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物理学第一分野DC3回生研究発表会

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Raman spectroscopy on the zigzag graphene nanoribbon

Nano-scale Quantum Condensed Matter Physics

Ryohei Nishinakagawa

Abstract We have fabricated graphene nanoribbon samples by chemical method. The atomic structure of the sample edge was investigated by Raman spectroscopy. In conclusion, we claim to have found out pure zigzag graphene nanoribbons for the first time, as confirmed by the luck of the D-peak in its Raman spectrum.

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Graphene is a single layer of carbon atoms, composed of honeycomb lattice. Some properties of the nano-scale graphene are very sensitive to the atomic structure of the edges. There are two typical types of graphene edges, i.e., zigzag and armchair edges. A peculiar property has been pointed out theoretically that electrons at low energy have a tendency to collect near the zigzag edge [1]. Therefore, in a graphene nanoribbon (GNR) with nano-size width, the electronic properties strongly depend on its width and edge structure. In graphene sheet the energy gap is zero, but in GNR as the width is narrower, the energy gap is non-zero and increase [1]. GNR with large energy gap is expected as a future ultrafast device. Nevertheless, good samples have not yet been obtained until today.

We have fabricated graphene nanoribbon samples by chemical method [2]. Preparation procedure is as follows: (I) Exfoliation of expandable graphite by rapid heating; (II) Some chemical processes; (III) Collection of thin pieces from exfoliated graphite on Si wafer; (IV) Search of GNR by atomic force microscopy (AFM) on wafer. Figure 1 shows an AFM image of our GNR samples. We have obtained many high quality samples with straight edges: width $w = 10 \sim 500$ nm, height $h = 0.8 \sim 4.0$ nm, length $l = 1 \sim 100 \mu$ m.



Fig.1 AFM image of our GNR. White squares are address marks are every 5 μ m on Si wafer. The GNRs are seen in the area surrounded by the yellow lines. The egdes are very straight.

Fig.2 (a) The atomic structure of the zigzag GNR. (b) Raman spectrum of our sample. Inset shows another group data [3].

We studied the property of GNRs with Raman spectroscopy. The properties of graphene can be examined by the D-peak ($\sim 1350 \text{ cm}^{-1}$), G-peak ($\sim 1580 \text{ cm}^{-1}$), and 2D-peak ($\sim 2700 \text{ cm}^{-1}$) in its Raman spectrum. The D-peak shows the existence of defects or edges in laser spot, and the line-width of the 2D-peak shows the layer number of graphene materials. Figure 2(b) shows the Raman spectrum obtained in our and another typical groups. Remarkably, though the laser beam surely hit the edge, the D-peak is absent in our sample. On the other hand, the D-peak is clearly observed in samples in other groups, where GNRs are etched by electron beam lithography [3] or made GNRs by similar chemical method [4]. It is to be emphasized that the sample should not show the D-peak provided it has pure zigzag edges [5]. In conclusion we have succeeded in fabricating pure zigzag GNR samples for the first time. I will present the detail of Raman experiment and our unique sample preparation process. **References**

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Interplay of Antiferromagnetsm and Superconductivity in Bilayer Superconductors

Condensed Matter Physics Group (YITP) Hiroyuki Yoshizumi

Abstract Motivated by a recent experiment in a multilayered high-Tc cuprate reporting the enhancement of antiferromagnetic order below the superconducting transition temperature, we study the proximity effect of the antiferromagnetic correlation in a bilayer system. We present the result of mean field theory that is consistent with the experiment and supports the proximity effect picture. © 2012 Department of Physics, Kyoto University

In the study of high-temperature superconductivity in the cuprates, there has been great interest in the interplay between antiferromagnetism and superconductivity. In the mechanism of superconductivity, antiferromagnetic (AF) correlation is believed to play an important role. Multilayer systems with multiple CuO₂ layers per unit cell are useful for investigating the AF correlation effect on superconductivity, since charge imbalance in the layers induces possible coexistence of antiferromagnetism and superconductivity within the unit cell. Recently Shimizu *et al.* studied the temperature dependence of the AF moment in a five-layered cuprate Ba₂Ca₄Cu₅O₁₀(F,O)₂ by NMR measurements [1]. They reported that the AF moment in the outer layer is enhanced below the superconducting (SC) transition temperature T_c . Such an enhancement of the AF moment below T_c does not appear in the coexistence phase of other superconductors. Therefore, the enhancement seen in the five-layered cuprate is essential for the enhancement [2], and thus need to clarify the mechanism of the AF moment triggered by the SC transition under the presence of multilayers.

We study the interplay between SC and AF order and also examine the possibility of coexistence of SC and AF order within a mean field theory. To describe a multilayer system consisting of two types of layers, we consider a bilayer system with interactions which stabilize SC and/or AF order in each layer (see Fig. 1(a)). The two layers are coupled through an interlayer tunneling. By controlling interaction parameters for the AF correlation and SC correlation, we found a clear enhancement of the staggered moment in AF layer below T_c as shown in Fig. 1(b) [3]. This enhancement of AF correlation below T_c is consistent with the NMR experiment in the multilayer cuprate [1].



Fig. 1. (a) Schematic view of the system consisting of *d*-wave SC order in the layer-1 and AF order in the layer-2. g_j and V_j (*j*=1,2) describe SC and AF interaction parameters in the layer-*j*, respectively. Energies are measured in units of intralayer nearest-neighbor hopping. (b) The temperature dependence of the AF order parameter m_2 in the layer-2 for two SC interaction parameters g_1 in the layer-1. $T_c = 0$ for $g_1 = 3.0$, while $T_c = 0.06$ for $g_1 = 4.0$.

