Multiband Effects on β-FeSe single crystals

Hechang Lei, Rongwei Hu, Hyejin Ryu, C. Petrovic (BNL CMPMSD); E. S. Choi, D. Graf, S. W. Tozer (NHMFL Tallahassee)

Introduction

The upper critical field ($\mu_0 Hc_2$) gives important insight into pair breaking mechanism in superconductors, coherence lengths, anisotropy and dimensionality. A complex binary alloy phase diagram and difficulties in single crystal preparation impeded the growth of pure β-FeSe single crystals [1]. Here, we report on the $\mu_0 Hc_2$ of pure β-FeSe single crystals at ambient and high pressures [2].

Experimental

Single crystals of β-FeSe were grown using a LiCl/CsCl flux [1]. The $\mu_0 H_{c2}$ is determined by measuring the radio-frequency (rf) contactless penetration depth up to 35 T at the NHMFL Tallahassee. Pressure measurements were performed in a diamond anvil cell. The pressure was calibrated at 4 K by comparing the fluorescence of a small chip of ruby within the DAC with an ambient ruby at the same temperature.

Results and Discussion

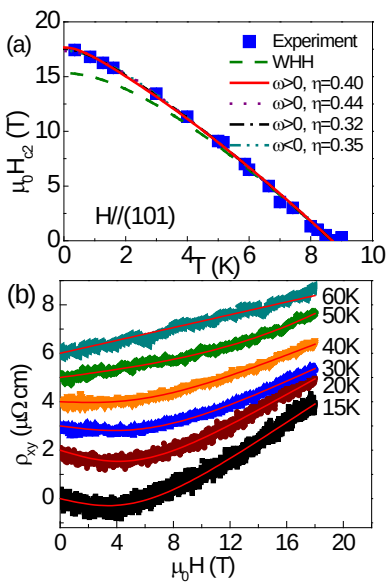

Figure 1: (a) Fits of $\mu_0 Hc_2$ for H↑↑(101) using Eq. (1). (b) Hall constant and fits using Eq. (2)

In the dirty limit with orbital pair breaking and negligible interband scattering:

$$a_0[\ln(t) + U(h)]\,[\ln(t) + U(\eta h)] + a_1[\ln(t) + U(h)] = 0 \qquad (1)$$

where $t = T/T_c$, $U(x) = \psi(1/2+x) - \psi(x)$, $\psi(x)$ is the digamma function, $\eta = D_2/D_1$, D_i (i = 1,2) are intraband diffusivities, $h = H_{c2}D_1/(2\Phi_0 T)$ where Φ_0 is the magnetic flux quantum. Constants a_0 and a_1 describe intraband and interband coupling strengths, $a_0 = 2\tilde{\omega}/\lambda_0$, $a_1 = 1+\lambda_-/\lambda_0$, where $\tilde{\omega} = \lambda_{11}\lambda_{22} - \lambda_{12}\lambda_{21}$, $\lambda_0 = (\lambda_-^2 + 4\lambda_{12}\lambda_{21})^{1/2}$ and $\lambda_- = \lambda_{11}-\lambda_{22}$; λ_{11} and λ_{22} are the intraband and λ_{12} and λ_{21} are the interband couplings. If $\eta = 1$, this reduces to Werthamer-Helfand-Hohenberg (WHH) model for dirty single band superconductors. By using the coupling constants from μSR experiment with very small interband coupling, the data can be well explained. The ratio of band diffusivities η = 0.4 is similar to 122 FeAs superconductors. The fits are insensitive to changes in coupling constants. Hence, either λ_{ii} and λ_{ij} are comparable or their difference is below the resolution of experiment.

Hall coefficient (**Figure 1(b)**) can be well described by two band model:

$$\frac{\rho_{xy}}{\mu_0 H} = R_H = \frac{1}{e}\frac{(\mu_h^2 n_h - \mu_e^2 n_e) + (\mu_h\mu_e)^2(\mu_0 H)^2(n_h - n_e)}{(\mu_e n_h + \mu_h n_e)^2 + (\mu_h\mu_e)^2(\mu_0 H)^2(n_h - n_e)^2} \qquad (2)$$

where μ_i and n_i (i = e,h) describe electron and hole-type carriers. Deviation from linearity is observed below 50 K. This is a signature of multiband transport, i.e. the presence of both electron and hole type carriers. The change of sign at 15 K indicates $\mu_h^2 n_h - \mu_e^2 n_e < 0$. Since $n_h - n_e > 0$ at higher field, this suggests that $\mu_e > \mu_h$ at low T. Under pressure both $\mu_0 H_{c2}(T)$ and its anisotropy are enhanced.

Conclusions

Two-band effects dominate the $\mu_0 H_{c2}(T)$, with influence of a spin paramagnetism. A nonlinear $\rho_{xy}(H)$ confirms this. Hole-type carriers dominate in high fields but electron-type carriers are important in low fields due to either increased carrier density or enhanced mobility.

Acknowledgements

Work at BNL is supported by the U.S. DOE by DE-AC02-98CH10886, (R.H. and H.R.) and in part by the Center for Emergent Superconductivity, an Energy Frontier Research Center (H.L. and C.P.). Work at the NHMFL is supported by the DOE NNSA DEFG52-10NA29659 (S.W.T. and D.G.), the NSF DMR-0654118, and FL state.

References

[1] Rongwei Hu *et al.*, Phys. Rev. B 83, 224502 (2011).

[2] Hechang Lei, *et al*., Phys. Rev. B 85,094515 (2012).