Features of determining the superconducting properties of single-crystal FeSe using EPR-spectrometer

S. I. Bondarenko[1], A. A. Prokhorov[2], N. N. Galtsov[1], V. P. Timofeev[1], V. P. Koverya[1], A. V. Krevsun[1]

[1]*B. Verkin Institute for Low Temperature Physics and Engineering of NAS of Ukraine, 47 Nauky Ave., Kharkiv, 61103, Ukraine*

[2]*Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*

koverya@ilt.kharkov.ua

Iron-based superconductors (IBSCs) are "unconventional" and promising high-temperature superconductors (HTSCs). Their critical temperatures (T_c) at normal pressure approach the boiling point of liquid nitrogen, which will stimulate the development and widespread use of IBSC devices. FeSe and FeTeSe compounds have been actively studied since 2008, however, many details regarding the mechanism of superconductivity development and its dynamics remain unclear. Non-contact magnetometric studies of single-crystal FeTeSe, including those using EPR spectroscopy, have demonstrated the potential of doping with hydrogen from the gas phase to increase the critical current density (J_c) in it by more than an order of magnitude [1]. We continued this study in the related compound FeSe, which has the simplest quasi-two-dimensional crystalline structure among IBSCs. Using a Bruker E580 EPR- spectrometer, we studied the dependences of the spectrometer signal (**Fig. 1**) in undoped FeSe ($T_c \approx 8$K) on temperature ($3.5 < T < 25$ K) in steady magnetic fields (in the range of 0–6000 Oe). The most interesting picture was observed for the non-resonant spectrometer signals in low magnetic fields (LFMA) ($0 < H < 30$ Oe) and at temperatures in the region of the superconducting phase transition (**Figs.2,3**). The observed pattern of non-resonant LFMA signals is caused by the application of a weak constant magnetic field and the influence of a microwave (MW) field. The dependences in **Figure 3** allow us to determine the width of the superconducting transition ($\delta T \approx 3$K) and the first critical magnetic field of FeSe at the transition ($H_P \approx 12$ Oe). The relationship between H_p and the first critical field H_{c1} of a sample with form factor N=0 is given by the formula $H_p \approx H_{c1}(d/w)^{0.5}$, where d and w are the thickness (0.4 mm) and width (2 mm), respectively, of the sample. For our sample $H_{c1} \approx 27$ Oe. In this magnetic field, the spectrometer signal changes from negative to positive, indicating the formation of Abrikosov vortices in the crystal and the absorption of MW radiation within it.

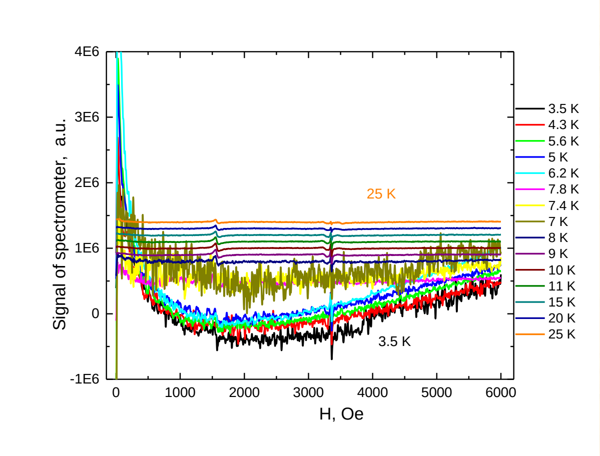

Fig.1 Field dependences of the EPR signal from a FeSe single crystal (in arbitrary units) on the magnitude of the magnetic field *H* at various temperatures. For ease of analysis, the experimental curves displaying the obtained characteristics are shifted along the vertical axis by equal intervals relative to the dependence at T = 3.5 K.

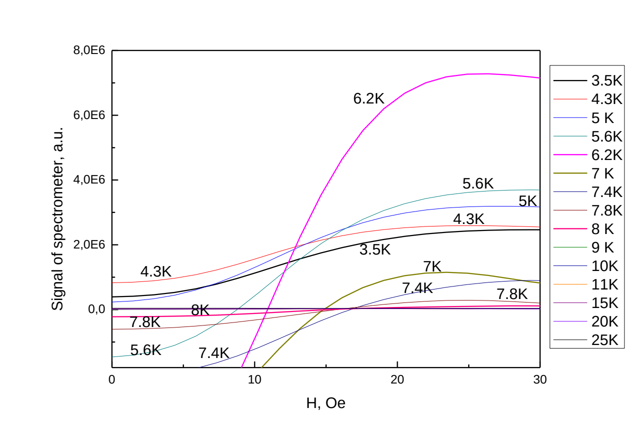

Fig. 2 Dependences of the non-resonant EPR signal of the crystal on the magnetic field, starting from its absence, up to 30 Oe at different temperatures (indicated next to each curve additionally for ease of reading).

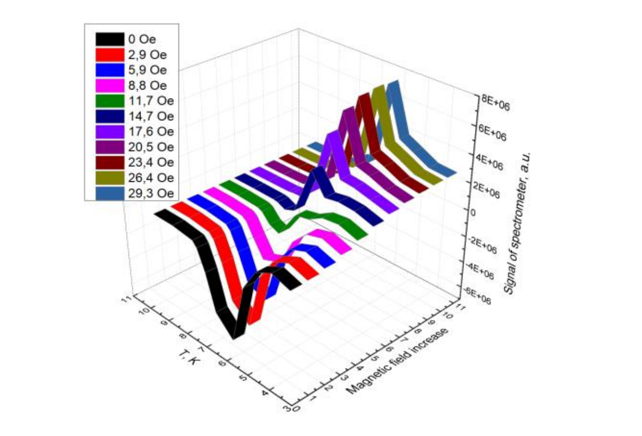

Fig. 3 Temperature dependences of the spectrometer output signal in magnetic fields of 0 – 29.3 Oe. These dependencies are obtained on the basis of Fig. 2.

Conclusions. Non-resonant EPR signals in FeSe single crystal vary versus magnetic field and temperature in the range H = 0 - 6000 Oe and T = 3.5 - 25 K, while EPR resonances exist only at H = 1400 Oe and 3400 Oe. Temperature dependences of non-resonant EPR signals from FeSe single crystal at temperatures of 3.5 - 8 K in zero and weak magnetic fields allow contactless determination of the temperature and magnetic parameters of its superconducting transition, in particular, the magnitude of the first critical magnetic field (H_{c1}) at the transition. The emergence of a mixed superconducting state in a FeSe single crystal in magnetic field H=12 Oe is accompanied by a previously unknown sharp change in the phase of the non-resonant EPR signal by 180 degrees. The nonlinear magnetic dependence of the non-resonant EPR signal of the superconducting FeSe single crystal at temperatures from 3.5 K to 8 K in a magnetic field from H_{c1} to 6000 Oe can be explained by the existence of a mixed state of the crystal as a type II superconductor. The resonance EPR signals made it possible to establish the values of the g-factors of the FeSe single crystal (4.8 and 2), at which its iron ions have a charge of +2 (Fe^{+2}).

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[1] S.I. Bondarenko, A.I. Prokhvatilov, R. Puzniak, J. Pietosa, A.A. Prokhorov, V.V. Meleshko, V.P. Timofeev, V.P. Koverya, D.J. Gawryluk, A. Wisniewski, Materials 14, 7900 (2021). https://doi.org/10.3390/ma14247900.