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Optimal observation time window for forecasting the next earthquake

Nonlinear Dynamics Group Takahiro Omi

Abstract We report that the accuracy of predicting the occurrence time of the next earthquake is significantly enhanced by observing the latest rate of earthquake occurrences. The observation period that minimizes the temporal uncertainty of the next occurrence is on the order of 10 hours, independently of geographic areas.

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Earthquakes occur unexpectedly in an instant, causing catastrophic damage. A great deal of effort has gone into understanding the timing of earthquake occurrences in a causal manner, for example, to understand how the main shock induces aftershocks. By classifying earthquakes into groups of cause and result, theories such as the Omori law, which indicates that the aftershock frequency decreases roughly in proportion to the inverse time after the main shock, have succeeded in reproducing some statistical aspects of earthquake occurrence. However, the main shocks are determined ex post facto, and their timing is simply attributed to an unpredictable random process. In contrast, a simple statistical analysis based on equal treatment of all earthquake occurrences has revealed that the distributions of interevent intervals, for different geographic areas and over a range of earthquake magnitudes, may collapse onto a unique distribution after rescaling time by the mean occurrence rate

If interevent intervals are independent and identically distributed, the occurrence time of the next earthquake depends only on the time of the most recent occurrence. However, several researchers have recently reported that consecutive interevent intervals are correlated, such that a short (long) interval tends to be followed by another short (long) interval, which indicates that a memory effect extends over a single interval. In other words, knowledge of the interevent interval between the ultimate and penultimate occurrences makes it possible to better assess the probability of the next occurrence time. This assessment consists of a conditional distribution of interevent intervals given the preceding interval.

In this contribution, we present a factor on which to base the prediction of the next earthquake occurrence that can be more relevant than the preceding interevent interval. For this discussion, we adopt the latest occurrence rate, evaluate its relevance to the next interevent interval, and optimize the duration of the observation time window over which this occurrence rate is defined. This optimization is performed by maximizing the mutual information function that relates the latest occurrence rate with the interevent interval between the most recent (i.e., past) occurrence and the next (i.e., future) occurrence. Here we show that the optimal observation period is on the order of 10 hours [1]. This result is independent of the threshold magnitude and is consistent across different geographic areas. This time scale is much shorter than the months or years that have previously been considered characteristic of seismic activities.

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Neurons as Ideal Change-point Detectors

Nonlinear Dynamics Group, Hideaki Kim

Abstract Every computational unit in the brain monitors incoming signals, instant by instant, for meaningful changes in the face of stochastic fluctuation. We demonstrate that a single neuron can achieve change-point detection close to that of theoretical optimal with biological parameters, implying that biological neurons could act as sophisticated change-point detectors. © 2012 Department of Physics, Kyoto University

In the theoretical field of statistical analysis, tasks of detecting changes in noisy signals have been formulated as well-defined mathematical problems [1-2]. Bayes-optimal algorithms used for individual tasks can be applied in places such as manufacturing to detect substandard products; late detection results in inferior goods, whereas false alarms lead to unnecessary production stoppages. Also for animals, detecting changes in the environment is critical; late detection increases the risk of being preyed upon or losing prey, whereas false alarms lead to energy wastage. In practice, animals often react as if they detect changes in weak sensory signals efficiently.

For such behavioral decisions to occur, individual computational units in the brain must be monitoring incoming signals instant by instant for meaningful changes in the face of stochastic fluctuation [3-4]. Although the physiological mechanism of such a statistical computation has not been revealed yet, recent studies show that even a single neuron can detect changes in the state of incoming signals almost instantaneously [5].

In this study, we assess the potential of a single leaky integrate-and-fire neuron to execute change-point detection by comparing its performance with that achieved by a Bayes-optimal algorithm [6]. Based on the knowledge of stochastic differential equations, we develop a method which uses the initial and final states of the incoming signal for exploring the parameters in the leaky integrate-and-fire neuron that optimize change-point detection. With this method, we demonstrate that a single leaky integrate-and-fire neuron can achieve change-point detection close to that of theoretical optimal, for uniform-state process, functions even better than a Bayes-optimal algorithm when the underlying state in the incoming signal deviates from a presumed uniform process. Furthermore, given a reasonable number of synaptic connections (order 10⁴) and the state of the incoming signals, the values of the membrane time constant and the threshold found for optimizing change-point detection are found to be close to those seen in biological neurons. These findings imply that biological neurons could act as sophisticated change-point detectors in the brain [7].

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Towards Quantum Gas Microscope of Ytterbium Atoms in an Optical Lattice

Quantum Optics Group Kosuke Shibata

Abstract I designed and constructed a new experimental system suited for imaging and addressing individual atoms in an optical lattice. This system will enable us to perform research on the behavior of cold atom gas in a direct and detailed way. The specification of the system will be presented. © 2012 Department of Physics, Kyoto University

In the neutral cold atom research area, various interesting phenomena have been observed. One of the most interesting topics is single site imaging [1, 2] and addressing [2]. Atoms are trapped in an "optical lattice" which is a periodic potential induced by light. They are separated each other only by less than 1 μ m, but can be detected individually in a single shot image thorough a high resolution optical imaging system. Addressing was achieved by exploiting a tightly focused laser beam. These techniques allow us to do research of lattice systems in a more direct and detailed way compared with conventional ways in which only properties of an atomic ensemble are obtained.

My research aims to achieve single site imaging and addressing of ytterbium (Yb) atoms, while previous researches use rubidium atoms [1,2]. The advantages of using Yb are as follows. Firstly, it has rich isotopes including 5 bosons and 2 fermions, so bosons and fermions and also the mixtures can be studied in the same setup. Secondly, it is an alkaline-earth like atom which has ultranarrow optical transitions and metastable states. One of the ultranarrow optical transition can be used for optical magnetic resonance imaging (MRI) [3]. Finally, it has an optical transition with the wavelength of 399 nm, which is advantageous for high resolution imaging.

