Fe-based Amorphous & Amorphous nanocrystalline

— soft magnetic materials

I. Basis for Material Classification

1. Amorphous Nanocrystalline Soft Magnetic Materials

   The **amorphous nanocrystalline soft magnetic materials**, after forming an amorphous ribbon via rapid solidification processes (e.g., single-roller melt spinning), specific heat treatments are applied to precipitate nanocrystallites (~10–20 nm in size), which form a dual-phase structure with the amorphous matrix. This nanocrystallization process significantly enhances permeability and high-frequency performance:

   - Initial permeability (at 1 kHz) can reach **33,000–80,000**;
   - Saturation magnetic flux density (Bs) is **1.2–1.9 T**, higher than that of conventional amorphous alloys (1.2–1.5T).

2. Amorphous Soft Magnetic Materials

   Conventional amorphous soft magnetic materials (e.g., Fe-Si-B alloys) retain a fully amorphous state without crystallization treatment. Their permeability typically ranges from **10000 to 100000**, but they exhibit higher high-frequency losses.

   In contrast, nanocrystallization endows the material with both high permeability and low coercivity (Hc can be as low as **0.5 A/m**), making it suitable for higher frequency bands (e.g., kHz–MHz).

II. Permeability Range and Influencing Factors

1. Typical Permeability Values
   - Initial Permeability (μi):
     - Without optimized processing: ~**10,000–30,000** (e.g., $Fe_{64}Ni_{12}Si_{13}B_8Nb_2Cu_1$ alloy);
     - With optimized processing (e.g., gradient annealing): Up to **80,000–100,000** (e.g., $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ alloy).
   - **High-Frequency Permeability (100 kHz)**:
     - ~**3,000–10,000**, significantly superior to ferrites.
2. Key Regulatory Factors
   - **Ni Content**: Adding Ni (e.g., 2–4%) refines grains and reduces coercivity, enhancing permeability;
   - **Heat Treatment Process**: Gradient annealing (e.g., staged holding at 380–585° C) optimizes grain distribution and minimizes internal stress, improving permeability stability by over 10%;

- **Nanocrystal Size:** Reducing grain size from 20 nm to 10 nm can increase permeability by ~30%.

III. Application Scenarios and Performance Advantages

1. **High-Frequency Power Electronics Field**
   - Suitable for switching power supply transformers and common-mode inductors operating at 50 kHz–100 kHz. Its high-frequency core loss (e.g., ~27 W/kg at 0.5 T/100 kHz) is only 1/3 that of ferrites;
   - In new energy vehicle motors, it can reduce the volume of 400 Hz variable frequency systems by 50%.
2. **Comparison with Other Soft Magnetic Materials**
   - **Ferrites:** Low saturation flux density (0.3–0.5 T) and limited high-frequency performance;
   - **Co-based Amorphous Alloys:** High cost and lower permeability than nanocrystalline alloys;
   - **Permalloy:** Requires high Ni content (30–80%), resulting in high cost and low Curie temperature.

IV. Summary

This Fe-Cu-Ni-Si-B alloy combines high permeability (10000–1000000) with low loss through nanocrystallization, belonging to **typical amorphous nanocrystalline soft magnetic materials**. Its performance advantages are irreplaceable in fields such as new energy and smart grids. In the future, with process optimization (e.g., development of non-precious metal formulations), costs will be further reduced.

Key Professional Terms Used:

- Amorphous nanocrystalline soft magnetic materials
- Amorphous soft magnetic materials
- Rapid solidification processes
- Single-roller melt spinning
- Nanocrystallites
- Dual-phase structure
- Initial permeability (μi)
- Saturation magnetic flux density (Bs)
- Coercivity (Hc)
- Gradient annealing
- Grain size
- High-frequency core loss
- Permalloy
- Curie temperature