CAPE Grand Challenge: Photonics and Electronics 2022

TOPIC 2: The Optimization Analysis of Components and Micro-structure of Magnetic Materials with High Magnetic Permeability and Low Noise

In order to meet the requirements for high performance magnetic shielding materials for SERF atomic magnetometer for cardiac and cerebral magnetic measurements, research on optimization of components and micro-structure of magnetic materials with high permeability and low noise is needed. The objective is the design of magnetic materials with initial permeability not less than 5×10^4 and conductivity not higher than $0.1\Omega^{-1}\cdot m^{-1}$, which lays the foundation for testing and calibration of high performance SERF atomic magnetometers.

Technical requirements:

（1）Initial magnetic permeability no less than 5×10^4@0.08A/m;

（2）Conductivity no higher than $0.1\Omega^{-1}\cdot m^{-1}$。

Note: The above indexes are to be verified by simulation analysis.

Attachment: Influence of noise and initial magnetic permeability of magnetic materials

Material magnetic noise mainly includes Johnson magnetic noise and hysteresis loss noise. Johnson noise is the main source of noise for the main materials, and for cylindrical shielding materials this noise meets:

$$\delta B = \frac{\mu_0\sqrt{k_B T\sigma d}}{(D+d)/2}\cdot\sqrt{\frac{2G}{3\pi}} \quad (1)$$

Where, μ_0 is the vacuum magnetic permeability, k_B is the Boltzmann constant, T is the temperature, σ is the conductivity, d is the inner layer thickness, D is the inner layer diameter, and G is the aspect ratio. Therefore, the key physical quantity that determines the material magnetic field noise is the electrical conductivity. Comparing and analyzing the common Permalloy 1J85 and Mn-Zn ferrite, the conductivity of Permalloy 1J85 is $1.6\times10^6\Omega^{-1}\cdot m^{-1}$, while the conductivity of Mn-Zn ferrite is $10^{-1}\Omega^{-1}\cdot m^{-1}$. By estimation, the thickness of 2cm, aspect ratio 0.4, and inner diameter 0.6m, for Permalloy 1J85 material magnetic field noise is $10fT/Hz^{1/2}$ order of magnitude, while the Mn-Zn ferrite magnetic field noise can be reduced by 3~4 orders of magnitude.

The magnetic field shielding coefficient of a material is positively related to the initial permeability. For the lJ85 Permalloy material, the initial permeability can be approximately 10^5, while the initial permeability of Mn-Zn ferrite is in the order of 10^4.

Comparison of common magnetic shielding material parameters

No.	Name	Initial permeability	Conductivity

1	Permalloy 1J85	10^5	10^6
2	Mn-Zn ferrite	10^4	10^{-1}

The ideal conditions would be to study materials with high initial magnetic permeability and low electrical conductivity to achieve high shielding and low noise. However, in principle there is a certain degree of contradiction between these two parameters: materials with high initial magnetic permeability are basically metallic materials, and the electrical conductivity of metallic materials is several orders of magnitude larger compared to metal oxides or metal salts.