In this work, I designed and constructed a new system especially suited for this aim. So far atoms are successfully trapped and cooled to a Bose-Einstein condensation in a thin glass cell of 14 mm thickness in a configuration compatible to the imaging and addressing. The performance of high resolution objective lens (Mitutoyo, custom-made) for imaging was checked and confirmed to be enough for this aim. In regard to addressing, optical MRI will be applied. I designed and made special coils for optical MRI. They have been installed around the glass cell. In addition, light-shift addressing of atoms in an optical lattice was performed, which proves to be a good tool for optical MRI of magnetically-insensitive states. Details and performance of the system will be explained in the presentation.



Fig. 1. Overview of the designed setup.

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Spin Excitation Assisted by Non-Softening Phonons for Spin-Peierls Model

Condensed Matter Physics Group (YITP) Takanori Sugimoto

Abstract We study spin dynamics in frustrated spin-Peierls chain by using dynamical density-matrix renormalization group method. In the spin-Peierls chain, we find a new spin excitation assisted by non-softening phonon in the antiadiabatic limit at zero temperature. © 2012 Department of Physics, Kyoto University

One-dimensional quantum spin systems coupled with lattice degree of freedom have been extensively studied experimentally and theoretically, since the systems provide a playground of spin-Peierls transition [1,2]. The experimental studies have shown that the spin-Peierls transition in an inorganic spin-Peierls compound CuGeO₃ is not explained by random phase approximation approach in the adiabatic limit, while the approach is consistent with the experimental studies on the conventional organic compounds. The theoretical studies have shown an explanation of spin-Peierls instability in the antiadiabatic limit, and this theory insists that no soft-mode phonons exist below the explanation of spin-Peierls transition.

exist below the critical temperature of the spin-Peierls transition.

In these studies, many attentions have mainly been focused on the ground state properties, and thus the dynamical and finite-temperature properties of these systems remain unresolved. In the antiadiabatic limit, the non-softening phonons are expected to influence the spin dynamical properties. Therefore, we investigate non-softening phonon effects on spin dynamical behaviors.

In the frustrated spin-Peierls chain, we investigate spin excitation with nearest-neighbor and next-nearest-neighbor Heisenberg spin exchange interactions together with a gapped and dispersionless phonon [2]. The dynamical spin correlation function and phonon excitation spectrum are calculated at zero temperature by using dynamical density-matrix renormalization group method. We find a new spin excitation assisted by non-softening phonon in Fig. 1. The excitation is located above phonon in energy and shows a dispersive feature with strong intensity near the momentum π in Fig. 1(b). The phonon excitation spectrum is also influenced by the spin-phonon interaction. We discuss the possibility of observing the spin-phonon coupled features in inorganic spin-Peierls compound CuGeO₃. The dynamical spin correlation function in an effective model is also calculated in Fig. 1(b). We note that the effective model does not give the new spin excitation into the dynamical spin correlation function.

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Fig. 1. The dynamical spin correlation function in the spin-Peierls chain without spin-phonon coupling (a), and with finite spin-phonon coupling (b). In Fig. (b), the blue dotted line denotes the dynamical spin correlation function in the effective model. The insets are the intensity maps.

Dynamics of quantized Auger recombination in semiconductor nanocrystals

Photonic Elements Science Seiji Taguchi

Abstract We studied multiexciton recombination dynamics in semiconductor nanocrystals using ultrafast laser spectroscopy. A clear correlation is observed between the biexciton Auger recombination rate and the single-exciton trapping rate in CdSe nanorods. We conclude that the Auger recombination rate in the elongated structure is enhanced by an increase of surface-state density.

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Semiconductor nanocrystals are one type of zero-dimensional nanostructures (quantum dots) and show unique size-dependent optical properties. Strong quantum confinement in nanocrystals enhances the Coulomb electron—electron interactions, leading to efficient quantized Auger recombination when multiple electron-hole pairs exist (multiexciton states) [1]. In nonradiative Auger recombination process, the recombination energy of one electron-hole pair (one exciton) is transformed to the kinetic energy of a residual electron or hole. The very rapid nonradiative Auger recombination of multiexcitons causes luminescence degradation and luminescence blinking of nanocrystals. Understanding the mechanism of Auger recombination is significant in fundamental physics and device applications. In this work, the mechanism of quantized Auger recombination was studied in various nanocrystal structures by means of time-resolved photoluminescence (PL) and transient absorption spectroscopy.

In order to evaluate the size and shape dependence of the Auger recombination lifetime, we studied multiexciton dynamics of CdSe spherical nanocrystals and elongated nanorods [2]. We found that in nanorods the biexciton Auger lifetime depends weakly on or is almost independent of the volume, while that in spherical nanocrystals increases linearly with the volume. The biexciton Auger lifetime becomes about 3 times shorter in nanorods than spherical nanocrystals with almost the same volume, clearly showing the enhancement of the Auger recombination rate in elongated structures. For clarifying the origin of this enhancement in more detail, we studied the influence of surface states on exciton recombination processes. We found that the PL decay rate of single excitons reflects the hole-trapping rate into surface states. Moreover, we found a good linear correlation between the Auger recombination coefficient of biexcitons and the PL decay rate of single excitons. Our findings indicate that the intrinsic Auger recombination rate is enhanced by an increase of surface-trap states in nanorods with large surface-to-volume ratios.

