Inhomogeneous noncentrosymmetric superconductors in magnetic fields

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Non-centrosymmetric superconductor (NCS)

Heavy-fermion superconductor CePt\textsubscript{3}Si

LaAlO\textsubscript{3} - SrTiO\textsubscript{3} Interface superconductor

Spatially inhomogeneous RSOC

Magneto-electric effect

Length scales

Field-induced Helical SC state

E. Bauer, Phys. Rev. Lett. 92, 257003 (98)

3D system

2D system

N. Roykin et al., Science 316, 1389 (07)

A. D. Caviglia et al., PRL 104, 206805 (05)

Lack of an inversion center

Anisotropic potential gradient: $E = \nabla V \propto r$  \hspace{1cm} $\cdots$ Rashba spin-orbit coupling (RSOC): $\sigma \propto (k \times E)$ \hspace{1cm} $\Rightarrow \theta \sigma \propto (k \times r)$

Coupling constant $\alpha = \frac{\hbar}{m_e} p y$

NCS in a magnetic field

Field-induced Helical SC state

H=0

H=0

Zeeman effect

$\Rightarrow$ Fermi surface shift

$\Rightarrow$ SC state with a modulation $\Delta H$

$\Delta = \exp(-q H)$

$\Rightarrow$ Helical SC state

$\cdots$ Helical SC state

Magnetic field $\times$ phase modulation (Helical state)

$\cdots$ magneto-electric effect

Spatially inhomogeneous NCS in a magnetic field

Spatially inhomogeneous RSOC

- Electric field applied to 2D SC film
- Crystalline defect  $\cdots$ Twin boundary

Spatial variation of RSOC constant $\alpha$

Internal field at inhomogeneity of RSOC

Two domains with opposite noncentrosymmetricities

Side-by-side

Top-bottom

Internal field parallel to H

Intensity boundary (H)

Internal field antiparallel to H

Enhancement of H\textsubscript{c1}(T)

Suppression of H\textsubscript{c2}(T)

Theoretical framework

Ginzburg Landau free energy

$\Pi = \frac{1}{2} \int d\tau [\Delta(0)^2 + \frac{1}{2} \Delta(0) \tilde{\Delta}(0) + K_1(\tilde{\Delta}(0)) + K_2(\tilde{\Delta}(0))] + \frac{\rho_0}{2} \int d\tau [\nabla \times A(\tau)]^2$

Magnetic electric effect due to RSOC

$\nabla \times A(\tau) = \frac{\rho_0}{2} \int d\tau [\nabla \times A(\tau)]^2$

Paramagnetic pair-breaking effect due to Zeeman field

$\rho_0 \Delta(0) = \frac{\rho_0}{2} \int d\tau [\nabla \times A(\tau)]^2$

RSOC

$\rho_0 \Delta(0) = \frac{\rho_0}{2} \int d\tau [\nabla \times A(\tau)]^2$

Model for twin boundary system

$K_{\text{norm}} \rightarrow K_{\text{norm}}(z) = K_{\text{norm}}(a z)$

Length scales

$\rho_0 \Delta(0) = \frac{\rho_0}{2} \int d\tau [\nabla \times A(\tau)]^2$

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Variational approximation

Twin boundary effect  \hspace{1cm} connection to harmonic potential introduced by $A$

$\Pi_{\text{val}} = \int d\tau \left[ \frac{\rho_0}{2} \int d\tau [\nabla \times A(\tau)]^2 + K_1(\tilde{\Delta}(0)) + K_2(\tilde{\Delta}(0)) \right]$

GL quadratic term

$\Pi_{\text{val}} = \int d\tau \left[ \frac{\rho_0}{2} \int d\tau [\nabla \times A(\tau)]^2 + K_1(\tilde{\Delta}(0)) + K_2(\tilde{\Delta}(0)) \right]$

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Boundary condition

$\Delta(\tau) = \left\{ \begin{array}{ll} \Delta_{\text{norm}} & (r \rightarrow \infty) \\ 0 & (r \rightarrow 0) \end{array} \right.$

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GL equations

$\mathcal{F}_{\text{val}} \partial_{\text{t}} \Delta(\tau) = \int d\tau \left[ \frac{\rho_0}{2} \int d\tau [\nabla \times A(\tau)]^2 + K_1(\tilde{\Delta}(0)) + K_2(\tilde{\Delta}(0)) \right]$