Comparison of flux motion in type-II superconductors including nano-rods and nano-particles by using 3D-TDGL simulation

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In type-II superconductors, the inhibition of flux motion has been tried by introducing artificial pinning centers (APCs) to improve the critical current density. However, critical current density for inclined external magnetic field varies according to the shape of the APC. Therefore, it is important to investigate the flux motion dependent on APC shapes and angle of external magnetic field. Our goal is an elucidation of the flux motion by using numerical simulation. Time-Dependent Ginzburg Landau (TDGL) equations provide us time development of Cooper pair density and magnetic field distribution in a superconductor. We carried out 3D-TDGL simulation to compare two kinds of superconductors which have different APC shapes. One includes only nano-rods and another includes only nano-particles.

In this simulation, we assumed these superconductors on a computer as shown in Fig. 1(a) and (c). The computational region was three-dimensional grid and the grid size was $10\xi_0 \times 15\xi_0 \times 10\xi_0$ in physical units. Where $\xi_0$ is coherence length at 0 K. The spacing between the grids was $0.5\xi_0$. An external magnetic field $(B_{ex})$ was inclined 45 degrees from the $z$-axis. The temperature and GL-parameter $\kappa$ were set to $0.5T_c$ and 3.0. In discretizing process of the 3D-TDGL equations, we introduced link variables into the equation of the vector potential [1]. The diameter of the nano-rods is $2\xi_0$ and introduced linearly along the $z$-axis. The diameter of the nano-particles is $2\xi_0$. The distribution of each APC is random.

In the Fig. 1, we show Cooper pair density in these superconductors without current. Since $B_{ex}$ was inclined 45 degrees from the $z$-axis, the flux also penetrated into the superconductors with inclined 45 degrees. A flux was partially pinned by the nano-rods in the Fig. 1(b). On the other hand, a flux located the whole of the nano-particles in the Fig. 1(d). When the difference of pinned flux shape is considered, we expect that Lorentz force applied flux is different in each superconductor. We will also discuss about flux motion in applying a current.

We would like to thank Prof. R. Kato belonging to Kagoshima University for the fruitful discussion about this simulation.

Fig. 1 The Cooper pair density in each conductor. (a) and (b) show that superconductor has two nano-rods, (c) and (d) show that superconductor has four nano-particles. $B_{ex}$ was set to $0.1675B_c$ and inclined 45 degrees from the $z$-axis. The gray flux tubes correspond to constant-surfaces of cooper pair density $|\varphi|^2=0.25$.

Vortex structure in chiral helimagnet/superconductor bilayer structure

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Superconductor/ magnetic material layer structures provide some specific physical properties by the interaction between subsystems. For example, in superconductor/ ferromagnet bilayer structures, vortex structures in superconductors are affected by ferromagnets, and there are strong pinning effect and matching effect \cite{1}. Superconductor/ ferromagnet layer structures have been studied for decades, but there are not many studies on the bi-layer of the superconductor with other magnets, for example, paramagnets, anti-ferromagnets, or chiral helimagnets. So, we focus on a chiral helimagnet/ superconductor layer structure. A chiral helimagnet comes from competition of the ferromagnetic exchange interaction and Dzyaloshinsky-Moriya (DM) interaction, which tilts spins slightly. The chiral helimagnet shows like helical rotation of spins along one direction, and has been focused in the development of new magnetic devices and the field of spintronics recently. In addition, chiral helimagnets show a chiral soliton lattice in which helix loosens periodically due to the applied magnetic field \cite{2}. We investigate the effects of the chiral helimagnet on the vortex structure in the superconductor.

