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Magnetic Field Dependence of Heat Capacity in Single Crystal $BaKFe_2As_2$ Superconductor

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Abstract. The observed heat capacity by external magnetic field for $BaKFe_2As_2$ single crystal is examined through the modified Phenomenological Ginzburg Landau (GL) theory of anisotropic type-II superconductor. In view of this, it has been observed the anisotropy existing with the existence of energy gaps in this particular system and the gaps lying along two perpendicular directions i.e. parallel to *ab*-plane and *c*-axis. Taking the expression of change in specific heat from GL-theory in modified form, we have explained successfully the existence of two bands in type-II superconductors. In doing so a quantitative analysis has been made by calculating and comparing the value of anisotropic ratio in terms of penetration depths.

Keywords: Iron pnictide superconductor, Thermodynamic properties, phase diagram

PACS: 74.25.Dw, 74.25.Bt, 74.70.Dd

1. Introduction

Due to different characteristic features like high quality single crystal, availability of the multiple substitution sites and simplicity of crystal structure, Fe-based superconductors and related other iron pnictide superconductors have elicited many experimental as well as theoretical scientists for the further intensive research in these materials. If one review the physics behind the cuprates and Fe-based compounds can find uniformity like both have layered structures and also are strongly correlated electronic system. Further, the newly discovered iron oxy pnictide superconductors have offered the supplementary compositional variation compared to the cuprate superconductors. Besides this, in a similar way FeAs layers play the same role in iron pnictides as CuO_2 plays in cuprate superconductors. Here in this present paper we have tried to explain the anomaly in specific heat as penetration depth with some simple modification of Ginzburg-Landau (GL) theory of single band model which to be applicable to two band model of type-II superconductors. Here particularly, for $BaKFe_2As_2$ superconductor considering two energy gaps and two critical temperatures the theoretical analysis has been made by calculating the anisotropic ratio (γ) in terms of penetration depths. However for page limitation we have presented only the anisotropic of penetration depth.

2. Phenomenological GL-theory

High temperature superconductors (HTSCs) are exceptionally type-II superconductors with GL parameter of the order of 10^2. Considering the Phenomenological mass tensor in to account, the anisotropic properties of HTSCs has been tried to observe with the correlation between anisotropic London equation as well as GL equation. It is worth to mention here that GL equation can be approximately used to observe the vortex state for low applied magnetic fields in the London limit and temperature close to superconducting transition temperature, T_c. Using anisotropic formulation, the change in specific heat has been derived earlier [1-3] and found to be successful in different single band superconducting systems. Again for two band system we have modified the change in specific heat earlier [4] and is given by

$$\langle \Delta C \rangle = \left[B_a T / (T_c)^2 \right] \left[\alpha \; \Theta(\gamma) / \lambda_m^2(0) \right] \qquad (1)$$

For two energy gaps existing in the system one has to split the equation considering two critical temperatures T_{c1} and T_{c2} as energy gap is directly proportional to the critical temperature and the segregated equations becomes

$$\langle \Delta C \rangle = \left[B_a T / (T_{c1})^2 \right] \left[\alpha \; \Theta(\gamma) / \lambda_{m1}^2(0) \right] \qquad (2)$$

$$\langle \Delta C \rangle = \left[B_a T / (T_{c2})^2 \right] \left[\alpha \; \Theta(\gamma) / \lambda_{m2}^2(0) \right] \qquad (3)$$

λ_{m1} and λ_{m2} corresponds to two critical temperatures having two energy gaps appearing at 6 and 12 meV respectively. Besides the above, other notations have usual meaning as presented in our earlier paper [4]. Further, anisotropic ratio of penetration depths for two critical temperatures can be obtained individually and total anisotropic ratio can be calculated as the sum of anisotropic ratios for larger and smaller energy gaps existing in the system.

3. Results and discussions

It has been reported earlier by Welp et.al. [5] about the behaviour of specific heat and upper critical field in a single crystal of $BaKFe_2As_2$ with a transition temperature of 34.6 K. ARPES studied in the same crystal reported the existence of isotropic gaps of Δ_1 of 12 meV and Δ_2 of 6 meV respectively. This gives T_{c1} and T_{c2} as 34.6 K and 17.3 K respectively. GL equation in the form of equation (1) is used for interpreting observations of ΔC vs. T for different applied fields. Here ΔC is linear with $\left[B_a T\alpha\ \Theta(\gamma)\right]/T_c^{\,2}\lambda_m^2(0)$. The liner regression has been made for applied fields in both orientations having field strength of 2, 4, 6 and 8T respectively. The square root of inverse of each slope of the linear regression for a given applied magnetic field gives value of mean penetration depth. Ultimately, for field parallel to *ab*-plane or field parallel to *c*-axis we got the value of penetration depths as λ_c and λ_{ab} respectively. The similar process has been carried out for both the critical temperatures. A sample curve of linear regression of change in specific heat with temperature is shown in figure 1. The variation of penetration depths ($\lambda_{c1},\lambda_{ab1}$ & $\lambda_{c2},\lambda_{ab2}$) with different values of applied field and their orientations has been shown in figures 2 and 3 respectively. It has been seen that variation of both penetration depths with applied field increases slowly for small fields. The anisotropic ratio $\gamma\left(=\lambda_c/\lambda_{ab}\right)$ has been calculated for each transition temperature and total anisotropic ratio calculated. Here we found it to be 2.38 as comparison to the experimental result of 2.6 in this particular system.

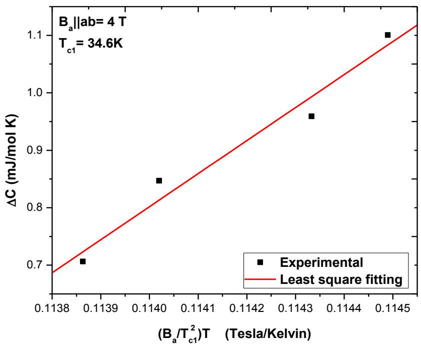

Fig. 1. Sample curve of regression for T_{c1} at applied field parallel to *ab*-plane.

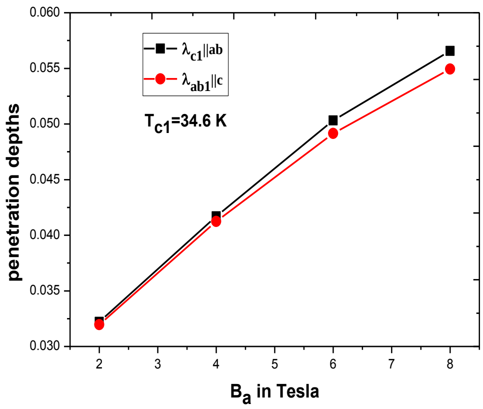

Fig. 2. Variation of penetration depths with applied magnetic field at T_{c1} in both orientations

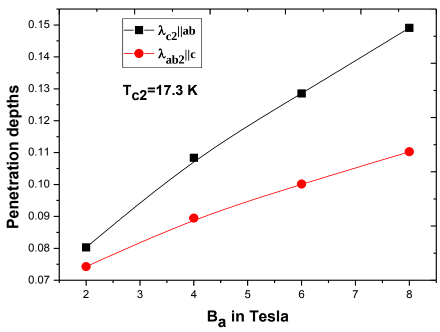

Fig 3. Variation of penetration depths with applied magnetic field at T_{c2} in both orientations

4. Conclusion

In this work we have tried to explain the experimental observation related to change in specific heat by using Phenomenological GL theory and observed quantitatively the variation of anisotropic ratio.

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