#### Magnetic properties of S = 5/2 triangular lattice dimer Cs<sub>3</sub>Fe<sub>2</sub>Cl<sub>9</sub>

<sup>1</sup>Y. Ishii, <sup>2</sup>Y. Matsushita, <sup>1</sup>H. Yoshida, <sup>1</sup>M. Oda,

 $^{3}\mathrm{A.}$  Takata,  $^{3}\mathrm{T.}$  Kida,  $^{3}\mathrm{Y.}$  Narumi, and  $^{3}\mathrm{M.}$  Hagiwara.

<sup>1</sup>Hokkaido Univ., <sup>2</sup>NIMS, <sup>3</sup>AHMF, Osaka Univ.

 $Cs_3Fe_2Cl_9$  is one of the members of  $A_3M_2X_9$  (A = Cs, Rb; M = Ti, V, Cr, Fe; X = Cl, Br, I) series compounds. The crystal structure consists of triangular lattice of  $(Fe_2Cl_9)^{3-}$  dimers. Three dominant magnetic interactions, an intra-dimer interaction  $J_0$ , and inter-dimer interactions  $J_p$ ,  $J_c$  are considered in this system<sup>[1]</sup>. These competing interactions often evoke exotic phenomena.

We succeeded in synthesizing single crystals of  $Cs_3Fe_2Cl_9$  by hydrothermal synthesis and measured the magnetic properties and the heat capacity on the single crystal. In the previous reports, the magnetic susceptibility of the powder sample showed no magnetic order<sup>[2]</sup>. However, our magnetic and heat capacity measurements on the single crystal revealed that  $Cs_3Fe_2Cl_9$  exhibited an antiferromagnetic long-range order at  $T_N = 5.3$  K under zero magnetic field. Unlike a normal antiferromagnetic transition, the easy-axis magnetic susceptibility showed a sudden drop at  $T_N$  and then it decreased toward zero with *T*-linear temperature dependence. In addition, metamagnetic transitions and successive magnetic phase transitions were observed in our experiments.

We estimated the interactions  $J_0 = -2.4$  K,  $J_1 = (J_p + J_c) = -1.2$  K from fitting by the susceptibility of weak coupled dimer model. The comparable and competing intra-dimer and inter-dimer magnetic interactions on the triangular lattice dimer give rise to the interesting magnetism under magnetic fields.



Fig. 1: A perspective view of the crystal structure of  $A_3M_2X_9(a)$  and the view along the *c* - axis(b).

#### References

- [1] B Leuenberger and Hans U. Güdel, Journal of Solid State Chemistry, 64, 90-101 (1986).
- [2] A. P. Ginsberg and M. B. Robin, Inorg. Chem., 2, 817-822 (1963).

# Muon Spin Relaxation Study on the Magnetic Order of $\pi$ -electrons in the Cesium and Sodium Superoxide

Fahmi Astuti<sup>1,2</sup>, Dita P. Sari<sup>1,3</sup>, Retno Asih<sup>1,3</sup>, Greame Blake<sup>4</sup>, Takashi Kambe<sup>5</sup>, Mizuki Miyajima<sup>5</sup>, Takeshi Kakuto<sup>5</sup>, Takehito Nakano<sup>3</sup>, Yasuo Nozue<sup>3</sup>, and Isao Watanabe<sup>1,2,3</sup>

*RIKEN Nishina Center*<sup>1</sup>, *Hokkaido University*<sup>2</sup>, *Osaka University*<sup>3</sup>, *University of Groningen*<sup>4</sup>, *Okayama University*<sup>5</sup>

Alkali metal superoxides ( $AO_2$ ) are one of ideal model systems to investigate the  $\pi$ -electron magnetism. The KO<sub>2</sub> and RbO<sub>2</sub> systems exhibit the antiferromagnetic (AF) order at temperature of 7 K and 15 K, respectively. Meanwhile, CsO<sub>2</sub> and NaO<sub>2</sub> have been less studied due to the difficulty in synthesizing samples. All  $AO_2$  compounds undergo structural distortions splitting the degeneracy of  $\pi^*$  orbitals causing an magnetic ordered state, so that a magnetically ordered state is expected to appear below in CsO<sub>2</sub> as well [1,2]. In the case of NaO<sub>2</sub>, very little is known about spin states at low temperauress while a 1D AF spin chain has again been predicted to form [3].

We have carried out longitudinal field (LF) and zero field (ZF) by using muon-spin-relaxation ( $\mu$ SR) measurements on CsO<sub>2</sub> and NaO<sub>2</sub> at the RIKEN-RAL Muon Facility in the UK and at the Paul Scherrer Institut (PSI) in Switzerland in order to investigate the magnetic properties of these superoxides. Figure 1 shows the  $\mu$ SR time spectrum of CsO<sub>2</sub> in the ZF condition. The appearance of the spontaneous muon-spin precession was observed at 9K indicating the formation of a magnetically ordered state. With further decreasing temperature below 10K, the frequency of muon spin precession became larger indicating the growth of internal fields at muon sites. At this moment, we did not observe any strong signs of the appearance of the magnetic order in NaO<sub>2</sub> down to 0.3K.



# The electronic properties of graphene on SiC and SrTiO<sub>3</sub> substrates

Jinwoong Hwang<sup>1</sup>, Hye-Jin Ryu<sup>2,3</sup>, Debin Wang<sup>4</sup>, Jonathan Denlinger<sup>2</sup>, Yuegang Zhang<sup>4</sup>, Alessandra Lanzara<sup>5</sup>, Sung-Kwan Mo<sup>2</sup>, and Choongyu Hwang<sup>1,†</sup>

<sup>1</sup> Department of Physics, Pusan National University, Busan 46241, Korea <sup>2</sup> Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA 94709, USA <sup>3</sup> Max Plank POSTECH Center for Complex Phase Materials, Pohang University of

Science and Technology, Pohang 790-784, Korea

<sup>4</sup> The Molecular Foundry, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

<sup>5</sup> Materials Sciences Division, Lawrence Berkley National Laboratory and Department of Physics, University of California, Berkeley CA 94720, USA

Interactions between two different materials sometimes induce novel physical properties that do not exist in each material alone or provide a viable route towards the comprehension of intrinsic physical properties of each material. In this talk, I introduce my recent study on the electronic properties of graphene on SiC(0001) and SrTiO<sub>3</sub> substrates investigated using angle-resolved photoemission spectroscopy. SiC(0001) is a well-known substrate for epitaxial growth of graphene, but hosts a controversial issue on the origin of the high intensity observed at the Dirac energy in the energy spectrum. The comparison of the electron band structure of single-layer graphene to that of zerolayer and double-layer graphene suggests a major role of in-gap states in constituting the observed spectral intensity. SrTiO<sub>3</sub> is one of the widely used materials as a substrate in preparing a thin film heterostructure, which induces a lot of intriguing physical properties of the adjacent thin film. The electron band structure of graphene on SrTiO<sub>3</sub> shows a deviation from the characteristic linearity that is not explained by the Fermi liquid theory. Such deviation is further enhanced with decreasing temperature revealing strong electronelectron correlations in graphene controlled by temperature.

Electron Transport Studies in Biological Molecules with Respect to the Science of Ageing

Harison Rozak\*, Shukri Sulaiman, Mohamed Ismail Mohamed Ibrahim, Isao Watanabe.

Computational Chemistry Physics Lab (CCPL), School of Distance Education, Universiti Sains Malaysia

#### \*Email: harisonrozak7@gmail.com

DNA or deoxyribonucleicacid store genetic information that consists of three structure phosphate, sugar and bases[1]. Between the bases of DNA, there are electron transport. This Electron transport in DNA considers as important biological phenomena and has relation with ageing[2]. The process of electron transfer is the movement of charger from one molecule to another molecule. Muon Spin Relaxation ( $\mu$ SR) technique provides a means to study such phenomena at the microscopic level where electron motion can be probed [3]. There are two mechanisms for electron transport namely tunneling and hopping[4]. The main objectives of this research are to characterize electron transfer in DNA. Consequently this study would allow theoretical and computational works to follow suit to determine the muon sites and the associated hyperfine fields in these simpler components. This research composes of two parts that is experimental and computational part . The Density Function Theory methodology will be employed to study the electronic structure of the host environment and the muonated system[5].



- 1. Pray, L. (2008) Discovery of DNA structure and function: Watson and Crick. Nature Education 1(1):100
- 2. Torikai, E., et al. "Electron transfer in DNA probed by the muon labelling method: A new interpretation." *Physica B: Condensed Matter* 374 (2006): 441-443
- Torikai, E., Nagamine, K., Pratt, F. L., Watanabe, I., Ikedo, Y., Urabe, H., & Grimm, H. (2001). Probing Electron Transfer in DNA–New Life Science with Muons. *Hyperfine interactions*, 138(1-4), 509-513.
- Boon, E. M., & Barton, J. K. (2002). Charge transport in DNA. Current opinion in structural biology, 12(3), 320-329
- Hubbard, P. L., Oganesyan, V. S., Sulaimanov, N., Butt, J. N., & Jayasooriya, U. A. (2004). Avoided level crossing muon spectroscopy of free radicals formed by muonium addition to the constituents of DNA. *The Journal of Physical Chemistry A*, 108(42), 9302-9309.

## Analysis of multichimera states in nonlocally coupled phase oscillators

#### Division of Physics, Hokkaido Univ. Yusuke Suda, Koji Okuda

In many various natural or artificial systems, nonlinear limit-cycle oscillators compose a many-body system, and interact with one another. The chimera state is one of the interesting behavior of these oscillator systems. The chimera state often appears in the systems of nonlocally coupled identical oscillators, and is characterized by the coexistence of coherent synchronous region and incoherent not-synchronous region. Especially, the chimera state with two or more coherent and incoherent region each is called the multichimera state.