In this study, we will present numerical simulations on vortex structures in the chiral helimagnet/ superconductor bilayer structure (Figure 1). We solve Ginzburg-Landau (GL) equation with the finite elements method:

\begin{equation}
\alpha |\psi|^2 + \beta |\psi|^2 \psi + \frac{1}{2m^*} \left( \frac{\hbar}{i} \nabla - \frac{e^*}{c} A \right)^2 \psi = 0
\end{equation}

\begin{equation}
J = \frac{e^* \hbar}{2m^* i} (\psi' \nabla \psi - \psi \nabla \psi') - \frac{e^* e^2}{m^* c} \psi' \psi A
\end{equation}

Vector potential \( A \) in the GL equation comes from a magnetic field from the chiral helimagnet, as \( A = (0, \int H_z(x)dx, 0) \), where \( H_z(x) \) is the magnetic field given by the magnetization of the chiral helimagnet: \( H_z(x) = H \cos(2\sin^{-1}(\text{sn}(cx|k))) + \pi + H_{ext} \), where \( H \) is the magnitude of the magnetic field, \( \text{sn}(cx|k) \) is the Jacobi’s elliptic function, \( c \) is constant, \( k \) is a modulus which is a function of the external magnetic field, and \( H_{ext} \) is an external field. We investigate vortex structures, solving these equations numerically.


Figure 1. Chiral helimagnet/ superconductor bilayer structure.
Impurity effects on vortex core states in topological s-wave superconductor

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Topological s-wave superconductor (SC), which is a two-dimensional electron gas with Rashba spin-orbit coupling, Zeeman coupling and s-wave superconductivity[1] has attracted attention as an engineered chiral p-wave SC. The realization of topological quantum computation (TQC), which utilizes the non-Abelian statistics obeyed by Majorana bound states, has been proposed by Kitaev[2] and Ivanov[3]. The robustness of the minigap against the randomness is important for realization of TQC; The minigap is a minimum excitation gap between the Majorana state and the excited state with the finite energy.

We investigate impurity effects on Caroli-deGennes-Matrincon(CdGM) mode in a topological s-wave SC. We calculate the density of states numerically within the scheme of Gor'kov equation with impurity self-energy. This scheme updates the Kopnin-Kravtsov scheme[2] in a proper way. Within a self-consistent Born approximation, we evaluate the relaxation time as the impurity effects through the width of the spectrum. We find a new type of CdGM mode in the sense that the energy dependence of the scattering rates is different from the case of s-wave SC and chiral p-wave SC. To understand these properties, we analytically solve the Bogoliubov-deGennes equation within the Andreev approximation and evaluate the scattering rates of the CdGM mode.

Solutions of the Ginzburg-Landau Equations for Three-dimensional Superconducting Networks in a Magnetic Field

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The numerical solutions of the Ginzburg-Landau equation for three-dimensional superconducting networks are presented. Vortex distribution of the superconducting networks near and below the transition temperature have the same symmetry as the shape of the network, when vanishing of the superconducting order at points of the strands can occur caused by the phase interference in order to keep the symmetry of vortex distribution. For the truncated icosahedron (C60) superconducting network, we can choose five, three or two-fold symmetry axis and we obtained the vortex configuration with these symmetry. In the weak field, field dependences of the transition temperature of these three cases have same behavior. In low temperature, the symmetries of vortex states are broken and the vanishing of the order parameter at points of strands cannot be found.
Twin Boundary Effects on Spontaneous Half-quantized Vortices in Superconducting Composite Structures (d-dot’s)

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A d-dot is a nano-sized composite structure that consists of a d-wave superconductor embedded in an s-wave matrix, as shown in Fig.1(a). Since the phase of the superconducting order parameter in the d-wave superconductor depends on direction, phase difference appears at a corner junction between d-wave and s-wave superconductors. Compensating this phase difference, a spontaneous half-quantized vortex appears. This is a feature of d-dot’s[1].

But it is pointed out that the spontaneous magnetic flux may not appear if phase differences across twin boundaries in YBa2Cu3O7-δ (YBCO) exist.