Furthermore, we studied optical responses of Mn-doped CdS nanocrystals to reveal the influence of exciton energy transfer process on multiexciton recombination mechanism [3,4]. In Mn-doped nanocrystals, rapid exciton energy transfer into doped Mn ions determines the single exciton recombination rate and the quantum efficiency of Mn-related luminescence. We found that the very rapid Auger recombination rate of multiexcitons reduces the energy transfer efficiency from excitons to Mn ions. The present work provides deeper understanding of quantized Auger recombination rate in semiconductor nanocrystals.

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Predrying transition on a hydrophobic surface: Statics and dynamics

Phase Transition Dynamics Group Ryohei Teshigawara

Abstract We investigate the static and dynamic properties of the predrying transition on a hydrophobic substrate for one-component van der Waals fluids [1]. Predrying transition is a first-order phase transition between a thin (higher density) and thick (lower density or vapor) layer on a submerged wall repelling the fluids.

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(1) Statics

Predrying transition occurs across a predrying line, which starts from the coexistence line and ends at a surface critical point in the phase diagram. We calculate the line numerically using the van der Waals model.

We also numerically realize a thin film and a thick low-density film on a hydrophobic spot. We suppose a cylindrical cell in the axisymmetric geometry and a circular hydrophobic spot on the bottom substrate. The cell is filled with one-component van der Waals fluids. In Fig. 1, we display the cross-sectional density profiles at y=0 near the hydrophobic spot in equilibrium states. A thin film is formed at a temperature $T=0.94T_c$ in the upper panel (a) and a thick low-density film is formed at $0.92T_c$ in the lower panel (b). T_c is the critical temperature. (2) Dynamics

We numerically examine the dynamics of a thin layer formed on the hydrophobic spot, using dynamic van der Waals model [2]. We prepare the equilibrium state at $0.94T_c$ in the panel (a) of Fig. 1 as an initial state at t=0. Then we cooled the top temperature from $0.94T_c$ to $0.92T_c$, fixing the bottom temperature at $0.94T_c$ for t>0. The top of the cell is far enough away from the bottom substrate. In Fig. 2, we show the temperature field in gradation and velocity field by arrows near the hydrophobic spot at t=1000, 1320, and 2000. The black line indicates the boundary between liquid and vapor. At t=1320, a predrying transition is taking place. We can see an upward flow in the liquid region and expansion of the film. There is a cooled region above the expanding film. This is because evaporation occurs and latent heat is absorbed to the film. At t=2000, a thick film appears and a nearly steady state is realized.

We also examine the dynamics of the predrying transition from a thick film to a thin film. During the transition, a heated region appears above the shrinking film due to latent heat release.

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Fig.1. Equilibrium density profiles on a hydrophobic spot.



Fig.2. Temperature field in gradation and velocity field by arrows near the hydrophobic spot.

Dynamics of nonlinear dissipative waves under external forcing and phase description by two phase variables

Nonlinear Dynamics Group Yousuke Tonosaki

Abstract We investigate the dynamics of propagating dissipative waves under external forcing which is periodic both in space and time. A phase diagram for the entrained and non-entrained states is obtained numerically. Results obtained by theoretical analysis in terms of phase description are in quantitatively good agreement with the numerical results. © 2012 Department of Physics, Kyoto University

Various self-organized structures emerge in nonequilibrium open systems. We focus our attention on the traveling periodic waves that are a self-organized structure and investigate theoretically response to space-time dependent external forcing. Our study is based on the model system undergoing phase separation and chemical reactions as

$$\frac{\partial u}{\partial t} = \nabla^2 \left[-\nabla^2 u - \pi u + u^3 \right] + a_1 u + a_2 v + a_3 + \Gamma, \qquad \qquad \frac{\partial v}{\partial t} = b_1 u + b_2 v + b_3 + \Gamma$$

where *u* and *v* are the local concentrations of the chemical species [1]. The parameters τ , a_i , b_i specify the phase separation and chemical reactions and Γ is the external force.

We consider the case that $\Gamma = \varepsilon \cos(q_f x - \Omega t)$ where ε , $2\pi/q_f$ and Ω is the magnitude, the spatial period and the frequency of the forcing, respectively. A phase diagram for the entrained and non-entrained states under the external forcing is obtained numerically as shown in Fig.1. Theoretical analysis in terms of phase description of the traveling waves is carried out to show that the transition between the entrained and the non-entrained states by changing the external frequency occurs either through a saddle-node bifurcation or through a Hopf bifurcation and that these two bifurcation lines are connected at a Bogdanov-Takens bifurcation point [2]. The results obtained by phase description are in quantitatively good agreement with the numerical results.





Fig.1: Phase diagram of the traveling waves under the external forcing on the $\varepsilon - \Omega$ plane. Each symbol indicates asymptotic behaviour of the traveling waves. Symbol +, \diamondsuit and • correspond to (a), (b) and (c) in Fig.2, respectively. The solid (dotted) lines are the saddle-node (Hopf) bifurcation thresholds. The Bogdanov-Takens bifurcation point is indicated by the double circle.

Fig.2: Space (horizontal)-time (vertical) plot of the propagating waves for $\varepsilon = 0.007$ (a) in the entrained state for $\Omega = 0.07$, (b) near the saddle-node bifurcation for $\Omega = 0.1$ and (c) near the Hopf bifurcation for $\Omega = 0.02$. The gray scale indicates the magnitude of the variable u.

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Topological interference of superconductivity in Pb/Ru/Sr₂RuO₄ junctions

Quantum Materials Laboratory

Taketomo NAKAMURA

Abstract We devise new proximity junctions with closed interfaces between *s*-wave superconductivity and the superconductivity of Sr_2RuO_4 . Such junction configuration gives rise to unusual quantum interference originating from the real space and *k*-space topologies of superconductivity. Thus, this junction configuration leads to a new concept of "topological superconducting junctions".