We consider the system of nonlocally coupled identical phase oscillators

$$\frac{\partial}{\partial t}\theta(x,t) = \omega - \int_{-\pi}^{\pi} dx' \, G(x-x') \, \sin(\theta(x,t) - \theta(x',t) + \alpha) \tag{1}$$

where  $\theta(x)$  is  $2\pi$ -periodic phase on the one dimensional space  $x \in [-\pi, \pi]$  under the periodic boundary condition,  $\omega$  is the identical natural frequency, and  $\alpha$  is the phase lag parameter. The coupling kernel G which is even provides nonlocal coupling, e.g.  $G(x) = (\kappa/2) \exp(-\kappa|x|)$  [1-2] and  $G(x) = (2\pi r)^{-1} H(\pi r - |x|)$  where H is the Heaviside step function [3]. It is known that the chimera state has the steady mean field obtained by solving the self-consistent equation.

In this study, we have studied the multichimera state for the Eq. (1), especially, which has two coherent and incoherent regions each as shown in Fig. 1, and analytically shown that the mean field of such multichimera state depend on only odd harmonic components  $\{g_{2l-1}\}$   $(l \in \mathbb{N})$  for the coupling kernel  $G(x) = \sum_{k=0}^{\infty} g_k \cos(kx)$ . Moreover, by using the coupling kernel  $G_{odd}(x) = \sum_{l=1}^{\infty} g_{2l-1} \cos((2l-1)x)$ , we have been able to obtain the mean field of the multichimera state for the Eq. (1) with  $G(x) = \sum_{k=0}^{\infty} g_k \cos(kx)$  by solving the self-consistent equation numerically.



Figure 1: The multichimera state for the Eq. (1) with  $\omega = 0$  and  $\alpha = 1.500$ . The left figure (a) shows the snapshot of phase  $\theta(x)$ , and the right figure (b) shows the profile of the average frequency  $\langle \dot{\theta}(x) \rangle$ . We use the coupling kernel  $G(x) = (2\pi r)^{-1} H(\pi r - |x|)$  with r = 0.360.

- [1] Y. Kuramoto and D. Battogtokh, Nonlinear Phenom. Complex Syst. 5, 380 (2002).
- [2] D. M. Abrams and S. H. Strogatz, Int. J. Bifurcation Chaos 16, 21 (2006).
- [3] O. E. Omel'chenko, Nonlinearity **26**, 2469 (2013).

# Gap structure of superconductivity mediated by orbital nematic fluctuations

Tomoaki Agatsuma and Hiroyuki Yamase

Graduate School of Science, Hokkaido University National Institute for Materials Science

Superconductivity mediated by spin fluctuations is extensively discussed for iron-based superconductors. However, the typical phase diagram of iron-based superconductors shows the proximity not only to the antiferromagnetic phase but also to the nematic phase, suggesting a possible important role of nematic fluctuations for the superconducting mechanism. In fact, assuming that the nematic phase is driven by the occupation difference between the  $d_{xz}$  and  $d_{yz}$  orbitals, Yamase and Zeyher found that orbital nematic fluctuations drive strong coupling superconductivity with a transition temperature comparable to that typically observed in ironbased superconductors [1].

In this study [2], following Ref. 1, we employ a minimal two-band model consisting of the  $d_{xz}$  and  $d_{yz}$  orbitals and choose model parameters to reproduce the typical Fermi surface geometry observed in iron-based superconductors (Fig. 1). We then solve the linearized Eliashberg equations down to low temperatures with keeping a renormalization function. Our new aspect is that we keep also a full momentum momentum dependence of the pairing gap in the Eliashberg equations, which was neglected in the previous study [1]. We can therefore elucidate one of the fundamental properties of superconductivity, namely the typical gap structure of superconductivity mediated by orbital nematic fluctuations.

We find that when the superconductivity occurs from the normal phase, the pairing gap exhibits a weak momentum dependence and can be approximated to be nearly isotropic. The superconducting instability can also occur from the orbital nematic phase. In this case, the pairing gap acquires a large modulation on each hole-like Fermi surface and becomes highly anisotropic. The gap on the electron-like Fermi surfaces, however, remains almost isotropic. These gap structures are compared favorably with some of angle-resolved photoemission spectroscopy data, indicating that orbital nematic fluctuations can be important to superconductivity in iron-based superconductors.

- [1] H. Yamase and R. Zeyher, Phys. Rev. B 88, 180502(R) (2013).
- [2] T. Agatsuma and H. Yamase, arXiv: 1609.02861.



Figure 1: Typical Fermi surfaces of iron-based superconductors. Black (red) curves denote hole-like (electron-like) Fermi surfaces.

# NMR study for charge ordered state in β"-(BEDT-TTF)<sub>4</sub>Pt(CN)<sub>4</sub>·H<sub>2</sub>O

Dept. of Phys. Graduate School of Science, Hokkaido Univ. Takumi Waragai, Yosuke Futami, Yoshihiko Ihara, Atsushi Kawamoto

In some organic superconductors, superconductivity is observed in the neighborhood of charge ordered phase. Charge fluctuation near the charge ordering instability has been suggested to induce such superconductivity. In the charge ordered state, electrons are localized. Localized electrons are, in principle, incompatible with superconductivity. It is very important to clarify the relationship between the superconducting phase and the charge ordering phase in order to understand superconducting pairing mechanism. In  $\beta$ "-(BEDT-TTF)<sub>4</sub>Pt(CN)<sub>4</sub>·H<sub>2</sub>O at ambient pressure, electric resistivity shows metallic behavior from 300 K down to about 200 K[1]. Below 200K, semiconductor-like electrical resistivity is observed. From the result of electronic resistivity measurement, it is revealed that a weak charge ordering transition occurs at 200K. From the result of Ramon spectroscopy measurement, it is also suggested that the charge separation occurs at ambient pressure[2]. In temperature-pressure phase diagram constructed from the electric resistivity measurement, semiconducting phase is located at the lower pressure side. This state is considered to

be the charge ordered phase. Under the hydrostatic pressure, the Pt salt shows superconductivity around  $T_c = 2K$ . Therefore, this salt is a good candidate to study the relationship between superconducting phase and charge ordered phase. We measured the temperature dependence of NMR spectrum and nuclear spin-lattice relaxation rate T<sub>1</sub> by means of <sup>13</sup>C NMR analysis in order to elucidate the electronic state in the charge ordered phase of the Pt salt at ambient pressure. Figure 1. shows NMR spectra of the Pt salt at ambient pressure. The magnetic field is 7 T and applied parallel to the conducting plane of the Pt salt. At 240 K, 4 peaks which originate from 4 crystallographically different <sup>13</sup>C sites were observed. However, spectrum was not observed once at 200K. then broad spectrum was observed at the lower temperatures. This result shows that there is the charge order transition at 200 K. We found the clear charge ordering transition at 200K. In the presentation, I will show the detailed analysis about the temperature dependence of NMR shift and T<sub>1</sub>.

H. Mori *et al.*, Solid State Communication 80, 412 (1991).
 T. Yamamoto, Crystals 2, 893-934 (2012).



Fig. 1. Temperature dependence of <sup>13</sup>C-NMR spectrum with applying magnetic field parallel to the conducting plane.

# Investigation of magnetic ordered states in the pyrochlore iridates (Nd<sub>1-x</sub>Ca<sub>x</sub>)<sub>2</sub>Ir<sub>2</sub>O<sub>7</sub>

R. Asih<sup>1,2</sup>, N. Adam<sup>1,3</sup>, S. S. Mohd-Tajudin<sup>1,3</sup>, S. Maeda<sup>4</sup>, K. Matsuhira<sup>4</sup>, M. Wakeshima<sup>5</sup>, Y. Hinatsu<sup>5</sup>, A. Miyake<sup>6</sup>, M. Tokunaga<sup>6</sup>, I. Watanabe<sup>1,2,3,5</sup>, T. Nakano<sup>2</sup>, and Y. Nozue<sup>2</sup>

RIKEN Nishina Center<sup>1</sup>, Dept. of Phys. Osaka Univ.<sup>2</sup>, Universiti Sains Malaysia<sup>3</sup>, Kyushu Institute of Technology<sup>4</sup>, Hokkaido Univ.<sup>5</sup>, ISSP University of Tokyo<sup>6</sup>

Pyrochlore iridates,  $R_2Ir_2O_7$  (R227, R = Y and lanthanide elements), have recently attracted growing interests because of their potential to realize topological states. The comparable of electron-electron correlation (U) and spin orbit interaction (SOI) in these well-known frustrated systems generates a large systematic variation in properties with changes in R [1, 2]. Among these iridates, Nd<sub>2</sub>Ir<sub>2</sub>O<sub>7</sub> stands out as a fascinating system because of additional interesting properties. Nd<sub>2</sub>Ir<sub>2</sub>O<sub>7</sub> is an ideal system to realize the all-in all-out (AIAO) magnetic structure where dipoles point the local axes toward and outward the tetrahedron center. This unique structure retains the inversion symmetry of the pyrochlore lattice realizing the topological semimetal states [2]. Moreover, AIAO structure has theoretically been predicted to drive a quantum critical point because the anisotropy of this structure can be tuned, for example, by using light carrier doping.

In this study, we report the effect of Ca substitution on the magnetic ordered states in  $Nd_2Ir_2O_7$ investigated by muon-spin relaxation. This Ca-substitution leads to the doping of carriers (holes) in the Ir 5d band. The pure Nd<sub>2</sub>Ir<sub>2</sub>O<sub>7</sub> shows metallic behavior at high temperature and undergoes metalinsulator transition (MIT) at 33 K [3]. As shown in the Fig. 1, the hole-doping gradually suppressed the  $T_N$  and the internal field coming from Ir<sup>4+</sup> ordering, while the internal field coming from Nd3+ ordered moments tended to increase. Nd<sup>3+</sup> moments show the static ordering below about 10 K which is independent to the Ca concentration. Detail results and discussions of the  $\mu$ SR measurements on  $(Nd_{1-x}Ca_x)_2Ir_2O_7$  will be presented in the talk.



