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THIN FILM FLAT SUPERCONDUCTING MAGNETIC FIELD CONCENTRATOR

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Background

Sensors of ultraweak (10 pT ÷ 1 fT) magnetic field (MFS) are the main tools for non-invasive registration of the magnetic field in a biological object. In this regard, a quantum magnetometer, the so-called superconducting quantum interference device (SQUID), is considered to be the most suitable instrument. Low threshold magnetosensitivity in SQUIDs is achieved using magnetic field concentrators (MFCs). The structure of the concentrates the measured weak magnetic field onto the local space, similarly to how a magnifying glass concentrates light at a focus. In most cases, a low threshold sensitivity of ≤1 nT is achieved in MFS due to the use of MFC based on superconducting films, for example, in a combined MFS (CMFS), in which various structures are used as magnetically sensitive elements (MSE): Josephson contact or matter, Hall sensor, sensors on the effects of spintronics, etc. [1]. Optimal nanostructuring of the active stripe (AS) of the concentrator in the CMFS leads to an additional increase in its concentration coefficient [2]. Accordingly, the threshold magnetosensitivity of the CMFS is further reduced and its efficiency is increased.

Aim

The purpose of this work is to calculate the magnetic field concentration coefficient in a planar film combined magnetic field sensor, when its active stripe can be in both unstructured and nanostructured states.

Methods

Figure 1 shows a sketch of the CMFS, where yellow is the substrate, blue is the MFC rings, and brown is the MSE. **Figure 2** shows the cuts sections on the AS film in the form of parallel black lines, which are located differently: in the middle (a), far from the MSE (b), and near the MSE (c). It has been established that the shielding current in the AS is distributed non-uniformly, since the continuous (unstructured) superconducting film is "wide" (the width of 50 μm is much greater than the depth λ of the penetration of the magnetic field). In a nanostructured film with cuts (slit width 20 nm), the largest part of the current can flow to the AS boundary, which is closer to the MSE (**Figure 2,** b), which increases the concentration factor *F* compared to the factor *F*0 for an unstructured (solid) film.

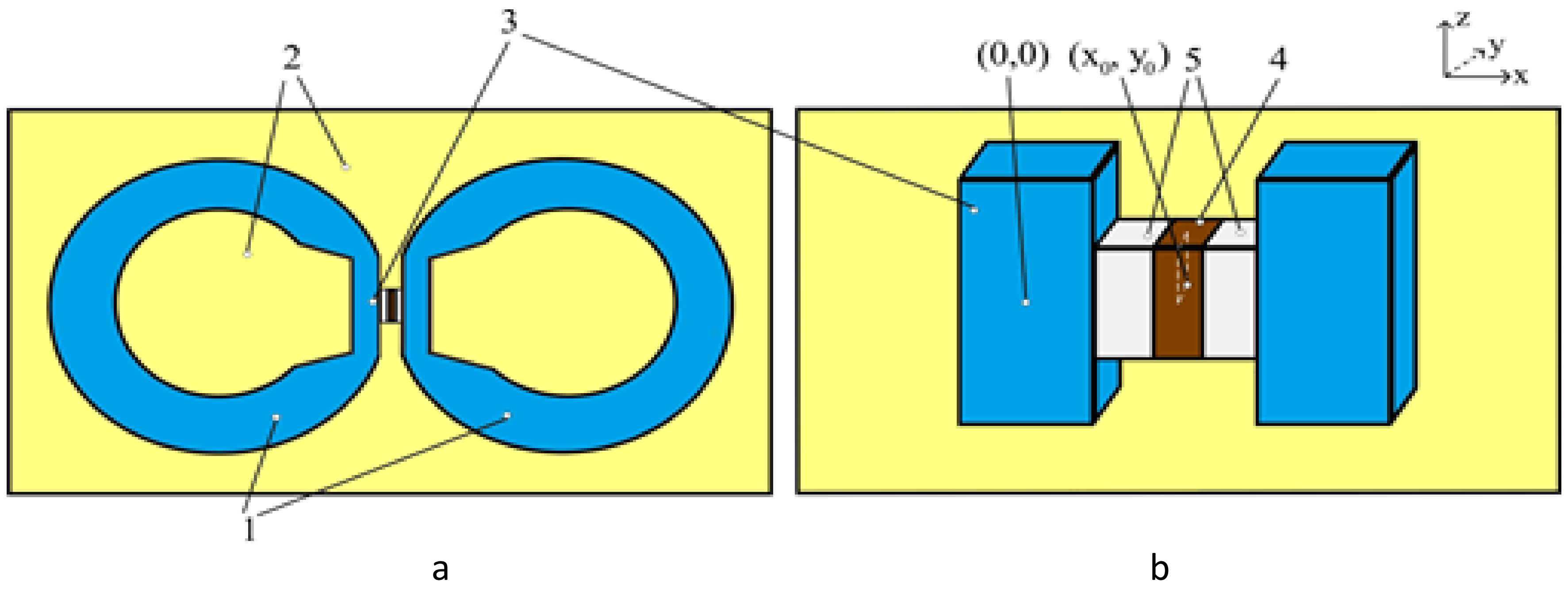

Figure 1. Schematic representation of the MFC, type “Planar”:

1– superconducting rings of the magnetic field concentrator, 2 – dielectric substrate, 3 – the active band of the concentrator on an enlarged scale (the proportions are not preserved),
4 – MSE, 5 – the gap between the boundaries of the AS and the MSE

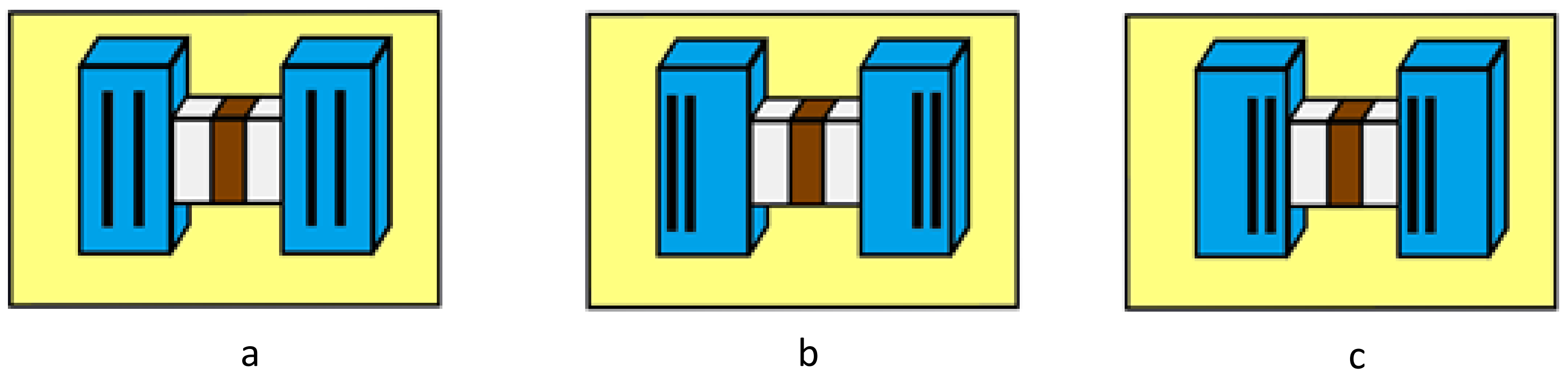

Figure 2. Active band of the concentrator with different locations of the cuts:
(a) – middle, (b) – far from the MSE, (c) — near the MSE

Results

Table 1 Calculated values of the ratios *F*/*F*0 at different locations of the cuts in accordance with **Figure 2**

w_0, nm	F/F_0		
	(a)	(b)	(c)
5000	3.92	4.89	3.28
1000	2.54	2.89	2.33
200	2.15	2.28	2.09

The following data were used in the calculations: w_0 – the distance between the nearest borders of the AS and the MS; MFC ring diameter – 2 mm; width AS – 30 000 nm; cuts width – 20 nm; thicknesses of MFC and MSE – 20 nm; width MSE – 10 000 nm; for heteroeitaxy layer niobium (HEL Nb) critical current density – $\geq 10^{10}$ A/m^2 and λ ~50 nm

From the data given in **Table 1**, it follows that nanosized cuts on the AS film increase the *F*/*F*0 ratio by 2–5 times, depending on the distance between the nearest boundaries between the AS and the MSE. However, the value of *F*/*F*0 varies slightly (≤50%) depending on the location of cuts in the AS film. Undoubtedly, the absolute values of *F* and *F*0 decrease sharply at large *w*0, so it is more advantageous to realize its minimum value, i.e. *w*0=200 nm. For this case, when the MFC is a film of high-temperature superconducting (HTSC) material with a characteristic value of λ=1000 nm, the *F*/*F*0 ratio is approximately 20% higher than for the low-temperature superconducting (LTSC) in the form of HEL Nb.

It should be noted that with an increase in the number *n* of cuts in the AS, *F* increases and the dependence *F*(*n*) reaches a plateau at certain values of *n*, for example, for the case of λ=50 nm - *n*≥80, and for λ=1000 nm - n≥30 . In this case, the absolute values of *F* ~ 100-200 are several times higher in the MFC based on the LTSC film than on the basis of the HTSC film.

Conclusions

It can be seen from **Figures 1** and **2** that the MSE is located between two rings of MFC, and all elements of the proposed MFC are located on the same plane and they do not intersect anywhere. In this case, both the MFC and the MSE can be made from the same material, in particular, from a superconducting Josephson medium. The CMFS considered here is planar and much easier to implement than the “sandwich” type CMFS proposed in other works [1-4].

Modern medicine needs non-invasive diagnostics of biological magnetic fields or registration of magnetic particles used in therastonics (ferro- or superparamagnetic particles / nanoparticles, carbon nanotubes, etc.) and control of the operation of implantable devices (artificial heart, stimulators, etc.). Apparently, along with SQUIDs, some problems in medicine can be solved using combined magnetic field sensors containing magnetic field concentrators based on film superconducting nanostructured active strips.

References

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