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We devise a new superconducting proximity junction in which an *s*-wave superconductor is surrounded by a chiral *p*-wave superconductor. Such a superconducting junction may be called as a "topological superconducting junction" because of its closed interface distinct from the open interface of conventional superconducting junctions. In the Sr_2RuO_4 eutectic system, micron-size Ru metal inclusions are embedded in Sr_2RuO_4 , which is one of the most promising *p*-wave superconductors[1]. By using the Sr_2RuO_4 -Ru eutectic system and Pb, we succeed in fabricating such junctions which exhibits clear superconducting interference[2]. In the present junctions, we reproducibly observe a strong suppression of the critical current just below the bulk transition temperature of Sr_2RuO_4 . In addition, at lower temperatures, the critical current increases again. This extraordinary temperature dependence is observed irrespective of the Ru arrangements in the junctions. We reveal that the essential configuration giving rise to such anomalous critical current is the Pb/Ru/Sr₂RuO₄ junction[3]. We propose that such a junction configuration can be classified as topological superconducting junctions.

In order to interpret the anomalous temperature dependence of the critical current, we introduce a topological phase competition model between the *s*-wave superconductivity in Ru induced by the proximity effect of Pb and the *p*-wave superconductivity of bulk Sr_2RuO_4 around Ru. In the present junctions, the *s*-wave superconductivity is surrounded by the superconductivity of Sr_2RuO_4 , whose order parameter has a different winding number from that of the *s*-wave order parameter of Ru as shown in Fig. 1. Therefore, such a difference of the phase winding numbers naturally derives cancellation of the Josephson current after integration over the circumference of Ru. In this sense, the observed strong suppression of the critical current confirms the non-trivial real space topology of the superconducting order parameter phase of Sr_2RuO_4 . Thus, topological interference of the superconductivities caused by the making use of both the *k*-space and the real space symmetry provides a new approach to realize novel superconducting phenomena.



Fig. 1 (Left) Schematic of superconducting wave-function phase of Sr_2RuO_4 surrounding Ru and (Right) angular dependence of the superconducting phase φ of Sr_2RuO_4 (solid line) and the phase of the proximity induced *s*-wave superconductivity in Ru (broken line). The local phase difference develops with respect to θ , which is defined as the directional angle normal to the interface.

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Alignment and anchoring of nematic liquid crystals related to the two-dimensional surface transition of aligning polymers

Soft Matter Physics Group Fumiya Nemoto

Abstract Comparing liquid crystal alignment prepared by two different methods, we found that the anchoring strength was independent of methods though it drastically changed bordering near the glass transition of polymers. This result concludes that "alignment" and "anchoring" of liquid crystals on the polymer surface are intrinsically distinguished from each other. © 2012 Department of Physics, Kyoto University

The interface between liquid crystals and polymers has been intensively studied because of its importance for many applications such as liquid crystal displays. To achieve homogeneously planar alignment of nematic liquid crystals (NLCs), solid polymer films are usually coated on substrates and rubbed unidirectionally by clothes. Although there exists the fact that mechanically induced anisotropy of polymers or grooved surface patterns aligns NLC, the essential mechanism for alignment with the rubbing technique and relation between the rubbing process and the anchoring, which is the phenomenon that NLC orientation is fixed at the surface, are not clear.

In this study, we attained "Self-Alignment" which is a new alignment process of NLCs in a cell without the rubbing. The result clearly pointed out that the "anchoring" force to fix NLC molecules on the polymer surfaces originates from the local molecular interaction between NLC molecules and polymers, and it is intrinsically distinguished from the "alignment" force to unidirectionally orient the director of NLCs by breaking the rotational symmetry in the aligning plane. In addition we also discuss the relation between the anchoring properties of NLC cells and the two-dimensional liquid-glass transition at aligning polymer surfaces.

We fabricated NLC sandwiched cells made of two substrates coated with soft polymer film, PMMA without the rubbing. At the temperature higher than a certain temperature $T_{\rm H}$, we could perfectly align NLCs to arbitrary directions along the low applied magnetic field (10 mT) parallel to the substrates. This behavior is quite consistent that the anchoring strength becomes zero on NLC-liquid interfaces [1]. When we simply cooled down to the temperature below $T_{\rm L}$, the director is automatically anchored preserving the same perfect alignment. Thus, the anchoring strength becomes sufficiently strong as well as that in the rubbed surface (see the following paragraph), and the orientation is hardly changed even in the application of the high field (400 mT). It is surprising that not only $T_{\rm L}$ but also $T_{\rm H}$ are lower than the bulk liquid-glass transition temperature ($T_{\rm g}$) of PMMA, and therefore it suggests that anchoring behavior should be deeply related to the two-dimensional liquid-glass transition on the NLC-polymer interface, different from that in the bulk state.

We measured the transmission spectra of NLC cells as a function of applied magnetic field to determine the threshold value of Freedericksz transition B_{th} and the corresponding anchoring strength W at room temperature. The magnetic field was applied parallel to the substrate plane and it induces the reorientation of the bulk NLC director above B_{th} . Fig. 1 shows the cell thickness dependence of B_{th}^{-1} and fitting results by linear functions in the rubbed and "Self-Alignment" PMMA cells explained above. The gradients of these fitting lines correspond to the bulk properties of NLCs, and the x-intercepts correspond to Ws. It was found that Ws are almost the same in the two types of cells, suggesting that W is a unique parameter due to the local interaction between NLCs and polymers and independent of aligning methods, and concludes that "alignment" and "anchoring" are essentially different.