Figure 1. Temperature dependence of the internal field at muon sites in  $(Nd_{1-x}Ca_x)_2Ir_2O_7$ . Solid lines are a guide to the eye. Ir moments order simultaneously at  $T_{MI}$  while Nd moments mainly order below 10 K.

#### References:

- [1] J. S. Gardner et al., Rev. Mod. Phys. 82, 53 (2010)
- [2] X. Wan et al., Phys. Rev. B 83, 205101 (2011)
- [3] K. Matsuhira et al., J. Phys. Soc. Jpn. 80, 094701 (2011).

# Effect of organic materials used in the synthesis on the emission of CdSe Quantum Dots

#### Jae-Won Lee, Min Jung Lee and Ho-Soon Yang\*

#### Department of Physics, Pusan University, Busan 609-735

Quantum dots (QDs) have attracted considerable interest for both basic researches and industrial application. QD nanocrystals have particular optical properties due to the quantum confinement effect and surface effect. The practical applications all require the fundamental understanding of the photophysical properties which are strongly affected by size and surface condition.

We prepare CdSe QDs using a chemical colloidal method, where the balance between nucleation and growth is the key for controlling QD size and size distribution of the resulting QDs. A chemical colloidal method, a low costing synthesis method, is widely used to grow QDs with a narrow size distribution. The surface of QDs prepared by the chemical colloidal method is complicated due to the surface imperfection and the organic materials used in the synthesis procedure. The number of atoms existing at QD surface reaches a half of total number of atoms forming a QD as the size reduces to a few nanometers, and therefore, the surface condition of QD is important in determination of the physical properties of QDs. This study focuses on the effects of organic materials on the surface on the emission of QDs.

As using 1-hexadecylamine or tri-octylphosphine oxide in the synthesis of QDs, we prepare two sets of CdSe QDs having different surface conditions. The QDs prepared with 1-hexadecylamine in the synthesis show strong emission, while the quantum dots prepared with tri-octylphosphine oxide exhibit a suppressed emission and an extra emission related with the surface energy traps. These organic materials make the surface conditions of quantum dots different. TEM images and X-ray diffraction patterns reveal that 1-hexadecylamine constructs a layer on the surface of quantum dot during the synthesis and this surface passivation by a layer of 1-hexadecylamine reduces the surface energy traps. Differently from 1-hexadecylamine, tri-octylphosphine oxide dangles from the surface, which causes a poorly passivated surface. This generates the surface deep trap levels giving rise to a significant and broad emission in the lower energy regime. The optical mechanism is studied by measuring the emission and the time-resolved spectra at various temperatures from 4 K to 300 K.

#### Muon-spin Relaxation Function in Dilute Spin System

#### By Muhamad Darwis Umar

#### Abstract

This work is only to analytically perform the previous results. In static internal field, our derivation to an applied field-Gaussian case confirms Kubo's *et al* work, but for Loretzian case, it shows a competition of divergent terms. This result was also reported by Larkin *et al* by applying Kubo Golden Rule (KGR). In dynamic case, our derivation confirms the Hayano's *et al* result. The strong collision and frozen muons at an interstitial sites models have been used to analytically re-derive Muon relaxation function in dilute spin glasses and confirm the work result by Uemura *et al*. The correlation function of spins is divided into two parts to cover the coexisting static and dynamic internal random fields.

# Ground state magnetic Raman scattering in antiferromagnetic spin tubes

# Department of Physics, Hokkaido University Takashi Inoue and Shoji Yamamoto

Magnetic Raman scattering is important probe to study magnetic excitation of antiferromagnets and there are many experimental observations and theoretical calculations. Magnetic Raman operator is described as exchange interaction by light and written by equation (1)[1]. Here  $\hat{e}_i$  and  $\hat{e}_s$  are the polarization vectors of the incident and scattered light,  $\delta$  is a vector connecting two sites,  $J_{\delta}$  is the exchange interaction on the  $\delta$  bond and  $S_r$  is a spin operator of site r. In terms of the eigenstates  $|n\rangle$  and eigenvalues  $E_n$  of the Heisenberg model, magnetic Raman scattering intensity is given by Fermi's golden rule and described by equation (2).

$$\mathcal{R} = \sum_{\boldsymbol{r}} \sum_{\boldsymbol{\delta}} J_{\boldsymbol{\delta}}(\hat{\boldsymbol{e}}_{i} \cdot \boldsymbol{\delta}) (\hat{\boldsymbol{e}}_{s} \cdot \boldsymbol{\delta}) \boldsymbol{S}_{\boldsymbol{r}} \cdot \boldsymbol{S}_{\boldsymbol{r}+\boldsymbol{\delta}}$$
(1)

$$I(\omega) = \sum_{n} \left| \langle n | \mathcal{R} | 0 \rangle \right|^2 \delta \left( \hbar \omega - (E_n - E_0) \right)$$
<sup>(2)</sup>

In this study, we evaluated Raman scattering intensity (2) of  $D_{4h}$  symmetry antiferromagnetic Heisenberg spin tube (Fig.1). Fig.2 shows the magnetic Raman spectrum which calculated by modified spin wave theory (non-perturbative case: MSW-NP, perturbative case: MSW-P) [2, 3] and exact diagonalization(ED)[4]. The spectrum of MSW-NP has two large peaks, but MSW-P spectrum has one large peak and one small peak. In comparison with ED result, peak positions and structures are improved by introducing to magnon-magnon interaction as perturbation. Details of calculations and discussions will be reported in the presentation.



Fig.2  $B_{1g}$  mode magnetic Raman spectra at spin tube length L = 4.

- [1] B. S. Shastry and B. I. Shraiman, Int. J. Mod. Phys. B 5, 365 (1991).
- [2] M. Takahashi, Phys. Rev. B 40, 2494 (1989).
- [3] C. M. Canali and S. M. Girvin, Phys. Rev. B 45, 7127 (1992).
- [4] A. W. Sandvik, S. Capponi, D. Poilblanc and E. Dagotto, Phys. Rev. B 57, 8478 (1998).

# Role of the $\pi$ -electrons in the anomalous anti-ferromagnetic insulating phase of $\lambda$ -(BETS)<sub>2</sub>FeCl<sub>4</sub>

Hokkaido university<sup>1</sup>, RIKEN<sup>2</sup> Nihon university<sup>3</sup>

<u>Taehoon Lee</u><sup>1,2</sup>, Yugo Oshima<sup>1,2</sup>, Hengbo Cui<sup>2</sup>, Akiko Kobayashi<sup>3</sup> and Reizo Kato<sup>2</sup>

The two-dimensional organic conductor  $\lambda$ -(BETS)<sub>2</sub>FeCl<sub>4</sub> is composed from the conducting  $\pi$ -electrons of BETS molecules and the magnetic d-electrons of Fe<sup>3+</sup> ions. Due to non-negligible interaction between  $\pi$ - and d-electrons,  $\lambda$ -(BETS), FeCl<sub>4</sub> has fascinating phase diagram as a function of temperature and magnetic



750

700

650

600

550

45

50

55

Fig. 2 Angular dependence of spin-flop resonance.

60

65

field such as an anti-ferromagnetic insulating (AFI) phase, a paramagnetic metal (PM) phase and a field-induced superconducting (FISC) phase [1]. The AFI phase of  $\lambda$ -(BETS)<sub>2</sub>FeCl<sub>4</sub> is under a strong debate whether the d-electrons are long range ordered or not [2,3]. Therefore, to have a microscopic information about AFI ground state, we have investigated the AFI and PM phases using X-band and high-field ESR spectroscopy.

Below 4 T, we have observed conventional anti-ferromagnetic resonance (AFMR) for hard-axis. However, we have surprisingly observed two ESR signals above 4 T (Fig. 1).

We have also performed X-band ESR measurements on  $\lambda$ -(BETS)<sub>2</sub>FeCl<sub>4</sub>. The magnetic field was rotated parallel to the ac-plane. We have observed the spin-flop resonance which has a bubble-like structure. The center of the bubble corresponds to the easy-axis, and the easy-axis seems to change with temperature (Fig. 2). These results suggest that the electric state of  $\pi$ -electrons is changing inside the AFI phase. In my presentation, I will discuss about this anomalous anti-ferromag-

netic ground state of  $\lambda$ -(BETS)<sub>2</sub>FeCl<sub>4</sub>

Angle (degree)

[1] S. Uji and J. S. Brooks, J. Phys. Soc. Jpn. 75, 051014 (2006).

easy-axis changing

75 80

70

- [2] H. Akiba et al., J. Phys. Soc. Jpn. 78, 033601 (2009)
- [3] L. Brossard et al., Eur. Phys. J. B 1, 439-452 (1998).

# Effect of oxidation in oxygen-deficient SrFe<sub>0.8</sub>Co<sub>0.2</sub>O<sub>3-δ</sub> thin films

Joonhyuk Lee, Eunyoung Ahn, Yu-Seong Seo\*, Younghak Kim\*\*, Jae-Young Kim\*\*, Jungseek Hwang\*\*, Yunhyeong Jang, Jinhyung Cho\*\*\*, and Hyoungjeen Jeen

Department of Physics, Pusan National University, Busan, 46241, Korea, \*Department of Physics, Sungkyunkwan University, Suwon, Gyeonggi-do, 16419, Korea, \*\*Pohang Accelerator Laboratory, Pohang University of Science and Technology, Pohang, 37673, Korea, \*\*\*Department of Physics Education, Pusan National University, Busan, 46241, Korea

X-ray absorption spectroscopy (XAS) is a powerful technique to measure the valence state of transition metals, degree of hybridization between oxygen and transition bond, element specific magnetism. Study of transition metal oxides is being many researched due to diverse physical properties. XAS is an invaluable tool, since these properties are often induced by the number of electrons in the transition metal ions. Controlling oxygen contents is a route to change the valence state in the transition metal oxides and often leads to various phase transitions. In this study, we studied effect of oxygen intercalation into  $SrFe_{0.8}Co_{0.2}O_{3-6}$  (SFCO) thin films. we grow epitaxial SFCO films on (001) (LaAlO<sub>3</sub>)<sub>0.3</sub>-(SrAl<sub>0.5</sub>Ta<sub>0.5</sub>O<sub>3</sub>)<sub>0.7</sub> substrates by pulsed laser deposition. We checked crystallinity from high resolution x-ray diffraction. From diffraction study, we could confirmed the oxygen intercalation into the SFCO thin films were successfully without losing crystallinity. From transport and optical study, the electronic phase transition from insulating phase to metallic phase upon oxygen intercalation took place. To compare between electronic properties and valence states of Fe, Co and O, we performed XAS measurement of Fe *L*-edge, Co *L*-edge and O *K*-edge spectra.

