribbon for FINEMET® and a typical FINEMET® core. The amorphous ribbon is the precursor material of FINEMET®. This ribbon, “which is about 18 µm in thickness”, is cast by rapid quenching, called “single roll method”, then the amorphous ribbon is wound into a toroidal core. Finally, the heat treatment is applied to the core for crystallization in order to obtain excellent soft magnetic properties of FINEMET®.

Crystallization Process of FINEMET®

Amorphous metal as a starting point, Amorphous → Cu-rich area → the nucleation of bcc Fe from Cu → bcc Fe(-Si) shows the crystallization process. At the final stage of this crystallization process, the grain growth is suppressed by the stabilized remaining amorphous phase at the grain boundaries. This stabilization occurs because the crystallization temperature of the remaining amorphous phase rises and it becomes more stable through the enrichment of Nb and B. Synergistic effects of Cu addition, “which causes the nucleation of bcc Fe” and Nb addition, “which suppresses the grain growth” creates a uniform and very fine nanocrystalline microstructure.

For safety and the proper usage, you are requested to approve our product specifications or to transact the approval sheet for product specifications before ordering. This catalog and its contents are subject to change without notice.
Annealing Conditions

The diagram shows the typical annealing conditions for M type. This process requires proper heat treatment conditions according to the desired magnetic properties.

Example of annealing for M type

Microstructure of FINEMET®

A below picture shows the microstructure of FINEMET® through a transmission electron microscope. FINEMET® consists of ultra fine crystal grains of 10nm order. Main phase is bcc Fe(-Si) and remaining amorphous phase around the crystal grains.
In the conventional soft magnetic materials, whose grain size is far larger than 1 µm, it was well known that soft magnetic properties become worse and coercive force increases when crystal grain size becomes smaller. For example, coercive force is thought to be inversely proportional to D. Therefore, main efforts to improve the soft magnetic properties were directed to make the crystal grain size larger and/or to make the magnetic domain size smaller by annealing and working. However, FINEMET® demonstrated a new phenomenon; reduction of grain size, “to a nano-meter level”, improves the soft magnetic properties drastically. In this nano-world, the coercive force is directly proportional to D on the order of D². This is absolutely contrary to the conventional concepts for improving the soft magnetic properties.

![Graph showing the relationship between crystal grain diameter (D) and coercive force (Hc)](image)

### Physical Properties

The table shows physical properties of two types of heat-treated FINEMET® materials. FINEMET® has resistivity as high as Fe-based amorphous metal, and has much lower magnetostriction and about 570°C higher Curie temperature than Fe-based amorphous metal. FT-3 is the improved version of FT-1, whose saturation magnetostriction constant of 10⁻⁶.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (X10³kg/m³)</th>
<th>Resistivity (µΩ·m)</th>
<th>Saturation magnetostriction (X10⁻⁶)</th>
<th>Curie temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT-1</td>
<td>7.4</td>
<td>14.1</td>
<td>1.5</td>
<td>950</td>
</tr>
<tr>
<td>FT-3</td>
<td>7.3</td>
<td>12.2</td>
<td>0.9</td>
<td>700</td>
</tr>
</tbody>
</table>

*FT-1 and FT-3 describes material property (chemical composition).