16 14 12 10 8 Bth -1 6 4 Rubbed 2 Self-Alignment 0 50 0 10 20 30 40 60 Cell thickness / um

Fig. 1: Threshold values of Freedericksz transition in the rubbed and "Self-Alignment" NLC cells as a function of the cell thicknesses.

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Correlated Bose-Fermi mixtures in optical lattices

Condensed matter theory group Kazuto Noda

Abstract We study the many-body effects in a Bose-Fermi mixture loaded in optical lattices. We find the emergence of the specific many-body effects in the presence of the bosonic superfluidity. As a consequence, the many-body effects make a peak near the Fermi level in a single-particle excitation spectrum for fermions. We also address how the many-body effects emerge in a supersolid phase; © 2012 Department of Physics, Kyoto University

Cold atoms in an optical lattice created by interfering laser beams have attracted much interest. In these systems one can tune several quantum parameters, such as interactions between atoms and lattice geometries, with high controllability using the magnetic field and the intensity of the lasers. We could consider these systems as ideal stages for studying the quantum many-body models in the conventional condensed matter field. It is well-known that the Hubbard model, which is a fundamental model but still describes the intriguing phenomena such as magnetism and superfluidity, has been realized experimentally in optical lattices [1, 2]. Recently, one can even make a correlated Bose-Fermi mixture in optical lattices [3] which makes a new route to study the many-body effects in a Bose-Fermi mixture system without any analog in the conventional condensed matter field.

Motivated by this, in this presentation, we study the correlation effects in a Bose-Fermi mixture in optical lattices using a generalized dynamical mean field theory combined with Wilson's numerical renormalization group. We reveal that the specific many-body effects in this mixture system emerge in the presence of the bosonic superfluidity [4]. The many-body effects induced by the bosonic degrees of freedom occur even in the empty or filled band limit while a conventional electron system has no correlation effects in these regions. We also find that the peak structure appears near the Fermi surface in the one-particle excitation spectrum for fermions as shown in Fig. 1. This peak structure is enhanced as the magnitude of the bosonic superfluidity become large, which confirms the many-body effects induced by the bosonic degrees of freedom.

Furthermore, we study how the many-body effects appear in a supersolid phase with the fermionic density wave order and bosonic superfluidity. In the previous study [5], Titvinidze et al. pointed out that the supersolid

phase has a peak structure in the one-particle excitation spectrum due to the instability to phase separations. However, our systematic calculations reveal that the many-body effects make this peak structure also in the supersolid phase. We expect that the peak will be observed experimentally in the near future.

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Fig. 1. One-particle excitation spectrum for fermions

Non-universal superconducting gap structure in iron-pnictides revealed by magnetic penetration depth measurements

Electronic Properties of Solids Kenichiro Hashimoto

Abstract High-precision magnetic penetration depth measurements have revealed that the superconducting gap structure of iron-based superconductors is not universal. The fact that the gap structure depends on the detailed magnetic and electronic structure of individual iron-based superconductors imposes an important constraint on the pairing mechanism of this system. © 2012 Department of Physics, Kyoto University

The recent discovery of superconductivity in LaFeAsO_{1-x}F_x has attracted much attention both experimentally and theoretically because of its high transition temperature $T_c \sim 26$ K. So far, various theories have been proposed for the pairing mechanism in this system, but a consensus for the mechanism is still lacking. Since the superconducting gap structure is intimately related to the pairing interaction, a detailed knowledge of the gap structure and how it varies as a function of material parameters will give a strong guide to establishing the pairing mechanism of this system.

In order to elucidate the detailed superconducting gap structure of iron-based superconductors, we performed high-precision measurements of the magnetic penetration depth λ for several iron-based materials such as BaFe₂(As_{1-x}P_x)₂ ($T_c \le 30$ K) [1], KFe₂As₂ ($T_c = 4$ K) [2], and LiFeP ($T_c = 5$ K) [3]. Fig.1 shows the normalized change in the penetration depth for the optimally doped BaFe₂(As_{0.67}P_{0.33})₂ ($T_c = 30$ K), compared with the results for the optimally doped (Ba_{0.45}K_{0.55})Fe₂As₂ ($T_c = 33$ K) [4]. In sharp contrast to the flat temperature dependence observed in the K-doped crystal, indicative of a fully gapped superconducting state, $\lambda(T)$ in BaFe₂(As_{0.67}P_{0.33})₂ exhibits a strong *T*-linear dependence at low temperatures, which demonstrates the presence of nodes in the gap. Moreover, we found that the presence of line nodes in the gap is a robust signature over a wide range of *x* in this P-substituted system, which is consistent with the nodes being on the electron sheets rather than the hole sheets, whose shapes significantly change with *x*.

In this study, we found that the superconducting gap structure of the iron-based superconductors is not universal. This non-universality is quite different to high- T_c cuprate superconductors which all have a nodal d_{x2-y2} pairing state. So unlike the cuprates, the way that the superconducting gap structure depends on the detailed magnetic and electronic structure of individual iron-based superconductors provides a stringent test of candidate theories.

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Fig. 1: The normalized change in the penetration depth for $BaFe_2(As_{0.67}P_{0.33})_2$ and $Ba_{0.45}K_{0.55}Fe_2As_2$.

Quantum Degenerate Mixtures of Alkali and Alkaline-Earth-Like Atoms

Quantum Optics Group Hideaki Hara

Abstract We realize simultaneous quantum degeneracy in mixtures consisting of the alkali and alkaline-earth-like atoms Li and Yb. These quantum degenerate mixtures can be the basis for the creation of ultracold molecules with electron spin degrees of freedom, and a good tool for quantum simulation of impurity systems.

