PC1-1-INV

High-Tc Research Over Thirty Years: Beyond The Common Knowledge of Superconductivity

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Thirty years have passed since the discovery of high Tc superconducting cuprates. So far a tremendous amount of efforts have been devoted to solve the mysteries of high Tc superconductivity. What we have learnt in these 30 years had been unexpected and beyond the common knowledge of superconductivity before the high Tc cuprates. In my talk, I will list up and revisit these issues that are different from the conventional superconductors. Some of them are important for practical application of this material. From the physical viewpoint, the strong electron correlation is a key issue causing various unusual properties such as the pseudogap and the precursor of superconductivity. It requires us a new picture beyond the BCS theory.

Keywords: unconventional superconductors, strong electron correlation, BCS-BEC crossover

PC1-2-INV

Scanning Tunneling Microscopy as a Tool for Superconductivity Research

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Scanning tunneling microscopy (STM) has been developed in the field of surface science as a tool to image atomic/molecular structures at the surfaces. Due to the capability to perform local tunneling spectroscopy with atomic spatial resolution and sub-meV energy resolution, STM can also be a powerful technique for analyzing the electronic states behind the novel functions of materials. Indeed, recent developments of STM technology are largely motivated by researches on unconventional superconductors. We will review electronic states of cuprate and iron-based superconductors revealed by modern STM techniques, especially spectroscopic-imaging STM combined with Fourier analyses. We will also discuss future directions of STM as a tool for superconductivity research.

Keywords: scanning tunneling microscopy, cuprate superconductor, iron-based superconductor

PC1-3-INV

Angle-Resolved Heat Capacity of Unconventional Superconductors

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Owing to a strong Coulomb repulsion, strongly correlated superconductors mostly have anisotropic gap functions which have nodes for certain direction in the momentum space. Since the nodal structure is closely related to the pairing mechanism, its experimental determination is of primary importance. Among various approaches, angle-resolved heat capacity measurements in a rotating magnetic field turns out to be quite useful in experimental determination of the gap structures. The basic idea is based on the fact that the field-induced density of states (DOS) of the vortex state in nodal superconductors exhibits characteristic field and orientation dependences. Zero-energy DOS (ZEDOS), in particular, rapidly increases roughly in proportional to $H^{1/2}$ at low fields. Importantly, this $H^{1/2}$ like increase of ZEDOS exhibits a weak anisotropy arising from the nodal structure, and in a low-field region $H \ll H_{c2}$, minima occur when H is parallel to the nodal direction [1]. This field-angular dependence of ZEDOS can be detected by heat capacity measurements in a rotating magnetic field at low temperatures, and can be a powerful tool to probe the gap nodal structures [1,2]. An important point of this experiment is that the measurements need to be done at very low temperatures ($\leq 0.1 T_c$) due to a sign-change issue [3]. In this presentation, recent advances in the angle-resolved heat capacity measurements on unconventional superconductors are discussed, including results on $CeCoIn_5$ [4], UPd_2Al_3 [5] and $CeCu_2Si_2$ [6].

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Keywords: Heat capacity, gap nodal structures, rotating magnetic field, angular oscillations

PC1-4-INV

What is the lowest possible vortex creep in superconductors, and how can we achieve it?

