



# PERFORMANCE COMPARISON BETWEEN NANOCRYSTALLINE AND FERRITE

## Introduction

Nanocrystalline alloys and ferrites (e.g., Mn-Zn, Ni-Zn) are two pivotal soft magnetic materials for inductors, transformers, and other electronic components. Their core properties directly impact suitability for applications, especially amid the drive for miniaturized, high-efficiency electronics. This article presents a systematic comparison of their key attributes.

## Key Performance Comparisons

### Magnetic Permeability ( $\mu$ )

#### Nanocrystalline Alloys

Ultra-high initial permeability ( $\mu_i=10,000-100,000$ ) from 5–20 nm grain structure and uniform magnetic domains, delivering excellent low-field magnetic response for precision sensors and low-frequency filters.

#### Ferrites

Moderate permeability ( $\mu_i=100-10,000$ ). Mn-Zn ferrites ( $\mu_i=1,000-10,000$ ) outperform Ni-Zn ferrites ( $\mu_i=100-1,000$ ) but are frequency-sensitive. Permeability drops sharply beyond their Snoek limit (100–500 kHz for Mn-Zn), limiting high-frequency applications.



# Saturation Flux Density ( $B_s$ )

## Nanocrystalline Alloys

Boast high  $B_s$  (1.2–1.8 T) because of their metallic matrix (Fe-based). This allows smaller core volumes in high-power applications (e.g., automotive transformers), as higher  $B_s$  reduces the required cross-sectional area.

## Ferrites

Low  $B_s$  (0.3–0.6 T) due to their ceramic nature and weak magnetic exchange coupling. Larger cores are needed to handle equivalent power, limiting miniaturization in high-current devices.

# Core Loss ( $P_e$ )

## Nanocrystalline Alloys

Exceptionally low core loss at high frequencies (e.g., 500 kHz–1 MHz). For example, Finemet shows  $P_e < 100 \text{ mW/cm}^3$  at 1 MHz and 0.1 T, far lower than ferrites. This makes them suitable for high-frequency switching power supplies (SMPS).

## Ferrites

Lower loss than traditional metals (e.g., silicon steel) at mid-low frequencies (50–200 kHz) but loss increases exponentially above 500 kHz. Mn-Zn ferrites have lower  $P_e$  than Ni-Zn at low frequencies but suffer from eddy current losses in high-frequency regimes.

# Temperature Stability

## Nanocrystalline Alloys

Moderate Curie temperature ( $T_c=400-550^\circ\text{C}$ ) and stable permeability up to  $120-150^\circ\text{C}$ . However, their magnetic properties degrade rapidly above  $200^\circ\text{C}$ , requiring thermal management in high-temperature environments.

## Ferrites

Higher  $T_c$  (Mn-Zn:  $200-300^\circ\text{C}$ ; Ni-Zn:  $300-500^\circ\text{C}$ ) and better thermal stability. Ni-Zn ferrites retain  $>80\%$  permeability at  $250^\circ\text{C}$ , making them preferred for high-temperature applications like industrial motors.

# Frequency Characteristics

## Nanocrystalline Alloys

Wide frequency range ( $100\text{ Hz}-100\text{ MHz}$ ) with stable permeability, thanks to suppressed eddy currents (thin ribbon form,  $\sim 20\text{ }\mu\text{m}$  thick) and nanograin-induced domain pinning.

## Ferrites

Limited by Snoek's law—permeability peaks at low frequencies and declines at high frequencies. Ni-Zn ferrites perform better at high frequencies (up to  $100\text{ MHz}$ ) than Mn-Zn but have lower  $B_s$ .

# Mechanical & Chemical Properties

## Nanocrystalline Alloys

Ductile metallic structure with high hardness (HV800–1200) and good corrosion resistance (via passivation layers). Can be bent or stamped into complex shapes, suitable for flexible components.

## Ferrites

Brittle ceramic materials (HV500–800) prone to cracking under mechanical stress. Poor corrosion resistance (susceptible to moisture) requires protective coatings, increasing manufacturing complexity.

# Cost & Manufacturing

## Nanocrystalline Alloys

Higher production cost due to rapid solidification (melt-spinning) and annealing processes. Raw material costs (Fe, Si, B, Cu) are moderate, but complex processing limits low-cost scaling.

## Ferrites

Low cost-abundant raw materials ( $\text{Fe}_2\text{O}_3$ , MnO, ZnO) and simple sintering processes. Mass production is mature, making them ideal for consumer electronics (e.g., TV inductors) where cost is critical.



