PC3-1-INV

Strong pinning theory: a review

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For more than two decades the description of vortex pinning was dominated by the qualitative theory of weak collective pinning, where the cumulative (statistical) action of many weak defects prevent vortex motion. Proposed already in the late sixties, the theory of strong vortex pinning [1,2] takes the opposite approach: few strong defects plastically deform the flux-lines and individually pin the vortex lattice. A complete framework has been developed over the last years to quantitatively predict macroscopic observables within the strong pinning regime, among which the critical current [3], the excess-current characteristic at zero temperature [4], the Campbell response to ac perturbations [5], and vortex creep [6]. I will revisit these analytic developments, explore with the help of analytic and numerical tools the regimes of higher defect densities [7], and bring the results in contact with recent experiments.

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Keywords: strong pinning, theory, vortex matter

PC3-2-INV

Fulde-Ferrell-Larkin-Ovchinnikov Phases in Layered Organic Superconductors

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In conventional superconductors, the superconducting order parameter is spatially homogeneous. However, when the superconductivity is in the clean limit and the orbital effect is strongly quenched, so-called Fulde and Ferrell, and Larkin and Ovchinnikov (FFLO) phase with an inhomogeneous order parameter can be stabilized in fields above the Pauli limit H_{Pauli}. Highly two-dimensional layered organic superconductors are best candidates for the FFLO phase studies. In the FFLO phase, the order parameter is given by $\Delta(\mathrm{r}) = \Delta_0\cos(\boldsymbol{qr})$, where $\boldsymbol{q}$ is the center-of-mass momentum of the Cooper pairs. When a magnetic field is applied parallel to the layers, flux lines penetrate the insulating layers, forming Josephson vortices (JVs). The JVs are easily driven by a perpendicular current, leading to nonzero interlayer resistance in the SC phase.
When the wavelength of the FFLO order parameter oscillation $\lambda_{\mathrm{FFLO}} = 2\pi/q$ becomes commensurate with the JV lattice constant l, the JVs are collectively pinned and dips periodically appear in the field dependence of the interlayer resistance. This commensurability (CM) effect is a powerful tool to estimate the order parameter oscillation in the FFLO phase. So far, we have found the CM effects in the FFLO phases for three different layered organic superconductors [Fig. 1] [1,2]. For these superconductors, the FFLO phases appear above ~ H_{Pauli} at low temperatures. On reasonable assumptions, we can estimate λ_{FFLO}, which decreases as the field approaches H_{c2}.

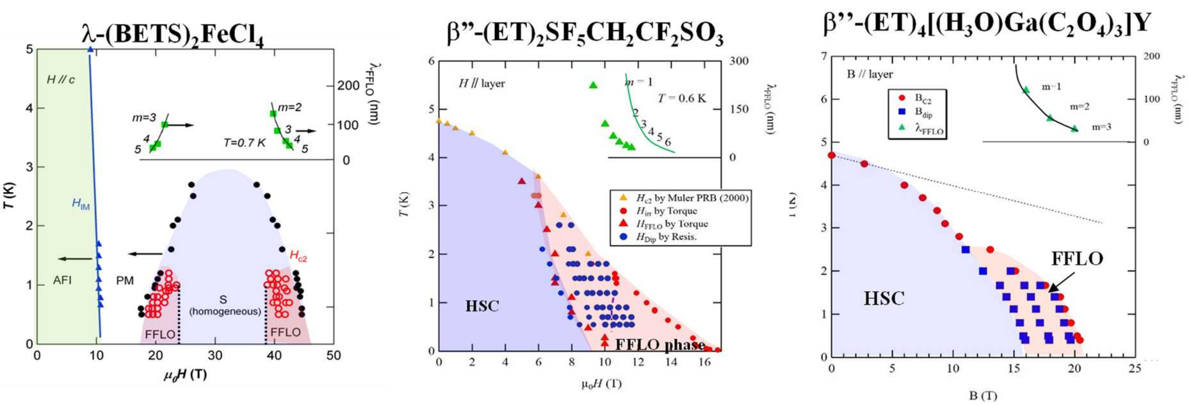

Figure 1: Superconducting phase diagrams for three different organic layered superconductors. Red regions show FFLO phases.

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Keywords: Organic superconductor, FFLO, high magnetic field

PC3-3-INV

Observation of vortices driven by dc current using scanning tunneling spectroscopy

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We have constructed a scanning-tunneling-microscopy/spectroscopy (STM/S) system which allows us to conduct transport and STM measurements at low temperatures and high fields for the same sample. We study configurations of vortices in weak pinning amorphous Mo_xGe_{1-x} films under dc currents I both in plastic-flow and flux-flow regimes. The applied field is well below the peak-effect field. First, we drive the vortices by I for a long time until the steady state is reached. After freezing the vortex configuration by switching off I, we perform STS measurements. We observe a triangular vortex lattice within a scanning area of 240 × 240 nm^2 for all I studied, not only in the flux-flow region at high I where the vortex configuration is considered to be an ordered lattice, but also in the plastic-flow region at low I where the configuration is expected to be disordered [1]. We find, however, that at low I, the orientation of the lattice with respect to the flow direction differs when we change the scanning area. Furthermore, real-time measurements of the tunneling spectrum at a fixed tip position show an intermittent vortex motion. These results indicate that the vortex flow at low I corresponds to that of vortex polycrystals with domain sizes larger than 240 × 240 nm^2. This is different from simulations predicting the formation of flow channels at the domain boundaries. At high I, on the other hand, we obtain images of a vortex lattice with the same orientation over a wide area, consistent with the results of a mode-locking resonance [2]. We will also show the significance of the present STS system for the study of nonequilibrium phenomena in the vortex system [3,4].