#### Hall effect in the Abrikosov lattice of type-II superconductors

Wataru Kohno, Hikaru Ueki, Takafumi Kita

Department of Physics, Hokkaido University, Sapporo 060-0810, Japan, e-mail: wataruv@phys.sci.hpkudai.ac.jp

The Lorentz force on electric currents flowing in magnetic fields generally induces charge redistribution before recovering a steady state to yield the Hall voltage that brings a force balance along the transverse direction. However, we still have quite a poor understanding of this phenomena in superconductors. This is because the force on supercurrent itself may easily be overlooked in the presence of the predominant diamagnetic effect by supercurrent. Indeed, the Lorentz force is missing from the standard Ginzburg-Landau and Eilenberger equations that have been used extensively in the literature, and can only be reproduced microscopically as a next-to-leading order contribution in the expansion in terms of the quasiclassical parameter based on the Gor'kov equations. Hence, physics of the Lorentz force in superconductors remains mostly unexplored theoretically. The main purpose of our study is to clarify the fundamental nature of the Hall effect in superconductors.

Hall effect in superconductors may be divided into two categories: one in equilibrium with persistent currents and the other in nonequilibrium situations with the motion of vortices and dissipation. The first one is inherent to superconductors and easier to handle but nevertheless has not been paid much attention in the literature. Here, we focus on this first category and study vortex charging in type-II superconductors as a function of the magnetic field based on the augmented quasiclassical equations of superconductivity [1,2]. We study the charge density and electric field due to the Lorentz force in the vortex lattice of clean type-II superconductors focusing on the two types of models below: (i) *s*-wave pairing with isotropic Fermi surface in two dimension [3] and (ii)  $dx^2-y^2$ -wave pairing with anisotropic Fermi surface obtained from the tight-binding approximation for two-dimensional square lattice model. Results and considerations are shown in detail in our presentation. The two figures below are part of the results obtained from our study.



Fig. 1. Field dependence of the charge density in an *s*-wave superconductor (model (i)) at the vortex center [2].  $\rho_{\text{single}}$  and  $\rho_{\text{Khomskii}}$  denote the charge density at the lower critical field and at the absolute zero temperature in Ref. [4].

#### References

- [1] T. Kita, Phys. Rev. B. 64, 054503 (2001).
- [2] H. Ueki, W. Kohno, and T. Kita, J. Phys. Soc. Jpn. 85, 064702 (2016).
- [3] W. Kohno, H. Ueki, and T. Kita, J. Phys. Soc. Jpn. 85, 083705 (2016).
- [4] D.I. Khomskii and A. Freimuth, Phys. Rev. Lett. 75, 1384 (1995).



Fig. 2. Spatial structure of the charge density in a *d*-wave superconductor with anisotropic Fermi surface (model (ii)) at  $T/T_c=0.3$  and  $H/H_{c2}=0.29$ , where  $T_c$  is transition temperature at H=0 and  $H_{c2}$  is upper critical, respectively. Black circle indicates the boundary of the region which occupies the half area of the unit cell in the vortex lattice.

#### High-pressure synthesis and thermoelectric properties of Eu<sub>x</sub>Co<sub>4</sub>Sb<sub>12</sub>

J. Sirimart, R. Nakajima, K. Nishine, Y. Mona, J. Hayashi, Y. Kawamura and C. Sekine Muroran Institute of Technology, 27-1 Mizumoto-cho, Muroran, 050-8585, Japan.

We present the thermoelectric properties of partially Eu filled skutterudite compounds  $Eu_xCo_4Sb_{12}$ prepared under high pressure using a cubic anvil press. CoSb<sub>3</sub>-based skutterudite compounds have been regarded as one of the best candidates of thermoelectric materials because the compound has excellent thermoelectric properties such as large Seebeck coefficients and high hole mobilities, while the lattice thermal conductivity is too high [1]. The vacancy inside the Sb-cage of  $CoSb_3$  can accept a relatively large guest ion. Therefore, a marked rattling effect is expected owing to the large vibration of the guest ion located inside the cage. We focused on Eu as a guest ion because Eu is believed to be easier to fill in the vacancy of CoSb<sub>3</sub>. The synthesis of Eu<sub>0.54</sub>Co<sub>4</sub>Sb<sub>12</sub> at ambient pressure has been reported [2]. However, higher Eu filled samples than  $Eu_{0.54}Co_4Sb_{12}$  has not been reported. In order to increase the filling ratio of Eu, we synthesized Eu<sub>x</sub>Co<sub>4</sub>Sb<sub>12</sub> by using the high-pressure synthesis method. The samples were prepared by reacting stoichiometric amounts of 3N (99.9% pure)-Eu, 4N-Co, and 6N-Sb powders at 2 GPa and kept at 600 °C. The phase compositions and actual Eu filling ratios were characterized by x-ray diffraction (XRD) and electron probe microanalysis (EPMA), respectively. The XRD results indicate the samples under high pressure and high temperature method have larger lattice parameter than any  $Eu_xCo_4Sb_{12}$  prepared at ambient pressure. The EPMA results show that the maximum actual Eu doping content was increased to 0.77. Thermal conductivity, Seebeck coefficient and electric resistivity for  $Eu_xCo_4Sb_{12}$  have been studied over the temperature range between 2 and 300 K. The electrical resistivity shows semi-metallic behavior. The Seebeck coefficient exhibits a behavior of n-type conductor. The highly doped Eu can enhance electrical conductivity and reduce thermal conductivity. The maximum value of electrical conductivity and thermal conductivity of  $Eu_xCo_4Sb_{12}$  at 300 K were 11.5×10<sup>4</sup> S/m and 5.43 W/mK, respectively.

[1] G. S. Nolas, J. L. Cohn, G. A. Slack, Phys. Rev. B 58, 164 (1998).

[2] W. Jeitschko, A. J. Foecker, D. Paschke, M. V. Dewalsky, C. B. H. Evers, B. Kunnen, A. Lang, G. Kotzyba,
U. C. Rodewald, M. H. Möller, Z. Anorg, Allg. Chem. 626, 1112 (2000).

# Muon in High-T<sub>c</sub> superconducting YBa<sub>2</sub>Cu<sub>3</sub>O<sub>6</sub>

# S.S. Mohd-Tajudin,<sup>1,2</sup> T. Nishizaki,<sup>3</sup> A. Kikkawa,<sup>4</sup> N. Adam,<sup>1,2</sup> E. Suprayoga,<sup>2,5</sup> M.I. Mohamed-Ibrahim,<sup>1</sup> S. Sulaiman,<sup>1</sup> and I. Watanabe.<sup>2</sup>

# <sup>1</sup>Universiti Sains Malaysia, <sup>2</sup>RIKEN Nishina Center, <sup>3</sup>Kyushu Sangyo University, <sup>4</sup>RIKEN CEMS and <sup>5</sup>Institut Teknologi Bandung.

Most of high-T<sub>c</sub> superconducting oxides are cuprate compound [1]. In the crystal structure,  $CuO_2$  planes are responsible for the electronic properties, the presence of superconductivity can be observed by doping carriers into the  $CuO_2$  plane of the antiferromagnetic (AF) Mott-insulator compound. With doping, the insulator-metal transition arises and the system changes from the Mott-insulator to high-T<sub>c</sub> superconductors. A rewarding strategy in understanding the electronic properties of high-T<sub>c</sub> has been to study Mott-insulator YBa<sub>2</sub>Cu<sub>3</sub>O<sub>6</sub> (YBCO) compound which shows a magnetic ordering.

One of the technique to understand the electronic states, spin structures and hyperfine field is Muon Spin Relaxation ( $\mu$ SR). [2] We implanted muon in the YBCO compound by  $\mu$ SR experiment and computational using Density Functional Theory (DFT) method. We observed the muon behavior in  $\mu$ SR experiment and DFT calculation. Since muon is a particle, it is vibrating and thus it has zero potential energy. In our presentation, we are going to report more detailed on who zero potential energy affect the hyperfine field.

References

[2] S.S. Mohd-Tajudin, J. Phys.: Conf. Ser. 551 012052 (2014).

<sup>[1]</sup> M.Cyrot and D. Payuna, *Introductin of Superconductivity and High-T<sub>c</sub> Materials*, World Scientific, Singapore (1991).

### Tests for the Novel Magnetoelectric Effects on a Toroidal Magnetic Ordered State of UNi<sub>4</sub>B

<sup>1</sup>Graduate School of Science, Hokkaido University, <sup>2</sup>KEK IMSS CMRC H. Saito<sup>1</sup>, N. Miura<sup>1</sup>, C. Tabata<sup>2</sup>, H. Hidaka<sup>1</sup>, T. Yanagisawa<sup>1</sup>, and H. Amitsuka<sup>1</sup>

Toroidal moment is one of the parameters which describes the strength of the magnetoelectric effect. In the last decade, the toroidal order, which is the ordered periodic array of toroidal moments, has attracted much interest in connection with multiferroic insulating materials. Recently, S. Hayami *et al.* suggested theoretically that such an exotic order can occur in metallic systems without local inversion symmetry at magnetic ion sites. In addition, they also suggested that the exotic phenomena such as magnetization induced by electric current and Hall voltage which is proportional to the square of electric current  $I^2$  can occur in the toroidal ordered metal [1].