### Standard Magnetic Characteristics

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (µm)</th>
<th>Br (T)</th>
<th>Hc (A/m)</th>
<th>Bμ1000 (X10²)</th>
<th>Hμ10000 (X10³)</th>
<th>Pcv (kW/m³)</th>
<th>Js (X10⁶)</th>
<th>Tc (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FINEMET® FT-1H</td>
<td>18</td>
<td>1.35</td>
<td>0.9</td>
<td>1.5</td>
<td>950</td>
<td>- 2.3</td>
<td>~ 570</td>
<td></td>
</tr>
<tr>
<td>FINEMET® FT-1M</td>
<td>18</td>
<td>1.35</td>
<td>1.0</td>
<td>1.5</td>
<td>750</td>
<td>+ 2.3</td>
<td>~ 570</td>
<td></td>
</tr>
<tr>
<td>FINEMET® FT-3H</td>
<td>18</td>
<td>1.23</td>
<td>1.2</td>
<td>1.5</td>
<td>350</td>
<td>0</td>
<td>~ 570</td>
<td></td>
</tr>
<tr>
<td>FINEMET® FT-3M</td>
<td>18</td>
<td>1.23</td>
<td>1.2</td>
<td>1.5</td>
<td>150</td>
<td>0</td>
<td>~ 570</td>
<td></td>
</tr>
<tr>
<td>Fe based amorphous</td>
<td>25</td>
<td>1.56</td>
<td>2.4</td>
<td>5.0</td>
<td>2200</td>
<td>+ 27</td>
<td>415</td>
<td></td>
</tr>
<tr>
<td>Co-based high permeability amorphous metal</td>
<td>18</td>
<td>0.55</td>
<td>0.3</td>
<td>115.0</td>
<td>280</td>
<td>0</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>Co-based high squareness amorphous metal</td>
<td>18</td>
<td>0.60</td>
<td>0.3</td>
<td>30.0 11.0</td>
<td>280</td>
<td>0</td>
<td>210</td>
<td></td>
</tr>
<tr>
<td>3%Si-steel</td>
<td>50</td>
<td>1.90</td>
<td>6.0</td>
<td>2.7</td>
<td>8400</td>
<td>- 0.8</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>6.5%Si-steel</td>
<td>50</td>
<td>1.30</td>
<td>6.5</td>
<td>1.2</td>
<td>5800</td>
<td>- 0.1</td>
<td>700</td>
<td></td>
</tr>
<tr>
<td>50%Ni Permalloy</td>
<td>25</td>
<td>1.50</td>
<td>12.0</td>
<td>2.4</td>
<td>3400</td>
<td>+ 25</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>80% Ni high permeability Permalloy</td>
<td>25</td>
<td>0.74</td>
<td>0.5</td>
<td>5.0</td>
<td>1000</td>
<td>0</td>
<td>460</td>
<td></td>
</tr>
<tr>
<td>80% Ni high squareness Permalloy</td>
<td>25</td>
<td>0.74</td>
<td>0.5</td>
<td>5.0</td>
<td>1200</td>
<td>- 0.6</td>
<td>&gt; 150</td>
<td></td>
</tr>
<tr>
<td>Mn-Zn low core loss ferrite</td>
<td>25</td>
<td>0.49</td>
<td>2.4</td>
<td>2.4</td>
<td>680</td>
<td>0</td>
<td>&gt; 200</td>
<td></td>
</tr>
</tbody>
</table>

*Note1: Br, Hc, Bs: DC magnetic properties (Hm=0A/m, 25°C), Bμ1000: relative permeability (1kHz, Hm=0.05A/m, 25°C), Hμ10000: relative permeability (1kHz, Hm=0.05A/m, 25°C), Pcv: core loss (100kHz, Bs=0.2T, 25°C), Js: Saturation magnetostriction, Tc: Curie temperature.

*Note2: Above properties are taken measurement by Hitachi Metals Ltd.
Frequency Dependence of Relative Permeability

The graph shows frequency dependence of relative permeability for FT-3M (medium square ratio of BH curve), Co-based amorphous metal, Fe-based amorphous metal and Mn-Zn ferrite. FT-3M has much higher permeability than Fe based amorphous metals and Mn-Zn ferrite, and has permeability as high as Co-based amorphous metals over a wide frequency range.

Frequency Dependence of Relative Permeability (After resin molding)

The graph shows frequency dependence of relative permeability for resin molded FT-1M and FT-3M. FT-3M and Co-based amorphous cores show small permeability degradation after the resin molding due to their small magnetostriction.

Complex Relative Permeability and Impedance Relative Permeability

The graph shows real part ($\mu'_r$) and imaginary part ($\mu''_r$) of the complex relative permeability and the impedance relative permeability ($\mu_{rz}$) for FT-1M material. $\mu''_r$ becomes larger than $\mu'_r$ at 50kHz. Relationship between $\mu_{rz}$, $\mu'_r$ and $\mu''_r$ is

$$\mu_{rz} = \sqrt{\mu'_r^2 + \mu''_r^2}$$
Core Loss

**Frequency Dependence of Core Loss (Before resin molding)**

The graph shows frequency dependence of core loss for non-resin molded cores made of FT-1M, FT-3M, Fe-based amorphous metal, Co-based amorphous metal and Mn-Zn ferrite. FT-1M and FT-3M cores show lower core loss than Mn-Zn ferrite and Fe-based cores, and have the same core loss as Co-based amorphous core.

*Note: Data may vary depending on resin and/or molding conditions.*

**Frequency Dependence of Core Loss (After resin molding)**

The graph shows frequency dependence of core loss for resin molded cores made of FT-3M and FT-1M. FT-3M core shows stable core loss over wide frequency range with lower core loss than ferrite cores and have the same core loss as Co-based amorphous core.