# PERFORMANCE COMPARISON BETWEEN NANOCRYSTALLINE AND FERRITE

## 引言

纳米晶合金与铁氧体（如锰锌、镍锌铁氧体）是电感器、变压器及其他电子元件中两类关键的软磁材料。它们的核心性能直接影响其应用适配性，尤其在电子设备向小型化、高效化发展的趋势下更是如此。本文将系统对比两者的关键特性。

## 核心性能对比

### 磁导率 ( $\mu$ )

#### 纳米晶合金

凭借 5-20 纳米的晶粒结构与均匀的磁畴，具备超高初始磁导率 ( $\mu_i=10,000-100,000$ )，可为精密传感器和低频滤波器提供出色的低场磁响应。

#### 铁氧体

磁导率中等 ( $\mu_i=100-10,000$ )。锰锌铁氧体 ( $\mu_i=1,000-10,000$ ) 性能优于镍锌铁氧体 ( $\mu_i=100-1,000$ )，但对频率敏感：超过其斯诺克极限（锰锌铁氧体为 100-500 kHz）后，磁导率会急剧下降，限制了其在高频场景的应用。



## 饱和磁通密度( $B_s$ )



### 纳米晶合金

因采用铁基金属基体，具备较高的饱和磁通密度 ( $B_s=1.2-1.8\text{ T}$ )。这使得它在高功率应用（如汽车变压器）中可缩小磁芯体积——更高的  $B_s$  能减小所需的横截面积。

### 铁氧体

受陶瓷特性与弱磁交换耦合的影响，饱和磁通密度较低 ( $B_s=0.3-0.6\text{ T}$ )。处理同等功率时需要更大的磁芯，限制了其在大电流设备中的微型化应用。

## 磁芯损耗( $P_e$ )



### 纳米晶合金

在高频段（如  $500\text{ kHz}-1\text{ MHz}$ ）的磁芯损耗极低。例如，Finemet 材料在  $1\text{ MHz}$ 、 $0.1\text{ T}$  条件下的  $P_e < 100\text{ mW/cm}^3$ ，远低于铁氧体，因此适用于高频开关电源（SMPS）。

### 铁氧体

在中低频段（ $50-200\text{ kHz}$ ）下，损耗低于传统金属（如硅钢），但在  $500\text{ kHz}$  以上频段，损耗会呈指数级增长。锰锌铁氧体在低频下的  $P_e$  低于镍锌铁氧体，但在高频场景下会受涡流损耗的影响。

## 温度稳定性



### 纳米晶合金

居里温度中等 ( $T_c=400-550^{\circ}\text{C}$ )，在  $120-150^{\circ}\text{C}$  范围内磁导率稳定。但在  $200^{\circ}\text{C}$  以上时，其磁性能会快速劣化，因此在高温环境下需要热管理措施。

### 铁氧体

居里温度更高（锰锌型： $200-300^{\circ}\text{C}$ ；镍锌型： $300-500^{\circ}\text{C}$ ），热稳定性更好。镍锌铁氧体在  $250^{\circ}\text{C}$  时仍能保持 80% 以上的磁导率，因此是工业电机等高温应用场景的优选材料。

## 频率特性



### 纳米晶合金

凭借抑制涡流（采用约  $20\mu\text{m}$  厚的薄带形态）和纳米晶粒诱导的磁畴钉扎效应，可在宽频率范围（ $100\text{Hz}-100\text{MHz}$ ）内保持稳定的磁导率。

### 铁氧体

受斯诺克定律限制——磁导率在低频段达到峰值，高频段则下降。镍锌铁氧体在高频段（最高  $100\text{MHz}$ ）的表现优于锰锌铁氧体，但饱和磁感应强度 ( $B_s$ ) 更低。

## 机械与化学性能



### 纳米晶合金

具有韧性金属结构，硬度较高（维氏硬度 800-1200），且通过钝化层具备良好的耐腐蚀性。可被弯折或冲压成复杂形状，适用于柔性组件。

### 铁氧体

属于脆性陶瓷材料（维氏硬度 500-800），受机械应力时易开裂。耐腐蚀性较差（易受湿气影响），需要防护涂层，增加了制造复杂度。

## 成本与制造



### 纳米晶合金

生产成本较高，因为需要快速凝固（熔体纺丝）和退火工艺。原材料（铁、硅、硼、铜）成本适中，但复杂的加工工艺限制了低成本规模化生产。

### 铁氧体

成本较低——原材料（氧化铁、氧化锰、氧化锌）储量丰富，且烧结工艺简单。量产技术成熟，因此是消费电子（如电视电感器）等成本敏感场景的理想选择。