UNi<sub>4</sub>B crystalizes in the orthorhombic structure (symmetry: *Cmcm*,  $D_{2h}^{17}$ , No. 63)[2]. The actual lattice can be treated as a slightly distorted hexagonal structure, where U ions form the distorted triangular lattice. Below  $T_N$  (= 20.4 K), UNi<sub>4</sub>B orders antiferromagnetically in a magnetic structure where the magnetic moments carried by the 2/3 of U ions make the vortices in each of triangular planes [3]. This magnetic structure is the same as the one assumed in the above theory.

In order to make a test for the theory, we have performed the measurements of magnetization under electric current and Hall coefficient in UNi<sub>4</sub>B for the first time. Magnetization measurements under electric current revealed that magnetization is changed by electric current below  $T_N$ . Comparing the features of this phenomena with the theory, we conclude that electric current induces magnetization in the ordered state of UNi<sub>4</sub>B[4]. Thus, in the sense that current-induced-magnetization is observed in a metallic system without local inversion symmetry, the validity of the theory is confirmed in part by the experiments. On the other hand,  $I^2$  dependence of Hall voltage is not observed in the accuracy of present measurements, may be due to the considerably small current-induced-magnetization.

- [1] S. Hayami et al., Phys. Rev. B 90, 024432 (2014).
- [2] Y. Haga et al., Physica B 403 900-902 (2008).
- [3] S. A. M. Mentink et al., Phys. Rev. Lett. 73, 1031 (1994).
- [4] H. Saito et al., JPS autumn meeting, 9aBK-13 (2014).

# High-pressure synthesis and magnetic properties of layered rare-earth phosphide GdZn<sub>3</sub>P<sub>3</sub> and DyZn<sub>3</sub>P<sub>3</sub>

K. Ikemori, K. Suzuki, Y. Kawamura, J. Hayashi and C. Sekine Muroran Institute of Technology, 27-1 Mizumoto-cho, Muroran, 050-8585, Japan

The ternary phosphide  $RZn_3P_3(R = rare-earth)$  crystallizes in the hexagonal ScAl<sub>3</sub>C<sub>3</sub>-type structure (space group P63/mmc) [1]. In the compound, R atoms form a two dimensional triangular lattice. The isostructural compound  $CeZn_3P_3$  is attracting much attention as a low-dimensional quantum spin system [2]. GdZn<sub>3</sub>P<sub>3</sub> and DyZn<sub>3</sub>P<sub>3</sub> are also expected to exhibit an anomalous magnetic behavior based on the frustrated R atom geometry. However, the physical properties of the compounds have not been investigated so far. In this study, we have prepared GdZn<sub>3</sub>P<sub>3</sub> and DyZn<sub>3</sub>P<sub>3</sub> samples using a high-pressure synthesis technique and their magnetic properties have been investigated for the first time. The magnetic susceptibility of  $GdZn_3P_3$  and  $DyZn_3P_3$  follows a Curie-Weiss law with the effective magnetic moment  $\mu_{eff} = 8.27 \ \mu_B/Gd$  and 11.61  $\mu_B/Dy$ , respectively. These values are in good agreement with 7.94  $\mu_{\rm B}$  /Gd and 10.63  $\mu_{\rm B}$  /Dy, respectively. Weiss temperature  $\theta_{\rm P} = -4.50$  K and -0.62 K, respectively. The specific heat of GdZn<sub>3</sub>P<sub>3</sub> and DyZn<sub>3</sub>P<sub>3</sub> indicates a phase transition around 4 K and 15 K, respectively. While magnetic susceptibility of  $GdZn_3P_3$  exhibit a cusp anomaly like an antiferromagnetic ordering around 4 K, the distinguished anomaly around 15 K was not observed for DyZn<sub>3</sub>P<sub>3</sub>. In spite of large magnetic moments, GdZn<sub>3</sub>P<sub>3</sub> has very low magnetic transition temperature and  $DyZn_3P_3$  exhibits no clear magnetic transition. The results suggest the existence of magnetic frustration in this system.

- [1] A. T. Nientiedt and W. Jeitschko, J. Solid State Chem. 146, 478 (1999).
- [2] A. Yamada, N. Hara, K. Matsubayashi, K. Munakata, C. Ganguli, A. Ochiai, T. Matsumoto, Y. Uwatoko, J. Phys.: Conf. Ser. 215, 012031 (2010).

# <sup>13</sup>C NMR study of insulating phase in $\lambda$ -(ET)<sub>2</sub>GaCl<sub>4</sub>

# <sup>a</sup>Department of Physics, Hokkaido University <sup>b</sup>The Institute for Solid State Physics, The University of Tokyo Y. Saito<sup>a</sup>, T. Kobayashi<sup>a</sup>, S. Fukuoka<sup>a</sup>, A. Kawamoto<sup>a</sup>, and H. Mori<sup>b</sup>

Quasi-two-dimensional organic conductors  $\lambda$ -(BETS)<sub>2</sub>MCl<sub>4</sub> (M = Ga, Fe) [BETS: bis(ethylenedithio)tetraselenafulvalene have attracted much attention because they show novel superconducting states such as Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state and magnetic field-induced superconductivity (FISC) state under high magnetic field [1-2]. A *d*-wave superconducting (SC) gap structure was reported by specific heat measurement [3]. The mechanism of the superconductivity of  $\lambda$  salts is still unclear, although the universal phase diagram was predicted, where the insulator phase is adjacent to the SC phase [4]. Nature of the insulating phase in the vicinity of SC phase gives important information to discuss the mechanism of the superconductivity. Previously, we performed <sup>13</sup>C NMR in  $\lambda$ -(STF)<sub>2</sub>GaCl<sub>4</sub> [STF: bis(ethylenedithio)diselenadithiafulvalene], which its ground state is located in the vicinity of SC phase of  $\lambda$ -(BETS)<sub>2</sub>GaCl<sub>4</sub>. Although a marked enhancement of antiferromagnetic (AF) spin fluctuation was observed with decreasing temperature, no magnetic ordering was observed down to 1.63 K. One of the reasons of suppressing AF ordering is that positional disorder of Se atoms in STF molecules. The ground state of  $\lambda$ -(ET)<sub>2</sub>GaCl<sub>4</sub> [ET: bis(ethylenedithio)tetrathiafulvalene], which is the more insulating side than  $\lambda$ -(STF)<sub>2</sub>GaCl<sub>4</sub> without positional disorder is interesting. Therefore, to clarify the magnetic nature of the insulating ground state of the  $\lambda$  salts without disorder, we performed <sup>13</sup>C NMR study for  $\lambda$ -(ET)<sub>2</sub>GaCl<sub>4</sub>.

Figure 1 shows the temperature dependence of  $(T_1T)^{\cdot 1}$ . The  $(T_1T)^{\cdot 1}$  gradually increases with decreasing temperature and exhibits a divergence peak at  $T_N = 13$  K. Simultaneously, a spectrum splitting was observed. These are clear evidence of AF ordering in  $\lambda$ -(ET)<sub>2</sub>GaCl<sub>4</sub>. We will show the detailed results in this presentation.

[1] W. A. Coniglio *et al.*, PRB **83**, 224507 (2011).

[2] S. Uji *et al.*, Nature **410**, 908 (2001).

[3] S. Imajo et al., JPSJ 85, 43705 (2016).

[4] H. Mori *et al.*, Phys. C Supercond. **357–360**, 103 (2001).



FIG. 1 Temperature dependence of  $(T_1 T)^{-1}$  of  $\lambda$ -(ET)<sub>2</sub>GaCl<sub>4</sub>.

# Sn-doping concentration-dependent physical property variation of Fe<sub>2</sub>O<sub>3</sub> powders

Sehwan Song<sup>1</sup>, Ji Woong Kim<sup>1</sup>, Dooyong Lee<sup>1</sup>, Jisung Lee<sup>1</sup>, Taewon Min<sup>1</sup>, Jong-Ah Chae<sup>2</sup>, Jong-Seong Bae<sup>3</sup>, Jaekwang Lee<sup>1</sup>, Jeong-Soo Lee<sup>4</sup> and Sungkyun Park<sup>1,2,\*</sup>

<sup>1</sup>Department of Physics, Pusan National University, Busan 46241, Korea <sup>2</sup>Core Research Facilities, Pusan National University, Busan 46241, Korea <sup>3</sup>Busan Center, Korea Basic Science Institute, Busan 46742, Korea <sup>4</sup>Neutron Instrument Division, Korea Atomic Energy Research Institute, Daejeon 34057, Korea

#### Abstract

In many useful energy harvesting applications based on binary oxide systems,  $Fe_2O_3$  is one of the useful materials in the photoelectrochemical cells applications [1]. However, relatively low electrical conductivity of the  $Fe_2O_3$  prohibited its possible application as a photoanode material. Recently, there were many researches to improve its electrical properties by doping 4+ ions in the system [2]. In particular, Sn can be a good candidate to improve electrical conductivity of the  $Fe_2O_3$  system. However, the details of physical mechanisms are less investigated.