**B<sub>m</sub> Dependence of Core Loss**

The graph shows B<sub>m</sub> dependence of core loss for FT-3H, 3M and 3L at 20kHz. FT-3M and 3L show lower core loss than FT-3H. As B<sub>m</sub> becomes higher, core loss difference among those materials becomes smaller.

---

For safety and the proper usage, you are requested to approve our product specifications or to transact the approval sheet for product specifications before ordering. This catalog and its contents are subject to change without notice.
### Temperature Characteristics

#### Temperature Dependence of Saturation Flux Density

The graph shows temperature dependence of saturation flux density ($B_s$) for FT-1 and FT-3. Both FT-1 and FT-3 have very small temperature dependence of saturation flux density. The decreasing rate of saturation flux density is less than 10% at range from 25°C to 150°C.

*Note: This data shows value of annealed (crystallized) material. Because $B_s$ value for H type, M type and L type are same, the data does not describes BH type.

#### Temperature Dependence of Relative Permeability

The graph shows temperature dependence of relative permeability at 10kHz for FT-1M. The variation of relative permeability is very small at a temperature range from 0°C to 150°C, "which is within ±10% of the average value".

#### Aging Effect on Relative Permeability

The graph shows aging effects at 100°C on relative permeability at 1kHz for FT-1M and Co-based amorphous metal. The relative permeability of Co-based amorphous metal decrease rapidly as the aging time increasing, however FT-1M is quite stable.

---

For safety and the proper usage, you are requested to approve our product specifications or to transact the approval sheet for product specifications before ordering. This catalog and its contents are subject to change without notice.
NOTICE OF DISCLAIMER

- Information in this brochure does not grant patent right, copyright or intellectual property rights of Hitachi Metals or that of third parties. Hitachi Metals disclaims all liability arising out using information in this brochure for any case of patent right, copyright or intellectual property rights of third parties.

- Do not duplicate in part or in entirety this brochure without written permission from Hitachi Metals Ltd.

- This brochure and its contents are subject to change without notice; specific technical characteristics are subject to consultation and agreement.

- Please inquire about our handling manual for specific applications of FINEMET®, these manuals detail the exact guaranteed characteristics of FINEMET® for a specific application.

---

Hitachi Metals, Ltd.
http://www.hitachi-metals.co.jp

Soft Magnetic Materials Company Head Office
2-1 Shibaura 1-chome, Seavans North Bldg.
Minato-ku, Tokyo 105-8614, Japan
Tel:+81-3-5765-4042   Fax:+81-3-5765-8313

Kansai Sales Office
5-29 Kitahama 3-chome, Nissei Yodoyabashi
building Chuo-ku, Osaka 541-0041, Japan
Tel:+81-6-6203-9751   Fax:+81-6-6222-3414

Chubu-Tokai Sales Office
13-19 Nishiki 2-chome, Takisada building,
Naka-ku Nagoya-shi, Aichi, 460-0003, Japan
Tel:+81-52-220-7470   FAX:+81-52-220-7486

North America

Hitachi Metals America, Ltd.
Cicaco Office
2101 S. Arlington Heights Road Suite 116
Arlington Heights, IL 60005-4142
Tel:847-364-7200   Fax:847-364-7279

Detroit Office
41800 W. Eleven Mile Road Suite 100
Novi, MI 48375-1818
Tel:248-465-6400   Fax:248-465-6020

South-East Asia

Hitachi Metals Singapore Pte. Ltd.
12 Gul Avenue, Singapore 629656
Tel:+65-6861-7711   Fax:+65-6861-9554

Europe

Hitachi Metals Europe GmbH
Immermannstrasse 14-16, 40210 Dusseldorf, Germany
Tel:+49-211-16009-57   Fax:+49-211-16009-60

China

Hitachi Metals (Shanghai) Ltd.
11F, Tian An Center, No.338 NanJing Road(West),
Shanghai, 200003, China
Tel:+86-21-6358-6334   Fax:+86-21-6431-8067

Hitachi Metals Hong Kong Ltd.
Units 2212-14, 22/F., Miramar Tower,
132 Nathan Road, Tsimshatsui, Kowloon, Hong Kong
Tel:852-2724-4183   Fax:852-2311-2095

---

Above contact addresses are as of March 2007. The addresses are subject to change without notice.
If you find difficulty contacting Hitachi Metals, please contact below:
  Tel : +81-3-5765-4076   Fax : +81-3-5765-8312   E-mail : hmcc@hitachi-metals.co.jp