In order to analyze effects of twin boundaries on spontaneous half-quantized vortices, we introduce orthorhombic structure of YBCO to two-components Ginzburg-Landau( GL) equations[2] in terms of anisotropy of effective mass in YBCO. Then we have following modified two-components GL equations.

\[
\begin{align*}
\Delta_x^* &= 2\lambda_x \left( V_x^{\ast} \Delta_x \right) \ln \left( \frac{2e^2 \hbar \omega}{\pi k_y T} \right) - 2\lambda_y \left( V_y \right) \alpha \left( \frac{\epsilon_F}{2m_y^\ast} \Pi_y + \frac{\epsilon_F}{2m_y^\ast} \Pi_y^2 \right) \Delta_x^* + \frac{\epsilon_F}{4m_y^\ast} \Pi_y \left( \Delta_y^* + 3\Delta_y \right) + \frac{1}{2}\Delta_y^2 \Delta_y^* \\
\Delta_y^* &= 2\lambda_y \left( V_y^{\ast} \Delta_y \right) \ln \left( \frac{2e^2 \hbar \omega}{\pi k_x T} \right) - 2\lambda_x \left( V_x \right) \alpha \left( \frac{\epsilon_F}{4m_x^\ast} \Pi_x + \frac{\epsilon_F}{4m_x^\ast} \Pi_x^2 \right) \Delta_y^* + \frac{\epsilon_F}{4m_x^\ast} \Pi_x \left( \Delta_x^* + 3\Delta_x \right) + \frac{1}{2}\Delta_x^2 \Delta_x^* 
\end{align*}
\]

Using the finite element method and solving these equations self-consistently, we investigate the effects of twin boundaries on spontaneous half-quantized vortices.


Figure 1. (a) A Schematic diagram of a d-dot. (b) Magnetic field distribution calculated by two-components GL equations with the finite element method.
Effects of Doping on the Superconducting Properties of Li-Based Ferropnictides

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LiFeAs is regarded as a unique Fe-based superconductor with $T_c \sim 18 \text{ K}$ without carrier doping. However, its reported synthesis method suggests a broad variety of different sintering temperature (740-1050°C) and synthesis conditions. To find the optimal synthesis procedure, we have synthesized polycrystalline stoichiometric LiFeAs by testing a wide sintering temperature range from 200-900°C and by applying a two-step solid state reaction method. Each sample was finally characterized under exactly the same conditions. Our study proved that a sintering temperature 600°C maintained at 48 h is the optimal condition for the synthesis of high quality bulk LiFeAs. These polycrystals showed the onset $T_c$ of 19.2 K with $RRR$ of 19.6 and a small NQR line width of 60 KHz, confirming the high quality and electronic homogeneity of our samples. Two distinct scales of current flow corresponding to inter- and intragranular currents were confirmed by the remanent magnetization and their calculated intergrain $J_c$ is very low. A series of Mn-doped LiFe$_{1-x}$Mn$_x$As and Fe-rich LiFe$_{1+y}$As bulks were prepared by the above optimized procedure to understand the role of doping in LiFeAs. A broad spectrum of characterization methods involving XRD, SEM, NQR, magnetoresistance, magnetization, specific heat and Hall effect have been applied. Both types of doping suppress $T_c$ rapidly, however the suppression rate of superconductivity for Fe-rich samples with $y > 0.04$ is about ten times larger than that of Mn-doped ones. Concisely, the electronic phase diagram is discussed with other Fe-based superconductors.

![Figure 1. Temperature dependence of zero-field-cooled (ZFC) magnetization under $H = 10 \text{ Oe}$ in LiFe$_{1-x}$Mn$_x$As.](image-url)
Effects of Heavy-Ion Irradiations in K-Doped BaFe$_2$As$_2$

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Iron-based superconductors are promising for high-field applications since they have very high upper critical fields over 50 T. For such applications, a large critical current density ($J_c$) has to be sustained even at such high fields. The particle irradiation is known as an effective method to enhance $J_c$ at all field range by introducing defects into superconductors. Our group has reported the effect of 200 MeV Au-ion irradiation in Co-doped BaFe$_2$As$_2$ single crystal, and observed columnar defects and a strong enhancement of $J_c$ [1]. In the present study, we have irradiated several kinds of heavy ions to optimally K-doped BaFe$_2$As$_2$ with $T_c \sim 38$ K. We find a strong enhancement of $J_c$, for example up to 15 MAcm$^2$ at 2 K under zero field when 200 MeV or 320 MeV Au ions are irradiated into the sample, which is 10 times larger than that in a pristine one. The field dependence of $J_c$ changes from $\sim H^{0.5}$ to $\sim H^{-1}$ after these irradiations in the intermediate field range, similar to the case of 1.4 GeV Pb irradiation [2]. This may indicate that the dominant vortex pinning centers are changed from intrinsic point defects to introduced columnar defects. An anomalous dip structure near zero field in the magnetization hysteresis loop is also observed in samples with higher matching fields ($B_\Phi$). However, these effects of irradiation have some difference depending on the irradiation condition. We will discuss the irradiation condition and $B_\Phi$ dependence of $T_c$ and $J_c$ in detail.