In this presentation, we showed the physical property variations of  $Fe_2O_3$  powders by varying Sn doping concentrations (0%, 1%, 2%, 3%, 4%, 5%). In the structural view, phase pure Sn-doped  $Fe_2O_3$  samples were obtained when Sn doping concentration is less than 2% with slight increase in a unit cell volume. For the higher Sn-doped  $Fe_2O_3$  powders, the formation secondary phase (i.e., SnO<sub>2</sub>) was noticed from Rietveld analysis. Furthermore, the energy-dispersive-spectroscopy analysis using transmission electron microscope revealed the non-uniform distribution of Fe and Sn while O remained uniform distribution. From the spectroscopic analysis using X-ray photoelectron spectroscopy,  $Fe^{2+}$  state increased with increasing Sn-doping concentration. The detailed correlation between electrical conductivity and chemical state variations (or the effect of secondary phase) will be discussed.

This work was supported by the Industrial Strategic Technology Development Program (10062130) funded by the Ministry of Trade, industry & Energy (MI, Korea), NRF Korea (NRF-2015R1D1A1A01058672) and the Korea Atomic Energy Research Institute.

[1] M. Gratzel. Nature 414 (2001) 388-344

[2] Y. Ling et al. Part. Part. Syst. Charact. 31 (2014) 1113-1121

\* psk@pusan.ac.kr

# $\mu$ SR and DFT studies on (Ce<sub>1-x</sub> La<sub>x</sub>) $M_2$ Al<sub>10</sub> (M = Ru, Os)

# <sup>1</sup>RIKEN Nishina Center, <sup>2</sup>Universiti Sains Malaysia <sup>1,2</sup>Noraina Adam

Ce-based caged-type compound  $CeM_2Al_{10}$  (M = Ru, Os) exhibits unusual Kondo semiconducting behavior with an anomalously high magnetic transition temperature,  $T_0 \sim 30$  K [1,2]. Neutron diffraction studies of Ce $M_2Al_{10}$  (M = Ru, Os) revealed small ordered moment along the *c*-axis with magnitude of 0.34  $\mu_B$  and 0.29  $\mu_B$  [3], respectively, although the magnetic susceptibility shows a large anisotropy along the *a*-axis followed by *c*- and *b*-axes [4]. The  $\mu$ SR investigation on hole doping effect in the 4d and 5d systems which is Ru and Os shows a similar behavior as the neutron diffraction studies where the magnitude of magnetic moment decreased gradually with increasing hole doping percentage until the T<sub>0</sub> disappeared without any spin flop behavior occurred [5,6]. However with few percentages of electron doping in the d system where Ru and Os are doped with Rh and Ir, respectively, the magnetic moment enhanced from ~0.3  $\mu_B$  up to ~1.0  $\mu_B$  and its direction changed from along *c*-axis to *a*-axis [7,8]. On the other hand, the investigation from neutron diffraction studies on hole doping effect in the 4f system by doping Ce with few percentages of La showed the magnetic moment reduced from ~0.3  $\mu_B$  to 0.1  $\mu_B$  along the hardest *b*-axis instead of *c*- or *a*-axes [9]. However, the spin flop behavior only occurred in  $Ce_{1-x}La_xRu_2Al_{10}$ , not  $Ce_{1-x}La_xOs_2Al_{10}$ . In this study, we are investigating the unusual behavior of  $Ce_{1-x}La_xM_2Al_{10}$  (M = Ru, Os) by using the  $\mu$ SR technique and DFT calculation. The investigation of these two compounds is beneficial in understanding the relation of *c*-*f* hybridization strength between *d* and *f* systems.

T. Nishioka *et al.* JPSJ **78**, 123705 (2009)
 M. Matsumura *et al.* JPSJ **78**, 123713 (2009)
 H. Kato *et al.* JPSJ **80**, 073701 (2011)
 Y. Muro *et al.* JPCS. 200, 012136 (2010)
 D. T. Adroja *et. al.* PRB **87**, 224415 (2013)
 J. Kawabata *et.al.* PRB **89**, 094404 (2014)
 R. Kobayashi *et al..* JPSJ **82**, 093702 (2013)
 D.D. Khalyavin *et al..* PRB **88**, 060403 (2013)
 D. T Adroja *et al.* PRB **90**, 174422 (2014)



Figure 1 The internal field analysis of  $Ce_{1-x}La_xOs_2Al_{10}$  from the µSR experiment

# Study of the charge density wave and superconducting phase in α-(BEDT-TTF)<sub>2</sub>RbHg(SCN)<sub>4</sub> probed by NMR spectroscopy under uniaxial pressure.

# Graduate School of Science Hokkaido Univ. A. Ohnuma, H. Kumagai, T. Waragai, T. Kobayashi, Y. Saito, S. Fukuoka, Y. Ihara, and A. Kawamoto

An isostructural series of organic conductors  $\alpha$ -(BEDT-TTF)<sub>2</sub>*M*Hg(SCN)<sub>4</sub> (*M* = K, Rb, NH<sub>4</sub>) have attracted attention due to the variety of the electronic properties. The charge density wave (CDW) state is observed below 8 K and 10 K in the K and Rb salts, respectively [1,2], and the superconducting (SC) state is observed below about 1.5 K in the NH<sub>4</sub> salt [3]. In this family, the SC phase appears very close to the CDW phase.

To investigate the relationship between the CDW and SC phases, the electrical resistance measurements under the uniaxial strain were performed in the K and  $NH_4$  salts [4]. The uniaxial strain within the conducting *ac* plane drastically changes the electronic properties, that is, the CDW state is induced by the *a*-axial strain, and the SC state is induced by the *c*-axial strain. Namely, the SC transition temperature increases up to about 7 K in the  $NH_4$  salt and up to about 3 K in the K salt.

<sup>13</sup>C-NMR measurement was performed to investigate the electronic properties, and revealed that the distribution of the local density of states (DOS) at each <sup>13</sup>C site.  $\alpha$ -type salts have four non-equivalent <sup>13</sup>C sites, A<sub>a</sub>, A<sub>b</sub>, B, and C, but we can measure the electronic properties separately by using the spectroscopic advantage of <sup>13</sup>C-NMR measurement. [5]. To reveal the uniaxial strain effects microscopically, we performed <sup>13</sup>C-NMR measurement under the *c*-axial strain in the Rb salt. From

the resistivity measurement, the Rb salt shows almost the same electronic properties except for the slightly higher  $T_{CDW}$  of 10 K. The *c*-axial strain will induce superconductivity also in the Rb salt.

In this study, we measured the spin-lattice relaxation time  $T_1$  and estimated the DOS at A and B sites under the *c*-axial strain. Fig.1 shows the *c*-axial strain dependence of the transition temperature and the DOS at A and B sites. It was revealed that the DOS at B site increases with inducing the SC state.

[1] T. Sasaki *et al* Solid State Communications **75**, 93(1990)

- [2] N. Kinoshita et al. JPSJ 60, 7 (1991)
- [3] H. H. Wang et al Physica C 166, 57(1990)
- [4] M. Maesato et al. PRB 64, 155104(2001)
- [5] Y. Ihara *et al.* PRB **90**, 041107 (2014)



*c*-axial Pressure (kbar) the transition temperature (a) and the DOS at A and B sites(b).

## $\mu$ SR Studies on h8- and d8- $\beta'$ -(BEDT-TTF)<sub>2</sub>ICl<sub>2</sub>

J. Angel<sup>1,2</sup>, F. Astuti<sup>1,2</sup>, D. Puspita Sari<sup>1,3</sup>, H. Taniguchi<sup>4</sup>, and I. Watanabe<sup>1,2,3</sup> *RIKEN Nishina Center<sup>1</sup>*, Hokkaido Univ.<sup>2</sup>, Osaka Univ.<sup>3</sup>, Saitama Univ.<sup>4</sup>

The quasi-two-dimensional organic antiferromagnet,  $\beta'$ -(BEDT-TTF)<sub>2</sub>ICl<sub>2</sub>, shows antiferromagnetic magnetic ordering at around 22 K. In this study, we report the effect of deuterium substitution in  $\beta'$ -(BEDT-TTF)<sub>2</sub>ICl<sub>2</sub> to investigate a change in the magnetic property and the critical phenomenon around the magnetic transition temperature by the muon spin rotation method ( $\mu$ SR). The sample was synthesized by a simple electrochemical method where eight protons in the BEDT-TTF molecule were all replaced by the deuteriums. Then, we describe this deuterated system as d8- $\beta'$ -(BEDT-TTF)<sub>2</sub>ICl<sub>2</sub>.



Figure 1 shows the µSR time spectra of  $d8-\beta'-(BEDT-TTF)_2ICl_2$  measured in the zero-field condition. The muon spin precessions were clearly observed, which shows the appearance of the magnetically ordered state. The precession frequency larger with decreasing becomes temperature. Detailed results of the  $\mu$ SR measurements d8-β'-(BEDTon TTF)<sub>2</sub>ICl<sub>2</sub> will be reported in our presentation.

#### References:

- [1] H. Taniguchi et al., Journal of Low Temperature Physics 142 437 (2006).
- [2] Y. Eto and A. Kawamoto, Phys. Rev. B 81, 020512(R) (2010).

#### Magnetic properties in $\pi$ -d system organic conductor $\lambda'$ -(BEDT-STF)<sub>2</sub> FeBr<sub>4</sub>

## Dept. of Phys. Hokkaido Univ. T. Wada, T. Minamidate, N. Matsunaga, K. Nomura, A. Kawamoto

Study of the  $\pi$ -d interacting system has been attracting much attention from researchers because of some unique and intriguing characters. For example,  $\lambda$ -(BETS)<sub>2</sub>FeCl<sub>4</sub> which becomes antiferromagnetism in the ground state is a hot topic as the first organic material which shows a field induced superconductivity [1]. We synthesized a novel quasi-two dimensional organic conductor  $\lambda$ '-(BEDT-STF)<sub>2</sub>FeBr<sub>4</sub> that consists of the conducting layers of donor (cation) molecule BEDT-STF with  $\pi$  electrons and the insulating layers of anion molecule FeBr<sub>4</sub> with d electrons. The  $\lambda$ ' structure is an isomorphous structure of the  $\lambda$  structure and only (BETS)<sub>2</sub>GaBr<sub>4</sub> has been reported as  $\lambda$ ' crystal besides  $\lambda$ '-(BEDT-STF)<sub>2</sub>FeBr<sub>4</sub> [2]. In the presentation, I'll report the crystal structure of  $\lambda$ '-(BEDT-STF)<sub>2</sub>FeBr<sub>4</sub> and its magnetisation.