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Ultracold atomic gas mixtures consisting of different elements have many new interesting possibilities. We focus on a pair of alkali (Li) and alkaline-earth-like (Yb) atoms, which has unique features different from other bi-alkali systems. Firstly, polar molecules which consist of alkali and alkaline-earth-like atoms have not only electric dipole moment but also electron spin degrees of freedom in the electronic ground state (${}^{2}\Sigma_{1/2}$). So LiYb molecules may enable us to implement quantum simulation of lattice-spin models[3]. In addition, the large mass ratio of Yb to Li (~29) enables us to study Efimov trimers LiYbYb, which have a much smaller discrete scaling factor ($e^{\pi/s0} \sim 4$) than those composed of identical bosons ($e^{\pi/s0} \sim 22.7$)[4]. Furthermore, the mixture with large mass difference loaded into an optical lattice is a good tool for quantum simulation of impurity systems, such as Anderson localization, where Li atoms behave as electrons and Yb atoms play a role as impurity in solids.

With these motivations, We have successfully produced quantum degenerate Bose-Fermi mixture of ⁶Li-¹⁷⁴Yb and Fermi-Fermi mixture of ⁶Li-¹⁷³Yb[5]. We first prepared simultaneous MOT of Li and Yb[6]. Then we transferred the atoms from the MOT into an optical dipole trap and cooled them to quantum degenerate regime by sympathetic evaporative cooling. Figure.1 shows the result for Bose-Fermi mixture. For ⁶Li, the total atomic number N_{Li} is 2.5×10^4 and temperature T_{Li} is 290 ± 30 nK, corresponding to 0.08 ± 0.01 T_F. For ¹⁷⁴Yb, T_{Yb} is 280 ± 20 nK, below the BEC transition temperature T_c = 510 nK. The number of atoms in the condensate is 1.5×10^4 . In the case of Fermi-Fermi mixture, T_{Li} = 220 ± 40 nK and T/T_F = 0.07 ± 0.02 for ⁶Li and T_{Yb} = 170 ± 10 nK and T/T_F = 0.52 ± 0.12 for ¹⁷³Yb. Using cross-thermalizaton studies, we also measure the elastic *s*-wave scattering lengths of both Li-Yb combinations, $|a_{6Li-174Yb}| = 1.0\pm0.2$ nm and $|a_{6Li-173Yb}| = 0.9\pm0.2$ nm. The equality of these lengths is found to be consistent with mass-scaling analysis. The optical lattice setup for the Yb-Li mixture is now prepared for the study of impurity problems.

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Fig.1 TOF absorption images of Bose-Fermi mixture of ⁶Li and ¹⁷⁴Yb. For ⁶Li, lower left is the integrated optical density and lower right is the azimuthally averaged distribution. For ¹⁷⁴Yb, lower is the integrated OD. Expansion time is 1 ms for ⁶Li and 16 ms for ¹⁷⁴Yb.

Numerical study of tilting effect on Dirac fermion localizatioin in two spatial dimension

Condensed Matter Physics Group (YITP) Takahiro Himura

We numerically study localization effects in the organic compound α -(BEDT-TTF)₂I₃ and show that the anti-localization effect associated with Dirac fermions is enhanced in the presence of Dirac cone tilting. We argue that this enhancement is understood as the breaking of time-reversal symmetry within a tilted Dirac cone.

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Recently Dirac fermions realized in condensed matter systems have attracted much attention since the discovery of unconventional quantum Hall effect in graphene[1]. Graphene, the isolated single layer of Graphite, can be described by four component massless Dirac equation. There are a variety of other materials in which low-lying properties of the conduction electrons are described by a massless Dirac equation with the velocity of light replaced by the Fermi velocity. One of such systems is an organic conductor, $\alpha - (BEDT-TTF)_2I_3$. Under ambient pressure the system exhibits a metal-insulator transition associated with the formation of a charge-density wave state. By applying pressure this metal-insulator transition is suppressed. Under high pressure, typically around 2GPa, the system exhibits the massless Dirac fermion spectrum[2]. In this system, the Fermi surface is reduced to a point, and the valence and conduction bands touch at two points, which are not located in highly symmetric points. In the vicinity of the contact points, the energy band has the form of a cone, which is called Dirac cone, and shows a linear dispersion. As we showed in Ref. [3], the parameters for Dirac fermions, such as the Dirac cone tilting angle and anisotropy within the Dirac cone, depend on applied pressure.

In Dirac fermion systems, electrons acquire an additional feature, which is called chiraltity. The Hamiltonian has the form of "Zeeman energy" term where the wave vector plays a role of magnetic field. There is a Berry phase effect associated with this chirality. Among others it is well known that backward scattering is suppressed due to the Berry phase effect[4]. In fact Dirac fermions in graphene have extremely long scattering time[5]. Contrary to conventional electron systems, we expect an anti-localization effect when inter-valley scattering can be neglected.

In this talk we present numerical simulation results suggesting that anti-localization effect is enhanced in the presence of tilt of the Dirac cone[6]. Physically this enhancement is understood as the breaking of time-reversal symmetry within the single Dirac cone. We use the Kubo formula in computing the longitudinal conductivity by taking the average over configurations of impurity potentials. We show that the anti-localization effect is enhanced compared to graphene in case of α -(BEDT-TTF)₂I₃ due to the presence of the Dirac cone tilt.

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Helical nanofilament arrangement controlled by nematic order

Soft Matter Physics Group Masatsugu Murase

Abstract We studied a mixture of bent-core and rod-like liquid crystals with isotropic-nematic phase transition, and found that the novel mesophase showing a characteristic pattern appears below the nematic phase. Using polarizing microscope, dynamic light scattering, and X-ray diffraction, we discussed the structure of this phase.