Stability of half-quantum vortices in chiral p-wave superconducting states

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A half-quantum vortex (HQV) is expected to be realized in the so-called A-phase of 3He and the chiral p-wave spin-triplet equal spin pairing superconducting state [1]. It is formed by a π-rotation of the superconducting phase and a π-rotation of d-vector around the vortex core. Thus the magnetic flux through HQV is one-half of the flux quantum Φ0. HQVs are topologically possible objects, however, the energetic stability is a more subtle question. Previous studies on this issue are based on phenomenological Ginzburg-Landau theory assuming a spin-orbit coupling [2-4].

In this talk, we study the stability of half-quantum vortices in a chiral p-wave superconductor based on a square lattice single band tight-binding model with an anisotropic attractive interaction between electrons on nearest-neighbor sites, a spin-orbit interaction, and the effects of magnetic field via a Peierls phase factor on the hopping term and a Zeeman coupling [5]. The superconducting vortex lattice states are described within the Bogoliubov-de Gennes theory. We investigate the phase diagram for the stability of HQV with respect to the anisotropy of the interaction and the strength of the spin-orbit coupling.

Vortex Tunneling Spectra of Iron-Based Superconductors

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Quasi-particles induced around a vortex core in multiband superconductors can reflect not only the pairing symmetry but also the relevant low-energy band structures for their superconductivity. Thus, it is interesting to study the vortex cores in iron-based superconductors since their pairing symmetries, mechanisms, and effective microscopic models have not been finally settled yet. Experimentally, Hanaguri et al. [1] observed vortex cores in LiFeAs, and found that the STS spectrum exhibit a pronounced peak structure just below the Fermi energy. They also found that the vortex cores are almost four-fold symmetric shape in real-space. By contrast, Song et al. found that the vortex cores in another iron-based superconductor FeSe are two-fold symmetric shape, although the orthorhombicity of its lattice may not be so large as causing such vortex core distortion.

Motivated by these backgrounds, in this work, we theoretically study the quasi-particle states induced around vortex cores in iron-based superconductors based on an effective two-band model on a square lattice [3] within the Bogoliubov-de Gennes theory. The prominent features of the STS spectra of LiFeAs [1] can be well reproduced by using this model, both in the cases of the pure superconducting state (Fig. 1) and in the vortex state (Fig. 2). We also show that the two-fold symmetric vortex cores can be realized when the intraband attractive interaction between electrons is different in each band of the model.


Fig. 1. Local density of states LDOS for s± wave similar to superconducting state of LiFeAs.

Fig. 2. LDOS for s± wave at vortex core and away from vortex core.
Size dependence of individual vortex penetration into intrinsic-Josephson-junction stacks of Bi$_2$Sr$_2$CaCu$_2$O$_{8+y}$

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By measurements of c-axis transport properties of a stack of the intrinsic Josephson junctions (IJJs) in magnetic fields parallel to c-axis, a penetration of individual vortices can be detected as a sudden jump or drop of resistance or critical current, which has already been reported in samples of small in-plane area (<2 $\mu$m$^2$) by Kakeya et al.[1]. We explored the individual vortex penetrations in much larger IJJs and successfully observed the same phenomenon even in a sample as large as 100 $\mu$m$^2$. The behaviors of the c-axis resistance and critical current accompanied by the individual vortex penetrations are investigated through the sample-size dependence in various temperatures and magnetic fields.