Figure 1 shows temperature dependence of magnetic susceptibility. The behaviour of susceptibility follows the Curie-Weiss law in high temperature region and it has a maximum at about 3 K. We fit the model, where Fe 3d spins are in a constant internal magnetic field below the antiferromagnetic transition temperature  $T_{AF}$ , to this behaviour of susceptibility. The red solid line depicts a calculated susceptibility from the model of 3d spins in 1.6 T internal field and it agrees with the data. It's been reported that the model of 3d spins in 4 ~5 T internal field well explains susceptibility of  $\lambda$ -(BETS)<sub>2</sub>FeCl<sub>4</sub> [3] and  $\lambda$ -(BEDT-STF)<sub>2</sub>FeCl<sub>4</sub> [4]. Therefore, in  $\lambda$ - $\lambda$ ' type crystals, it's a common characteristic that 3d spins in an internal magnetic field are the origin of magnetisation below  $T_{AF}$ .



Figure 1: Temperature dependence of magnetic susceptibility at 0.75 T

# Titanium nitride nanoparticles supported ceramic microfibers as efficient solar steam generators

Manpreet Kaur<sup>1,2</sup>, Satoshi Ishii<sup>2,3\*</sup>, Satish Laxman Shinde<sup>2,3</sup> and Tadaaki Nagao<sup>1,2,,3\*</sup>

<sup>1</sup>International Center for Materials Nanoarchitectonics (WPI- MANA), National Institute for Materials Science (NIMS), Tsukuba, Ibaraki, 305-0044, Japan

<sup>2</sup>Department of Condensed Matter Physics, Hokkaido University, Sapporo 060-0810, Japan

<sup>3</sup>Core Research for Evolutional Science and Technology (CREST), Japan Science and Technology

Agency (JST), Kawaguchi, Saitama, 332-0012 Japan.

Considering the fact that energy consumption to heat rooms and water can exceed 50 percent even in developed countries, solar water heating systems are one of the most successful applications of solar energy utilization to generate heat even in such countries [1,2].Titanium nitride (TiN) nanoparticles (NPs) exhibit broad plasmonic resonances which cover the majority of solar spectrum from UV to near infrared. The damping of plasmonic resonances leads to generate highly localized heat in nanometer scale. Since TiN is chemically stable and non-toxic, TiN is an excellent candidate for solar heat applications [3,4]. Due to the promising results obtained for TiN NPs as efficient sunlight absorbers, we select them for developing an effective solar heating composite. So far, TiN NPs were simply dispersed in water, which makes them difficult to handle and re-use for real application in society [5].

We develop a composite material where titanium nitride nanoparticles (TiN NPs) are immobilized to ceramic fiber wools (CWs). The composite sample has improved photothermal performance compared to TiN NPs dispersed into water. The composite structure effectively keep water supply to the surfaces by microfibers capillary force. The wide absorption wavelength and localized plasmonic effect of TiN NPs along the microfibers of the CWs resulting in solar thermal conversion efficiency of more than 80% at only 100 mWcm<sup>- 2</sup> illumination irradiance. This reusable and portable structure can be used for solar water distillation as well as solar water heating without losing the nanoparticles into water.

<sup>[1]</sup> P. Qin, H. Zhu, T. Edvinsson, G. Boschloo, A. Hagfeldt, L. Sun, J. Am. Chem. Soc 2008, 130, 8570-8571.

<sup>[2]</sup> A. Shukla, D. Buddhi, R. Sawhney, *Renew. Sustainable Energy Rev.* 2009, 13, 2119-2125.

<sup>[3]</sup> M. Quinten, Appl. Phys. B 2001, 73, 317-326.

<sup>[4]</sup> A. Reinholdt, R. Pecenka, A. Pinchuk, S. Runte, A. Stepanov, T. E. Weirich, U. Kreibig, *The European Physical Journal D-Atomic, Molecular, Optical and Plasma Physics* **2004**, *31*, 69-76.

<sup>[5]</sup> S. Ishii, R. P. Sugavaneshwar, T. Nagao, J. Phys. Chem. A 2016, 120, 2343-2348.

# Electron Correlation Effect on Non-equilibrium Phase Separation Studied by Polarized Femtosecond Spectroscopy

K. Nakagawa<sup>1</sup>, S. Tsuchiya<sup>1</sup>, J. Yamada<sup>2</sup>, Y. Toda<sup>1</sup>

<sup>1</sup>Depertment of Applied Physics, Hokkaido University <sup>2</sup>Graduate School of Material Science, University of Hyogo

Strong electron correlation plays a key role in the exotic phenomena such as unconventional superconductivity, fluctuating electronic order and a phase separation between metal and insulator. So far, its effects have been studied in thermally equilibrium states with controlled carrier density or bandwidth. As regards the non-equilibrium states, however, which can be studied by ultrafast optical spectroscopy, electron correlation effects on them are still unclear because of a lack of systematic study.

In this study to investigate electron correlation effects on the non-equilibrium electronic states, we performed femtosecond pump-probe spectroscopy in the strongly correlated organic molecular conductors  $\kappa$ -(BEDT-TTF)<sub>2</sub>Cu[N(CN)<sub>2</sub>]Br ( $\kappa$ -Br) and  $\kappa$ -(BEDT-TTF)<sub>2</sub>Cu(NCS)<sub>2</sub> ( $\kappa$ -NCS), which has effectively weaker electron correlation than  $\kappa$ -Br. The pump-probe measurements were carried out using 120 fs laser pulses centered at 400 nm for a pump (63-134  $\mu$ J/cm<sup>2</sup>) and 800 nm for a probe extracted from a cavity-dumped Ti:sapphire oscillator with a repetition rate of 54 kHz. The pump and probe beams were coaxially overlapped and irradiated perpendicular to the conducting planes. The probe polarization was rotated by a half-wave plate.



Figure 1: Probe polarization angular dependences of  $\Delta R/R$  in  $\kappa$ -NCS at 75 K and 60 K.



Figure 2: Temperature dependences of amplitude of the anisotropic responses in κ-Br and -NCS.

Figure 1 shows probe polarization angular dependences of  $\Delta R/R$ in  $\kappa$ -NCS at 75 K and 60 K. At 75 K,  $\Delta R/R$  is independent of the probe polarization, corresponding to the electronic energy relaxation in the metallic state, while at 60 K, it is anisotropic, indicating a broken rotational symmetry. For further analysis, we extracted the anisotropic components from  $\Delta R/R$  and their amplitudes are plotted in Figure 2 as a function of temperature for  $\kappa$ -NCS (open circles) and  $\kappa$ -Br (closed circles). In  $\kappa$ -NCS the anisotropic component appears below about 70 K and develops steeply with lowering temperature, indicating that an energy gap opens at the Fermi surface since  $\Delta R/R$  is proportional to photo-excited carrier density. Contrarily, in K-Br the anisotropic component shows gradual increase below around 80 K, which is qualitatively different from that in  $\kappa$ -NCS. A possible interpretation is that the increase of the anisotropic components in both salts corresponds to a photoinduced phase separation between metal and insulator [1] and the qualitative difference in the temperature dependences between them can be associated with the difference in electron correlation: that is, fluctuating nature can be enhanced in K-Br by strong electron correlation.

[1] Y. Toda et al., Phys. Rev. Lett. 107, 227002 (2011).

## Study of spin dynamics of a staircase kagome material

# investigated by spin polarized muons

# <sup>A</sup>Advanced Meson Science Laboratory, RIKEN Nishina Center <sup>B</sup>Department of Physics, The Catholic University of Korea <sup>C</sup>Department of Physics, Chung-Ang University Sungwon Yoon<sup>A, B</sup> S.-H. Do<sup>C</sup>, K.-Y. Choi<sup>C</sup>, I. Watanabe<sup>A, B</sup>, and B. J. Suh<sup>B</sup>

PbCu<sub>3</sub>TeO<sub>7</sub> was suggested as a new anisotropic kagome system for the staircase kagome lattice [1]. The crystal structure of PbCu<sub>3</sub>TeO<sub>7</sub> is an orthorhombic lattice with the space group, *Pnma*, No. 62. PbCu<sub>3</sub>TeO<sub>7</sub> is composed by buckled kagome layers of Cu<sup>2+</sup> ions settled in the *bc* plane, and those layers are stacked along *a* axis. In the buckled kagome layer, Cu<sup>2+</sup> ions can be affected by the different sorts of magnetic exchanges caused by different environments of O<sup>2-</sup> ions, the octahedral, and, the tetrahedral environments, respectively [1, 2].

Fig. 1 exhibits the DC magnetic susceptibility of the  $PbCu_3TeO_7$  polycrystalline sample measured at 1 kOe. It shows three distinct anomalies around 17 K, 25 K, and 36 K, and the Weiss temperature is approximately 180 K. With the comparison of

the previous susceptibility, and specific heat results [1], PbCu<sub>3</sub>TeO<sub>7</sub> is expected to be in the frustrated spin state due to the competition of different sorts of exchanges as previously mentioned.

We carried out the microscopic investigation by using spin polarized muons in order to understand the nature of magnetic anomalies, and to get information on the spin dynamics of an anisotropic kagome material. Details will be reported in the presentation



Fig.1 Temperature dependence of magnetic susceptibility

including a distinguishable behavior of the phase transition at 36 K. [1] B. Koteswararao *et al.*, J. Phys.: Condens. Matter **25**, 336003 (2013).

[2] DAI Jia et al., Chin, Phys. Lett. 32, 127503 (2015).

