Theory of Mixed State in Dirty Two-Band Superconductor

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We investigate two-band properties of the vortex state in magnesium diboride (MgB_2) within a microscopic model: a two-band superconductor with strong intraband and weak interband scattering. For field along c-direction we compute the pair potentials and local densities of states for two bands for an isolated vortex and find their field evolution. The existence of two distinct length and field scales corresponding to different bands is demonstrated. We calculate the upper critical field for different field orientation. Due to a large difference between the c-axis coherence lengths in two bands, the GL theory does not describe properties of this superconductors: the H_{c2} anisotropy has strong temperature dependence and the angular dependence of H_{c2} strongly deviates from a simple effective-mass law.

Two-band superconductivity in **MgB_2**:
- quasi-2D strongly superconducting σ-bands, $\Delta_\sigma \approx 7$ meV
- 3D π-bands with induced superconductivity, $\Delta_\pi \approx 2.2$ meV

Two-band features in the properties of mixed state ?

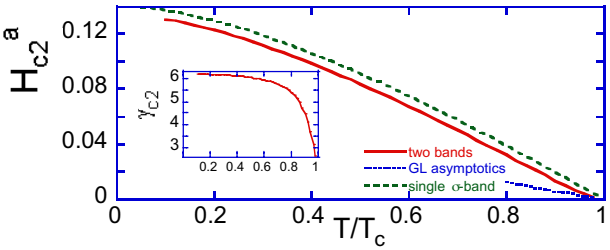
Model: Two-band Usadel equations

$$\omega_s F_\alpha - \sum_j \frac{D_{\alpha,j}}{2}\left[G_\alpha\left(\nabla_j - \frac{2\pi i}{\Phi_0}A_j\right)^2 F_\alpha - F_\alpha \nabla_j^2 G_\alpha\right] = \Delta_\alpha G_\alpha$$

$$\Delta_\alpha = 2\pi T \sum_{\beta,s} \Lambda_{\alpha\beta} F_\beta$$

G_α, F_α Green's functions
$\alpha = (1,2) = (\sigma,\pi)$ band index
Δ_α pair potentials
$\Lambda_{\alpha\beta}$ coupling constants
$D_{\alpha,j}$ diffusion constants
$\omega_s = 2\pi T(s+1/2)$

Upper critical field

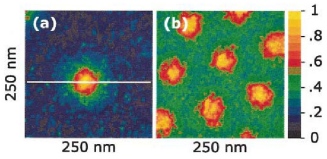


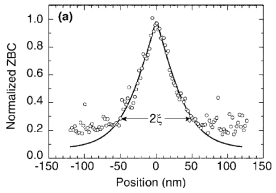
Temperature dependence of the upper critical field in the a-direction (red solid), single-band curve (green dashed), and GL asymptotics (blue dotted). Inset: temperature dependence of the anisotropy parameter.

Features:
1. Almost at all temperatures both $H_{c2,c}$ and $H_{c2,a}$ are mainly determined by the strong σ-band
2. π-band strongly suppresses $H_{c2,a}$ only in *very narrow GL region* in the vicinity of T_c leading to temperature-dependent anisotropy.

Structure of vortex state for H along c

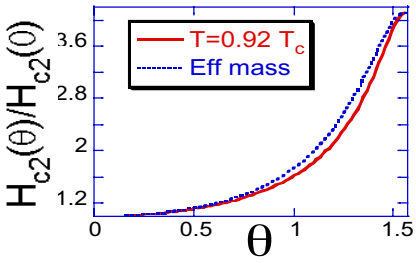
STM imaging of vortices in MgB_2 (Eskildsen et al. Phys. Rev. Lett. **89**, 187003 (2002)) [tunneling to π-band]





Large vortices: $\xi_v \gg \xi_{c2}$

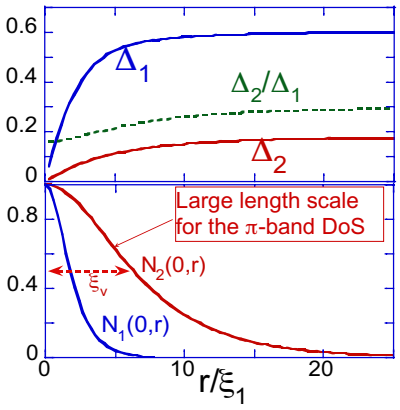
Angular dependence



Effective-mass (AGL) angular dependence $H_{c2}(\theta)$

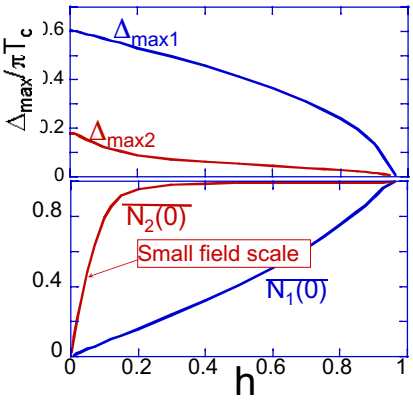
$$(H_{c2}\cos\theta / H_{c2,c})^2 + (H_{c2}\sin\theta / H_{c2,a})^2 = 1$$

Theory: Isolated Vortex



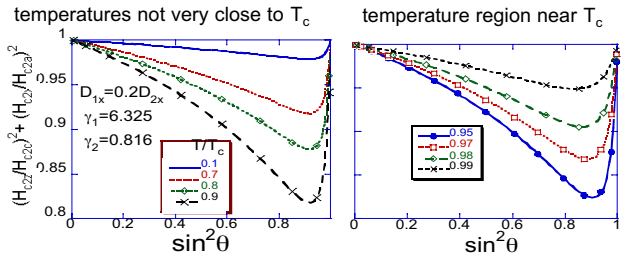
Spatial dependencies of pair potentials, $\Delta_\alpha(r)$, and partial DoS at E=0, $N_\alpha(0,r)$, for $D_1 = 0.2D_2$. Partial DoS in π-band, probed by STM, has large length scale.

Field dependencies



Field dependencies of pair potentials and averaged DoS at E=0. π-band DoS reaches the normal value at small field scale

Deviations from the AGL angular dependence



See Poster for comparison with experiment !!!

A. E. Koshelev and A. A. Golubov, Phys. Rev. Lett. 90, 177002 (2003); Phys. Rev. B 68, 1045XX (2003)

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