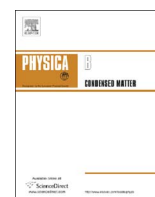




Contents lists available at ScienceDirect

Physica B

journal homepage: www.elsevier.com/locate/physb

Specific heat of FeSe: Two gaps with different anisotropy in superconducting state

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ARTICLE INFO

Keywords:

Superconductors
Fe-based superconductors
FeSe
Two-gap superconductivity
Specific heat

ABSTRACT

We present detailed study of specific heat of FeSe single crystals with critical temperature $T_c = 8.45$ K at 0.4 – 200 K in magnetic fields 0 – 9 T. Analysis of the electronic specific heat at low temperatures shows the coexistence of isotropic *s*-wave gap and strongly anisotropic extended *s*-wave gap without nodes. It was found two possibilities of superconducting gap parameters which give equally description of experimental data: (i) two gaps with approximately equal amplitudes and weight contribution to specific heat: isotropic $\Delta_1 = 1.7$ meV ($2\Delta_1/k_B T_c = 4.7$) and anisotropic gap with the amplitude $\Delta_2^{max} = 1.8$ meV ($2\Delta_2^{max}/k_B T_c = 4.9$ and anisotropy parameter $m = 0.85$); (ii) two gaps with substantially different values: isotropic large gap $\Delta_1 = 1.65$ meV ($2\Delta_1/k_B T_c = 4.52$) and anisotropic small gap $\Delta_2^{max} = 0.75$ meV ($2\Delta_2^{max}/k_B T_c = 2$) with anisotropy parameter $m = 0.71$. These results are confirmed by the field behavior of the residual electronic specific heat γ_r .

1. Introduction

Iron selenide FeSe has the simplest crystal structure among Fe-based superconductors (FeBSC). Its critical temperature $T_c = 8 - 9$ K is rather low [1] but may be increased up to 15 K by Te partial substitution [2,3] or up to 37 K by applied pressure [4] and reaches 100 K in FeSe monolayer on SrTiO₃ substrate [5]. FeSe shows many characteristic properties of FeBSC family and its simple structure may give the key to understanding of the pairing mechanism in these compounds. FeSe has layered structure of weakly coupled FeSe layers, band calculations [6] and ARPES measurements [7] show several bands crossing Fermi level and form cylinder-like Fermi surface, electronic around the M point and hole around the Γ point, that may lead to forming of multiple superconducting condensates. FeSe undergoes a phase transition from tetragonal to orthorhombic phase at $T_s \approx 90$ K [8] with nematic electronic phase.

The main and most discussed issue regarding the FeBSC is the structure of their order parameter in superconducting state. Despite the significant number of theoretical and experimental studies, this

question is still unresolved [9]. Several theoretical models have been developed for FeBSC, such as s^\pm and s^{++} [10–12], but none have been confirmed yet.

To the present time, a large number of experimental studies of the order parameter in FeSe are available, but the data are rather contradictory. Most authors reported the coexistence of two gaps, but their magnitude, symmetry and the existence of nodes remain questionable. In particular, the Andreev spectroscopy [13–15] and the magnetic penetration depth data [16–18] confirm the presence of two isotropic gaps. Thermal conductivity data confirms the absence of nodes [19,20]. The results of specific heat (SH) studies show the coexistence of an isotropic and strongly anisotropic gap [21,22], or even *d*-wave with nodes [23]. Noteworthy, the results of these papers differ greatly in gap magnitudes. Scanning tunneling spectroscopy (STS) detects both the presence of nodes [24,25] as well as their absence [22] and even a full gap on the twin boundaries [26].

Here we report the results of the specific heat measurements on FeSe single crystals in order to determine the number, magnitude, and symmetry of superconducting gaps in a given compound.

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<http://dx.doi.org/10.1016/j.physb.2017.10.041>

Received 30 June 2017; Accepted 9 October 2017

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