Temperature Dependence of Glassy Exponent in YBa$_2$Cu$_3$O$_{7-δ}$ Films

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Precise measurements of relaxation of magnetic moment of YBa$_2$Cu$_3$O$_{7-δ}$ films in time-window form $t_1 = 30$ s to $t_2 = 3600$ s were carried out in low magnetic field $H = 910$ Oe in temperature range $4.2 < T < 80$ K. The experiments were performed by a special technique allowing one to measure change of magnetic moment of a sample with time or temperature when the sample is stationary located in one of the pickup coils of SQUID magnetometer during the measurements [1,2]. The relaxation rate $S = - d \ln J / d \ln t$ and the glassy exponent $μ$ of the activation energy dependence on current $U(J) = (U_c / μ)[(J_c / J)^μ - 1]$ for vortices movement were obtained via fitting of measured $J(t)$ curves by the relation $J_2 / J = [1 + μS_2 \ln(t / t_2)]^μ$ following from the dependence $J(t) = J_c / [1 + (μT / U_c) \ln (t / t_0)]^{1/μ}$ [3,4]. Here $J_2$ and $S_2$ are values of the current and the relaxation rate taken at time $t_2$. Maley’s analysis [5] was applied to construct $U(J)$ dependencies from measured $J(t)$ curves. It was shown that the glassy exponent non-monotonously changes with temperature in the range from -1 to 1.2-1.7 while the $U(J)$ dependencies are well described by a single $μ$ value in a wide range of currents (see Figure 1). Note, that since the value of magnetic field was low in a whole temperature range of our experiments, the relaxation should be caused by motion of individual vortices. In this case one expects transition from $μ = -1$ at low temperatures, (if $J_c$ is of the order of the critical current $J_c$), to the constant value $μ = 1/7$ obtained for a three-dimensional pinning of individual vortices in the frame of the collective pinning theory [3], or to some constant value $μ < 1$ predicted by the vortex-glass model [6,7] at higher temperatures. Such a behavior is only in part confirmed by our experiments. The work was supported by state-order No 3.1540.2014/K of the Ministry of Education and Science of the Russian Federation.


Figure 1. Temperature dependencies of the relaxation rate $S_2$, glassy exponent $μ$ and dependencies $U(J)$ obtained for two YBa$_2$Cu$_3$O$_{7-δ}$ films at applied magnetic field $H = 910$ Oe.
Magnetic-Field-Induced Metallic Phase at Low Temperature in Two-Dimensional Superconductors

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In disordered two-dimensional (2D) superconductors a transition from a superconducting to an insulating phase takes place with increasing the magnetic field $B$. It has been reported in some 2D superconductors that there is an intervening metallic phase between the superconducting and insulating phases. This phase is identified with a field region where the temperature independent resistance, a so-called flat tail, persists down to zero temperature. The origin of the metallic phase is considered to be a quantum liquid of vortices. To the best of our knowledge, however, there is no convincing experimental evidence for this. In this work, to prove the existence of the vortices in the metallic phase, we have performed time-dependent measurements of voltage $V_{ac}$ in response to the ac current. We have observed the relaxation of the amplitude $|V_{ac}|$ toward the steady-state value. The relaxation time as a function $B$ shows a power-law divergence near the threshold field between the superconducting and metallic phases. The results, combined with our recent results on the non-equilibrium depinning transition [1], demonstrate the presence of the vortices in the metallic phase.

Melting of the Distorted Vortex Lattice

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When a magnetic field $B$ is applied perpendicular to the plane of superconductors, the isotropic Abrikosov lattice is formed. When $B$ is tilted by $\theta$ from normal to the sample plane, the Abrikosov lattice is expanded in the tilted direction. Recent mode-locking experiments have revealed that when the vortex lattice is driven at moderate velocity, one side of the triangle is parallel to the direction of the tilted field, independent of whether the vortex lattice is driven parallel or perpendicular to the direction of the tilted field [1]. Here, we present measurements of the magnetoresistance and field-dependent depinning current in the tilted field by $\theta = 36^\circ$ and determine the melting field $B_c$. We find that $B_c$ in the tilted field is larger than that in the non-tilted field ($\theta = 0$). We interpret the data using the Lindemann criterion and propose the condition determining the melting of the distorted lattice.