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The B4 phase, which is one of specific mesophases formed by bent-core liquid crystals, forms chiral nanofilament structures in spite that it was composed of achiral molecules^[1]. In the binary system of a bent-core liquid crystal P8-O-PIMB and a rod-like nematic (N) liquid crystal 5CB, the B4 phase was stabilized and the Bx phase appears below B4 in mixtures with high concentration of 5CB^[2]. It was $\overline{\underline{J}}_{120}$ found that the mixture forms the micro-phase separation of P8-O-PIMB and 5CB, and B4 is diluted by isotropic liquid of 5CB, and B4-Bx phase transition originates from the isotropic-N phase transition of 5CB rich region^[3]. In this paper, we found that another micro-phase separated phase (Bx') appears when the

N Bx Bx' 110 60 65 35 40 45 50 55 P8-O-PIMB[wt%] Fig.1 Phase diagram of P8-O-PIMB - MixA B4-like structure was formed from the nematic order, and experimentally studied its structure in details.

Iso.

B4

140

We mixed the bent-core liquid crystal P8-O-PIMB and a rod-like nematic mixture (MixA). Figure 1 shows the binary phase diagram of them determined by microscope observation. In case that the N phase appears below the isotropic phase, the mesophase forming the stripe texture parallel to the nematic director appears below N. Since this texture was quite different from that observed in B4 or Bx, we call this phase Bx' here.

Figure 2 shows the wavenumber dependence of the relaxation frequency, namely, the dispersion relation, in Bx'. Just below the N-Bx' phase transition, the dispersion relation almost satisfied the diffusive mode $1/\tau = \Gamma k_s^2$ like N. suggesting that Bx' contains the nematic order structure like Bx. However, temperature dependence of them differs from that of pure nematic liquid crystals, and the dispersion relation is gradually lost with decreasing

temperature. This result suggests that the nematic director fluctuation is localized in a certain domain like Bx, but that the coherent size of domains has a distribution and gradually decreases with the decrease in temperature dislike Bx.

In order to discuss the structures in details, we studied the orientational correlations of the nematic phase and Bx' phase of mixtures using 2D small angle x-ray scattering. The results of Bx' showed the existence of layer structures, and the layer spacing is the same as that in B4 of pure P8-O-PIMB. Therefore, it is considered that the Bx' phase also contains helical filaments like Bx. Furthermore, broad halo peaks originating from the nematic ordered structure

were also observed in Bx', and its director orientation was parallel to the helical axis of helical filaments. Comparing 2D-patterns in Bx' and N, we considered that the nematic director works as a orientational field for the helical filament when it forms in Bx'.

Namely the results clearly indicated that it is possible to control the arrangement of B4 filament by the orientational order of surrounding micro-separated nematic liquid crystals. Now, we are trying to produce novel super-structures of chiral filaments using the spatial modulation of the director induced by the various types of external fields, such as DC/AC electric field, laser light exposure and doping the chiral dopants.

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¹⁰⁰ 10 msec⁻¹ 14 • 124℃ × 120℃ ▲ 122°C +118°C ■114°C -116℃ $k_s [\mu m^{-1}]$ Fig.2 Wavenumber dependence of relaxation frequency

Simple spiking neuron model for reproducing diverse firing patterns and predicting precise firing times

Nonlinear dynamics group Satoshi Yamauchi

Abstract For large-scale simulations of realistic neuronal circuitry, we propose a new simple spiking neuron model by augmenting an existing model. The proposed model succeeded in reproducing various firing responses of real neurons to various transient inputs and predicting firing times of a biological neuron given an *in-vivo* like fluctuating input. © *2012 Department of Physics, Kyoto University*

Information processing performed by animals is carried out by a huge number of neurons in the nervous system which communicate with each other through the exchanging of stereotyped electric pulses, called spikes. In simulating realistic neuronal circuitry composed of numerous neurons by a practical computer system, we need an elemental mathematical model that is not only efficiently simple, but also capable of reproducing input-output relationship of spike signals observed in each single biological neuron.

A well-known simplistic model, the leaky integrate-and-fire model, which had been regarded as a simple toy model of a single neuron, have significantly developed in the direction of quantitatively analyzing electrical properties of real neurons by enhancing their adaptability to data. Recently, the multi-timescale adaptive threshold (MAT) model, based on the linear leaky integration of input currents with a moving threshold, reproduces and predicts precise spike times of regular-spiking, intrinsic-bursting, and fast-spiking neurons, under any in-vivo like fluctuating current[1]; however, this model is supposed to be incapable of reproducing such specific firing responses as inhibitory rebound spiking in response to inhibitory input, or resonate spiking in response to a set of pulse inputs.

In this presentation, we aim to build a simple spiking neuron model that is capable of not only quantitatively reproducing spike times of biological neurons given in vivo-like fluctuating inputs[2], but also qualitatively representing a variety of firing responses to transient current inputs[3]. To build such a neuron model, we start from the investigation of basic dynamical property of the MAT model, which already have a favorable simplistic form and prominent capability of predicting neuronal firing times. As the result of the dynamical analysis, we reveal its poor reproducibility of various neuronal responses in various input situations. Then, by adding a minimal augmentation to the model, we compensate its weakness; that is, the augmentation enables the model to reproduce a full variety of firing responses to various transient current inputs. Despite the augmentation, the model has only four free parameters and is implementable in an efficient algorithm for large-scale simulation due to its linearity, serving as an element neuron model in the simulation of realistic neuronal circuitry.

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