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Keywords: vortex dynamics, plastic flow, scanning tunneling spectroscopy

PC3-4

Thermoelectric study of the anomalous metallic state in amorphous superconducting thin films

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The superconductor-insulator transition in a two-dimensional electron system is known as a quantum phase transition [1]. This transition is driven by magnetic field or disorder and has been studied in disordered superconducting thin films [2]. On the other hand, an unusual metallic phase intervening between the superconducting phase and the insulating phase has been reported in various thin-film systems including amorphous, granular, and highly crystalline films [3]. This state is called an anomalous metal and shows characteristic features reminiscent of superconductivity, e.g., residual resistivity much smaller than the normal resistivity just above the transition temperature, and giant positive magnetoresistance. Many theoretical models for the metallic state have been constructed assuming the existence of Cooper pairs and superconducting vortices [3]. However, whether the vortices are really present in the metallic phase has not been completely verified from resistivity measurements.

In this study, we performed a Nernst measurement using a dilution refrigerator. We studied an amorphous Mo_xGe_{1-x} thin film with a thickness of 12 nm prepared by rf sputtering. The field-induced superconductor-metal-insulator transition was observed in the zero-temperature limit from the magnetoresistance measurement. We measured Nernst signals by sweeping the field at high temperatures just below the transition temperature, and found vortex Nernst signals in wide field ranges corresponding to the thermal vortex liquid phase [4]. With decreasing temperature, the field range where the vortex signals are observable decreases but remains finite toward zero temperature, indicating the existence of a quantum vortex liquid state. Moreover, the observed quantum vortex liquid state is located within the anomalous metallic phase defined by the magnetoresistance. These results strongly suggest that the metallic ground state is induced by mobile vortices due to quantum fluctuations.

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Keywords: Nernst effect, two-dimensional superconductor, anomalous metal, quantum vortex liquid

PC3-5

Local Density of States of Quasi-particles around a Vortex Core in a Square Superconducting Plate under Random Impurity Potentials

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For applications of superconductors, pinning of vortices is important. There are several kinds of pinning sites. A nanorod is one of examples of these pinning sites. On the other hand, there are superconductors such as amorphous superconductors where impurities uniformly distribute. In order to investigate behaviors of vortices in these superconductors into, we include the random impurity potential to the Bogoliubov-de Gennes (BdG) equation. We self-consistently solve this BdG equation for a square superconducting plate, using the Finite Element Method and obtain the order parameter $\Delta(\boldsymbol{r})$ and local density of states (LDOS) of quasi-particles. Examples of $\Delta(\boldsymbol{r})$ and LDOS are shown in Figs. 1 and 2. We find the deformation of a vortex and spatial variation of the LDOS from these figures.
In order to explain these results of the effect of impurity potential on the vortex core, we consider two simple impurity potentials, a Gaussian potential and a sinusoidal potential.
We solve the BdG equation with these two impurity potentials.
In this presentation, we will show $\Delta(\boldsymbol{r})$ and LDOS and *core radius of the vortex* under these impurity potentials.

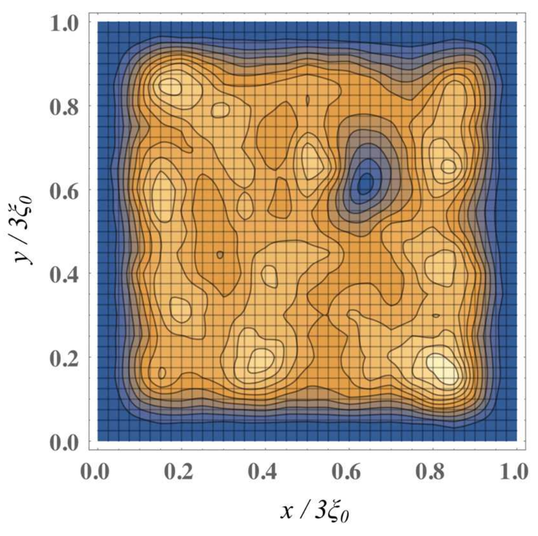

Fig. 1. $\Delta(\boldsymbol{r})$ in the case of $V_{impmax}/E_c = 0.5$

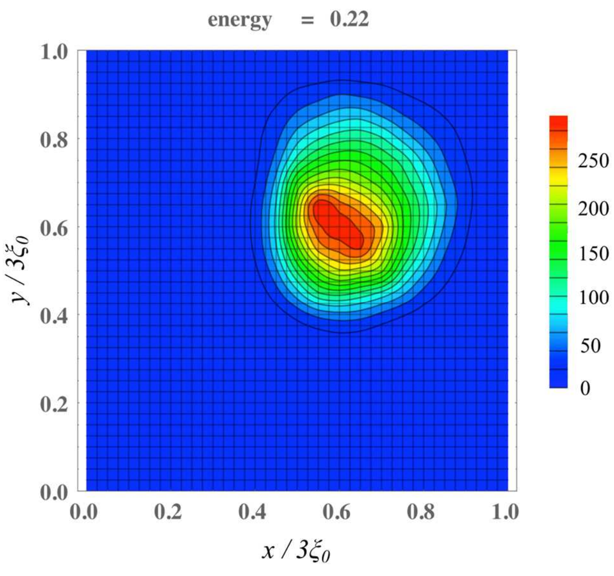

Fig. 2. LDOS in the case of $V_{impmax}/E_c = 0.5$

Keywords: Vortex, Bogoliubov-de Gennes equation, Local density of states, Finite element method