Dynamic Depinning Transition by Ac Drive

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In recent years, we have studied general phenomena of dynamic (plastic) depinning and reversible-irreversible flow transitions by measuring transient dynamics of vortices driven by suddenly applied dc and ac ($I_{ac}$) currents, respectively [1]. We have found that the critical behavior of the depinning transition is commonly observed independent of the initial vortex configuration, suggesting the universality of the transition [2]. It is generally known that pinning effects are less pronounced for ac drive, whereas it has not yet been clarified whether the critical behavior of the depinning transition is also observed for ac drive. Here, we investigate a dynamic ordering process of vortices subject to ac drive to clarify the issue. We observe the relaxation of the ac-voltage amplitude toward the steady-state value. The relaxation time plotted against $|I_{ac}|$ exhibits a power-law divergence at the depinning threshold. The results strongly suggest that the dynamic depinning transition also occurs for ac drive.

Reversible-Irreversible Transition in the Presence of Strong Pinning

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We have shown in our recent work that a reversible to irreversible flow transition (RIT), as originally observed in the sheared colloidal suspensions, also occurs in periodically sheared vortices in a Corbino disk (CD) [1]. In both systems, the particles (vortices) are rotated back and forth around the center of the system by the global shear force. The simulation for the periodically sheared vortices predicts that even in the strip samples where the global shear is absent, RIT should be observed as long as the samples contain moderately strong pinning centers that generate local shear [2]. To verify the prediction, we have prepared a strip-shaped film of amorphous Mo$_x$Ge$_{1-x}$ with stronger pinning than for CD and measured flow noise and time evolution of the voltage generated by the vortices subjected to ac drive. We again obtain evidence of RIT with a critical behavior similar to that for CD. However, the reversible phase is suppressed and the relaxation time for the system to settle into the steady state grows significantly. They are attributed to the stronger pinning effects.

Vortex Phase Diagram near $T=0$ Probed by Pulse Mode Locking

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Using a mode-locking (ML) technique, we previously observed melting of a driven vortex lattice in amorphous Mo$_x$Ge$_{1-x}$ films down to 0.8 K [1]. At low temperature $T$, the dynamic melting line shows a weak $T$ dependence and is significantly suppressed compared to the static melting line. In our previous work, we were unable to conduct the ML experiment lower than 0.8 K because joule heating might seriously affect the ML data. To determine the dynamic as well as the static vortex phase diagram at $T \approx 0$ and explore the true quantum phase transition(s) induced by $B$, however, the ML measurements well below 0.8 K are indispensable. Here, we perform the pulse ML measurement with which joule heating can be significantly suppressed, typically, lower than 0.1 % for the previous ML. Thus, we present the vortex phase diagram at $T \approx 0$, which shows that the intrinsic quantum melting of the vortex lattice occurs very close to the static order-disorder transition.

Instabilities of Fast Driven Vortices in Tilted Fields

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We have recently found velocity-induced instabilities of vortex flow from measurements of current-voltage ($I-V$) characteristics in different fields $B$. With increasing $I$, the voltage exhibits a steep jump at a $B$-dependent characteristic voltage $V_c$. For low fields $V_c(B)$ is described by the Larkin-Ovchinnikov theory for a single vortex, while for high $B$, $V_c(B)$ is explained by a picture taking account of the vortex lattice: As the velocity increases and the characteristic time for the vortex to travel one lattice spacing becomes comparable to the quasi-particle life time, each flow channel will be filled with quasi-particles spreading out of vortex cores, resulting in the instability in the $I-V$ curves. Within this lattice picture, the lattice spacing in the direction of vortex flow is essential. To obtain further support for this picture, we perform $I-V$ measurements in tilted fields where the lattice spacing is expanded in the direction of the tilted field. The lattice is driven either in the direction of the tilted field or in the direction perpendicular to it. For high $B$ we obtain two sets of $V_c(B)$ depending on the flow direction, consistent with the lattice picture for the anisotropic lattice. For low $B$ where the single vortex mechanism dominates, we again observe the two sets of $V_c(B)$, which suggests that the vortex core is expanded in the direction of the tilted field.
Observation of Vortex-Lattice Flow on the Conical Surface