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Thermal and quantum fluctuations play only a minor role on the vortex properties of many low temperature superconductors (LTS). However, they dramatically influence vortex matter in high temperature superconductors (HTS) such as oxides and Fe-based, creating a proliferation of vortex liquid phases that occupy substantial portions of the phase diagram and fast dynamics of the metastable states (flux creep). This fascinating physics has been a topic of continuous interest for decades, but on the other hand is detrimental for applications. The strength of the thermal fluctuations is quantified by the Ginzburg number (*Gi*) that measures the ratio of the thermal energy to the condensation energy in an elemental superconducting volume. The combination of the small coherence length (x), large anisotropy (g) and high transition temperatures (T_c) in the HTS results in *Gi* values several orders of magnitude higher than in LTS. For instance, $Gi \sim 10^{-9}$ in Nb and $\sim 10^{-2}$ in $YBa_2Cu_3O_7$, naturally accounting for the much faster creep rate (S) in the latter. We have found that, for strong pinning superconductors in the Anderson-Kim (AK) creep regime, there is a universal minimum attainable $S \sim Gi^{1/2}(T/T_c)$. This lower limit has been achieved in a few materials including $YBa_2Cu_3O_7$, MgB_2 and our $BaFe_2(As_{0.67}P_{0.33})_2$ films and, to our knowledge, violated by none. This hard constraint has two important, broad implications: first, the creep problem in HTS cannot be fully eliminated and there is a limit to how much it can be ameliorated, and secondly, we can confidently predict that any yet-to-be-discovered HTS will have fast creep. On the other hand, many SC exhibit S values higher, sometimes orders of magnitude higher, than the lower limit. The reason is that *Gi* only sets the lowest limit for S, but in order to achieve it the pinning landscape must be optimized. I will show that S can be reduced by appropriate engineering of the pinning landscape, in some cases (such as in irradiated $Ba(Fe_{1-x}Co_x)_2A_2$ single crystals) dramatically so and all the way down to the lower limit imposed by *Gi*. Finally I will discuss some of our studies of creep outside the AK limit and in very clean (weak pinning) samples, where collective effects are relevant and different glassy and plastic dynamic regimes can be observed and tuned by methods such as irradiation and film thinning.

Keywords: vortex matter, vortex dynamics, flux creep

PC1-5

Detecting changes in the vortex configuration associated with dynamic ordering and disordering

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When many particle systems with a random initial distribution are periodically sheared and the number (n) of the shear cycle is increased, the particles gradually self-organize to avoid future collisions and transform into an ordered structure. This is called random organization or dynamic ordering [1]. We have shown that dynamic ordering reported in colloidal suspensions [1] also occurs in a periodically driven vortex system of amorphous Mo_xGe_{1-x} films with weak random pinning. This was detected from the time-evolution of voltage $V(t)$ that increases toward a steady-state value [2-4]. Quite recently, we have developed a new method to detect the vortex configuration using the similar $V(t)$ measurements, where after freezing the vortex configuration by switching off the ac driving current, we executed subsequent readout measurements of $V(t)$ in response to ac drive. Thus, we have made an unexpected, striking finding that the transient vortex configuration formed during the dynamic-ordering process is not microscopically homogeneous but consists of disordered and organized regions, and that the ration of the latter region increases with n [5].

We also know that, in the presence of random pinning, an initially organized vortex configuration becomes disordered when a small dc driving force is applied to the vortex system [2,3]. This process is called the dynamic disordering. Thus, an interesting question arises: how does the vortex configuration evolve associated with the dynamic disordering by the dc drive? In this work, we study this issue by using the same vortex system of amorphous Mo_xGe_{1-x} films driven by the dc current. The results show that the vortex configuration during the dynamic-disordering process is homogeneous, in contrast to the case of the dynamic ordering by ac drive [2-4]. Therefore, the origin of the coexistence regions found in [5] is attributed to the ac drive and/or dynamic ordering.

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Keywords: vortex dynamics, self-organized systems, nonequilibrium phase transition, pinning

PC1-6

Molecular Dynamics Simulations on Melting Transition of Vortex Matter in Nano-Sized Superconductors

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In the H-T phase diagram for bulk cuprate High-Tc superconductors, there is a melting line of vortex lattice. This melting behavior comes from weak pinning, large thermal and quantum fluctuations in the cuprate High-Tc superconductors.

Recently, Ooi et al. showed the melting temperature in a nano-sized superconducting cuprate square plate oscillates with increasing magnetic field. They explained this oscillation comes from the stability of configuration of n^2 vortices (n=1,2,3,4,…)[1].

Previously, in order to confirm this phenomenon, we studied the vortex lattice melting in nano-sized superconductors using the molecular dynamics method[2,3] for vortices. Temperature dependence of vortex dynamics comes from the fluctuation force and penetration dependence in the vortex-vortex interaction. Using the standard deviation of the positions of vortices, we determined the melting temperature. Changing the vortex numbers, we found the melting temperature oscillates with increasing the vortex number. But we used periodic boundary conditions [4].

In this presentation, we extend our method to fixed boundary condition case and show the size dependence and shape dependence of the vortex-melting curves.

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Keywords: Vortex matter, Melting Transition, Molecular Dynamics, High-Tc superconductor