Two-band Superconductivity in MgB_2

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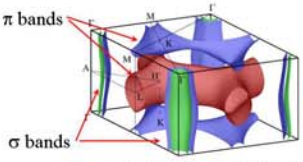
- Explore nature of two-band superconductivity theoretically and experimentally.
- Develop a simple microscopic model of magnesium diboride (MgB_2): *two-band superconductor with strong intraband and weak interband scattering*.
- Describe the vortex state: multiple length and field scales in local densities-of-states (DoS)
- Identify the role of *interband* and *intraband* scattering in a two-band superconductor.
- Breakdown of Ginzburg-Landau theory
  - Temperature dependence of the upper-critical-field anisotropy
  - Anomalous angular dependence of the upper-critical-field



Liu *et al. PRL.* **87**, 087005 (2001)

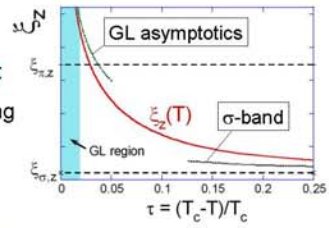
Theoretical Model: Two-band Usadel equations

Input: coupling constants $\Lambda_{\alpha\beta}$, diffusion constants $D_{\alpha,j}$, $\alpha=(1,2)=(\sigma,\pi)$

Output: pair potentials $\Delta_\alpha(r)$; partial local DoS $N_\alpha(E,r)$, upper critical field $H_{c2}(\Theta,T)$ …

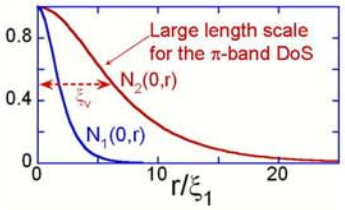
- **Reduced applicability of GL theory**:

π-band induces strong nonlocality along c-direction



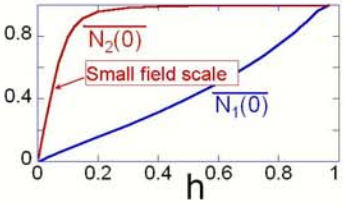
Theory: Density of States in Magnetic Field

Theory: Local DoS of vortex



Spatial dependencies of partial DoS at E=0, $N_\alpha(0,r)$, for $D_1 = 0.2D_2$.

Field dependence of DoS



Field dependencies of space-averaged DoS at E=0.

STM imaging of vortices: tunneling into π-band

Eskildsen et al. Phys. Rev. Lett. **89**, 187003 (2002): Large vortices: $\xi_v \gg \xi_{c2}$

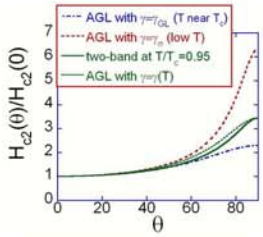
Two-band Effects in the Phase Diagram of MgB_2:

- Temperature-dependent anisotropy
- deviation from Ginzburg-Landau angular dependence
- experimental determination of microscopic parameters

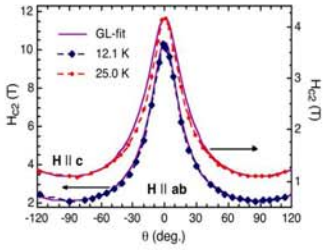
Anisotropic Ginzburg-Landau (AGL) angular dependence $H_{c2}^{AGL}(\theta)$

$$H_{c2}^{\mathrm{AGL}}(\theta) = \left[\left(\frac{\cos\theta}{H_{c2}^{c}}\right)^2 + \left(\frac{\sin\theta}{H_{c2}^{a}}\right)^2\right]^{-1/2}$$

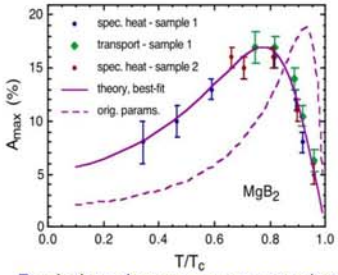
Theory



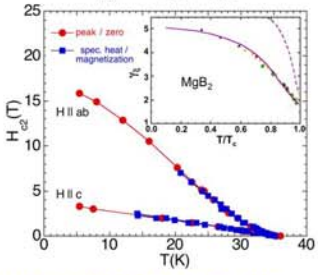
Experiment (Specific heat)



Deviations from AGL angular dependence
$A_{max} = \max\{1 - [H_{c2}(\theta)/H_{c2}^{GL}(\theta)]^2\}$



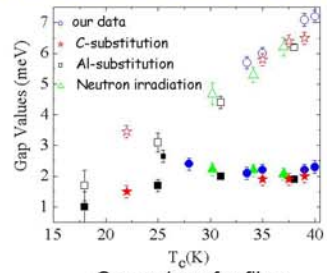
Strong temperature-dependent H_{c2}-anisotropy
$\gamma_\xi = H_{c2}^{ab}/H_{c2}^{c}$



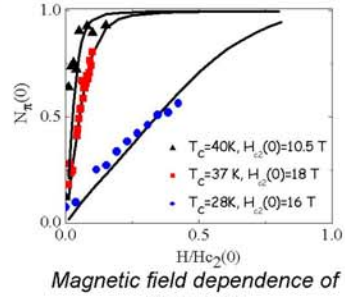
Deviations have non-monotonic temperature dependence and are largest near T_c

Scanning Tunneling Spectroscopy of MgB_2:

- Gap values measured with the STM scale with T_c independent on the origin of disorder
- The magnetic field scale for the filling of the π-gap is set by the ratio of the diffusivities in the two bands



Gap values for films with different T_c



Magnetic field dependence of the π-gap

Future:

- **Neutron irradiation of off-axis thin films of MgB_2**
- **Magnetic doped MgB_2**
- **Quantitative theory for doped MgB_2**
  - Recent controlled doping with C and Al allowed to fabricate samples with extremely high H_{c2}'s with only moderate suppression of T_c
  - Theory will correlate evolutions of T_c, gaps, and H_{c2}'s
- **Structure of tilted vortex**
- **Thermodynamics in tilted field**
- **Fluctuation properties** (in collaboration with A. Varlamov, Coherentia-Univ. of Torvergata, Rome)

A. Rydh et al., Phys. Rev. B 70, 132503 (2004); M. Iavarone et al., Phys. Rev. B 71, 214502 (2005); A. Koshelev et al. Phys. Rev. Lett. 92, 107008 (2004)

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