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How does the Abrikosov lattice flow on curved surfaces of three dimensional objects? This is a very interesting question that has not been answered theoretically or experimentally. In order to observe the moving vortex lattice on a curved surface, we have performed measurements of a mode-locking (ML) resonance for driven vortices on a conical surface. The magnetic field is applied parallel to the height of the cone and a radial current is injected from the top of the cone to the perimeter of the bottom circle. As a result, the vortices circulate around the top of the cone by feeling the Lorentz force inversely proportional to the distance from the top. The clear ML resonance is observed in the vortex solid phase. This is the first observation of the Abrikosov lattice moving on a curved surface. We have found metastable states in the lattice orientation, which is in contrast to the results for the planar samples.
Superconductor-Insulator Transition Tuned by Thickness in Molybdenum Nitride Thin Films

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We report on superconductor-insulator (S-I) transition in molybdenum nitride (MoN) films onto a MgO substrate. MoN films have been deposited by the reactive DC-magnetron sputtering method under 5 mTorr of mixture of argon and nitrogen gas using the Mo target. The resistance of films that were patterned by using photolithography and reactive-ion-etching techniques was measured by standard four probe method. The analysis of crystalline properties of deposited films was performed by XRD and surface roughness was determined by atomic force microscope (AFM). Results of XRD measurements indicate that films are crystallized in cubic phase. The superconducting transition temperature $T_c$ is around 6.6 K for 100nm-thick films. The sheet resistance $R_{sq}(T)$ even for the 10nm thick film shows a sharp superconducting transition, unlike the quasi-reentrant resistive transitions of granular films. The $T_c$ of MoN films decreases as increasing the normal state $R_{sq}$ which increases with decreasing thickness, as shown in Fig 1. We found that the S-I transition occur at a critical $R_{sq}$ smaller than the quantum resistance $R_Q = 6.45 \, \Omega [1]$. The reduction of $T_c$ caused by enhanced Coulomb interactions in homogenously two-dimensional systems was theoretically given by Finkel’stein [2]. To analyze the magneto-conductance at low temperatures, the weak localization, the Aslamazov-Larkin, and the Maki-Thompson fluctuation correlation were used. The experimental results seem to be consistent with the sum of these theories.


Figure 1. Semi-log plot of the sheet resistance $R_{sq}$ versus temperature $T$ for MoN films
Modified Current Sweep Reversal Method for Reducing the Screening Current-Induced Field in No-Insulation Magnets

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The screening current-induced field (SCF) in a no-insulation (NI) magnet fabricated for a 10-MHz nuclear magnetic resonance (NMR) spectrometer was investigated to allow reduction of the SCF through the use of the current sweep reversal (CSR) method. In order to identify the SCF in the NI magnet, the magnetic flux density ($B_z$) was calculated using the equivalent circuit model and compared to the $B_z$ obtained empirically. In addition, the charging scenario for the current sweep reversal (CSR) method was modified to eliminate the effect of the charging delay of NI magnets on the SCF. Marked reduction of the SCF of the NI magnet charged directly at 30 A was observed when the magnet was subjected to the modified charging scenario for CSR at 36 A. Therefore, by using the modified CSR method, the SCF in the NI magnet could effectively be reduced temporally and spatially for the development of compact and stable NI-NMR magnets.

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The Formation of Magnetic Flux Domain in the Type II Superconductors with Ferromagnetic Defects

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The magnetization of 2D high-temperature superconductors with internal ferromagnetic defects under application of transport current and external dc magnetic field was studied by using Monte-Carlo method. The current-voltage characteristics were obtained. The S-type nonlinearity of current-voltage characteristics of the superconductor/ferromagnet system in external magnetic field due to the local reversal magnetization of magnetic particles by the field of vortices was demonstrated. The velocities of vortex creep near the nonlinearity were calculated. The existence of groups of vortices with different velocities at regions with different defectiveness (magnetic flux domains) was shown. The formation of magnetic flux domains and the wave of defects magnetization during vortex flow were demonstrated. The conditions for electromagnetic generation at the region of nonlinearity were found and the frequency of such a generation was estimated.