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Physics of Superconductors for Haloscopes: The Cases of NbTi, Nb3Sn and Fe(Se,Te)

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***Abstract*–High quality factor (*Q*) resonant cavities ("haloscopes") have been proposed [1] to detect the decay of an axion, an hypotetical constituent of cold dark matter, into a conventional photon in presence of a dc magnetic field *B* of the order of several tesla – the Primakoff effect [2], with the axion-to-photon signal power $P \propto B^2 Q$. High *Q* requires low surface resistance R_S = Re{Z_S} of the cavity walls (Z_S is the surface impedance). However, superconducting coatings in high dc magnetic fields show large high- frequency dissipation due to vortex motion. The physics involved is very different to superconducting rf accelerating cavities: defects can be exploited to improve pinning; the penetration of the microwave field is a combination of the London and vortex motion penetration depth; the overall microwave response depends on a complex combination of the operating frequency, the scattering processes in the vortex core, and the efficiency of pinning centres with respect to tiny vortex oscillations; finally, flexibility of vortices must be taken into account. Adequate knowledge of the high frequency vortex response is then needed.**

We here explore the little-known microwave physics of vortex motion in NbTi and Nb3Sn, where coating deposition is actively improving, and in Fe(Se,Te), because of its potential for electrodeposition, as possible superconductors for haloscopes. Nb3Sn samples were grown by vapor diffusion (VD) on bulk Nb at Fermilab [3], and by DC magnetron sputtering (DCMS) at INFN-LNL. NbTi films were grown at INFN-LNL by DCMS on quartz substrates [4]. Fe(Se,Te) films were grown by PLD on CaF_2 at CNR-SPIN [5].

Microwave measurements (ν = 8/16/27 GHz) of $Z_S(H,T)$ ($\mu_0 H \leqq 12$ T, 6 K $\leqq T \leqq T_c$) were taken by a dual frequency dielectric loaded resonator [6]. We extract the flux-flow resistivity ρ_{ff}, the pinning constant k_p, the depinning frequency ν_p and the creep factor χ. We find that ρ_{ff}, a manifestation of the scattering processes in the vortex cores, is reasonably well described by conventional Time-Dependent Ginzburg-landau theory in Nb compounds, whereas in Fe(Se,Te) the two-band nature dominates. In no case a simple Bardeen-Stephen behaviour is followed. Different regimes of vortex pinning are found in different compounds. VD-Nb3Sn exhibits signatures of weak collective pinning already at

a few tesla; DCMS-Nb3Sn sample shows a marked signature of Josephson coupled network of grain boundaries, acting as sites for the effective pinning observed; Fe(Se,Te) exhibits a crossover from a nearly-single-pinning regime to a collective pinning at a few tesla.

Potential performances of several superconductors as coatings for haloscopes are evaluated referring to a specific case study [7]. Using our experimental data, we calculate the figure of merit B^2Q in a wide (T, H, v) parameter space, according to [8]. We find that, although vortex pinning plays obviously a major role, the often-disregarded flexibility of vortex lines and the penetration depth strongly affect the final Q factor of the haloscopes, so that the choice of the material is not straightforward.

***Keywords (Index Terms)*–Surface Impedance, Vortex Motion, Fe-based superconductors, NbTi, Nb3Sn, Haloscopes**

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References
[1] P. Sikivie, Phys. Rev. Lett. Vol. 51, p1415 (1983)
[2] H. Primakoff, Phys. Rev. Vol. 81, p99 (1951)
[3] S. Posen et al., Supercond. Sci. Technol. Vol. 34, p025007 (2021)
[4] G. Ghigo et al., Sci. Rep. Vol. 13, p9315 (2023)
[5] A. Palenzona et al., Supercond. Sci. Technol. Vol. 25, p115018 (2012)
[6] A. Alimenti et al., Meas. Sci. Technol. Vol. 30, p065601 (2019)
[7] D. Alesini et al., Phys. Rev. D Vol. 99, p101101(R), 2019
[8] A. Alimenti et al., Instruments Vol. 6, p1 (2022)

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