# ESR measurements of the Valence Bond Solid material EtMe<sub>3</sub>P[Pd(dmit)<sub>2</sub>]<sub>2</sub>

## **RIKEN<sup>1</sup>**, Hokkaido Univ.<sup>2</sup> <u>Sunghyun Kim</u><sup>1,2</sup>, Y. Oshima<sup>1,2</sup> and R. Kato<sup>1</sup>

The anion radical salt  $\beta'$ -X[Pd(dmit)<sub>2</sub>]<sub>2</sub> (X is monovalent cation) are Mott insulators which consist of *S*=1/2 triangular lattice. A wide variety of ground states such as the antiferromagnetic state, quantum spin-liquid state and charge-ordered state are observed in  $\beta'$ -X[Pd(dmit)<sub>2</sub>]<sub>2</sub> depending on the degree of geometrical frustration controlled by the monovalent cation X [1]. Recently, a new type of anion radical salt EtMe<sub>3</sub>P[Pd(dmit)<sub>2</sub>]<sub>2</sub>, which have a *P*2<sub>1</sub>/*m* symmetry, has been synthesized. EtMe<sub>3</sub>P[Pd(dmit)<sub>2</sub>]<sub>2</sub> forms also a triangular lattice but its molecular stacking are slightly different with the  $\beta'$ -X[Pd(dmit)<sub>2</sub>]<sub>2</sub> salts. It is known from the magnetic susceptibility measurement that EtMe<sub>3</sub>P[Pd(dmit)<sub>2</sub>]<sub>2</sub> turns into a valence bond solid (VBS) state at *T*<sub>VBS</sub>=25 K which is analogous to the spin-Peierls state [2]. ESR is one of the sensitive probe that can deduce the energy gap between the singlet and triplet states,  $\Delta E$ , from the temperature dependence of integrated intensity. Therefore, we have performed ESR measurements of EtMe<sub>3</sub>P[Pd(dmit)<sub>2</sub>]<sub>2</sub> to determine the spin gap of the VBS state.

The integrated intensity of the ESR signal, which corresponds to the spin susceptibility, is shown in Fig. 1. Our result shows a smooth decrease below 50 K, and only a small number of spins remain at  $T_{\text{VBS}}$ . In contrast to the magnetic susceptibility measurement, this suggests that the VBS order occurs at much more high temperature, and the ESR contributions of single spins on the Pd(dmit)<sub>2</sub> dimer

and the excited states of VBS state can not be ignored at high temperature. Therefore, we have considered a model where single spins on the dimer decrease with  $\exp(-\Delta E/k_{\rm B}T)$ , and pairs of single spins form a singlet state and its excited state contributes to the ESR intensity. Our result is well-fitted with the  $\Delta E$ =135 K curve. Detailed analysis of the ESR measurements will be presented and its magnetic properties will be discussed.

[2] M. Tamura, A. Nakao, and R. Kato, J. Phys. Soc. Jpn., **75** (2006) 093701.



**Fig. 1** Integrated intensity of the ESR signal

<sup>[1]</sup> M. Tamura and R. Kato, Sci. Technol. Adv. Mater. **10** (2009) 024304.

# Simulation of LIDAR multiple scattering in aerosol and

# metamaterial perfect absorbers for remote sensing

# Department of Condensed Matter Physics, Hokkaido University International Center for Materials Nanoarchitectonics, NIMS Doan Tung Anh

Much of our understanding of the physical properties of a medium comes from its interaction with electromagnetic waves. Based on Mie and Rayleigh scattering theories[1], we have proposed some algorithmic improvements in calculating single elastic scattering parameters such as scattering cross-section, extinction coefficient and scattering phase function for arbitrary homogeneous spherical particles. Dramatically faster Mie algorithms have been made possible by vector structuring and by much more efficient handling of the scattering matrix elements' calculation. For LIDAR (Light Detecting and Ranging) applications, the calculations were extended to multiple scattering simulation using Monte Carlo method to retrieve optical properties of aerosol media such as particle density and size distributions. For deducing other important but challenging parameters of aerosol media, such as components' identity and temperature profile, spectrally selective narrow-band detectors and emitters are needed. Electromagnetic metamaterial, which is arrays of structured subwavelength elements described as effective materials via electric permittivity  $\epsilon(\omega)$  and magnetic permeability  $\mu(\omega)$ [2], is a promising candidate detect and emit spectrally selective signals [3][4]. Using finite integration technique, we proposed an approach to explain the underlying physics of metamaterial cut-wire pair (CWP) isotropic perfect absorbers in microwave and THz regime by systematically manipulating the electrically and magnetically induced losses[5]. In time to come, further research will be conducted to manipulate

various structures of nanoscale metamaterials to achieve near unity absorption at desired infrared spectral bands with wider tunability to integrate to temperature sensing systems.

[1]C.F. Bohren, ISBN: 9780471293408, (1983)

[2]J. B. Pendry et al., Phys. Rev. Lett 76, 4773 (1996).

[3] N. I. Landy et al., Phys. Rev. B 79, 125104 (2009).

[4] Claire M. Watts et al., Adv. Mater. 24, OP98–OP120 (2012).

[5] Doan Tung Anh *et al*, AIP Advances **5**, 077119 (2015).



**Fig1.** Evolution of the absorption spectra of the proposed CWP metamaterials by transforming square-to-diamond

#### $\mu$ SR and DFT Study of Organic Superconductor $\lambda$ -(BETS)<sub>2</sub>GaCl<sub>4</sub>

Dita Puspita Sari<sup>1,2)</sup>, Retno Asih<sup>1,2)</sup>, Koichi Hiraki<sup>3)</sup>, Yasuyuki Ishii<sup>4)</sup>, Toshihiro Takahashi<sup>3)</sup>, Takashi Koretsune<sup>5</sup>, Hitoshi Seo<sup>5</sup>, Isao Watanabe<sup>1,6)</sup>, Takehito Nakano<sup>2)</sup>, and Yasuo Nozue<sup>2)</sup> <sup>1</sup>RIKEN Nishina Center, <sup>2</sup>Osaka U., <sup>3</sup>Gakushuin U., <sup>4</sup>Shibaura Institute of Technology, <sup>5</sup>CEMS-RIKEN, <sup>6</sup>Hokkaido University

The quasi two-dimensional organic superconductor,  $\lambda$ -(BETS)<sub>2</sub>GaCl<sub>4</sub>, (BGC), is composed of conductive BETS and insulating GaCl<sub>4</sub> layers which are alternatively stacked. BETS molecules has fourfold quasistacking along *a* axes which may make a phase adjacent to superconducting phase non magnetic Mott insulator despite a prediction of antiferromagnetic spin fluctuation which occurs in most of TMTTF and ET superconductors [1]. Furthermore, a recent specific heat measurement results *d*wave pairing symmetry [2], likely  $\kappa$ -ET-NCS superconductor. A microscopically point of view is important in order to understand the superconducting state of BGC. Muon spin rotation ( $\mu$ SR) is an ideal tool for such investigation.



Figure 1. BGC crystal in the conducting *ac* plane. Transfer integral value is reported in the unit of Ev.

**References:** 

- 1. H. Tanaka et al, J. Am. Chem. Soc., 121, 760-768 (1999).
- 2. S. Imajo et al, J. Phys. Soc. Jpn., 85. 043705 (2016).

We have carried out transversefield  $\mu$ SR in fields of 30 G and 60 G, from 0.3 to 10 K and have determined the temperature dependence of magnetic penetration depth which indicates the presence of nodes in the superconducting gap. Additionally, by density functional theory (DFT) we recalculated Fermi surface and transfer integral of BGC to understand the appearance of that node and to understand the phase adjacent to superconducting phase. Figure 1 shows the transfer integral estimated from our calculations. We are going to present the more detail calculations results and understand low analysis to the temperature superconducting state.

#### Antiferromagnetic fluctuation in unconventional organic superconductor λ-(BETS)<sub>2</sub>GaCl<sub>4</sub> by <sup>13</sup>C NMR

Takuya KOBAYASHI and Atsushi KAWAMOTO,

Department of Condensed Matter Physics, Graduate School of Science, Hokkaido University

Organic superconductor  $\lambda$ -(BETS)<sub>2</sub>GaCl<sub>4</sub> is one of the most attractive materials in solid state physics, suggesting Fulde—Ferrell—Larkin—Ovchinnikov (FFLO) superconducting state [1] and *d*-wave superconducting gap symmetry [2]. To understand this unconventional superconducting state, the contribution from magnetic or charge fluctuations has been suggested. NMR spectroscopy is the important probe to detect the magnetic fluctuations, but reliable results have not been obtained in previous <sup>77</sup>Se and <sup>1</sup>H NMR measurements because of (i) the low sensitivity and broad linewidth in <sup>77</sup>Se NMR, and (ii) weak coupling of the <sup>1</sup>H nuclei with the  $\pi$  conduction electrons. To overcome these difficulties and reveal the effect of magnetic fluctuations, we performed <sup>13</sup>C NMR measurements for a <sup>13</sup>C-enriched sample.

Figure 1 shows the temperature dependence of spin-lattice relaxation rate divided by temperature  $1/T_1T$ . Above 90 K,  $1/T_1T$  increases with decreasing temperature, which can be ascribed to the Curie-like behavior (solid line in Fig. 1). In fact, our group has measured the  $1/T_1T$  of  $\lambda$ -(STF)<sub>2</sub>GaCl<sub>4</sub> and  $\lambda$ -(ET)<sub>2</sub>GaCl<sub>4</sub> salts, and observed the clear antiferromagnetic (AF) phase transition in  $\lambda$ -(ET)<sub>2</sub>GaCl<sub>4</sub> salt and increase in  $1/T_1T$  derived from the AF fluctuation down to 1.5 K in  $\lambda$ -(STF)<sub>2</sub>GaCl<sub>4</sub> salt [3]. Therefore, the enhancement of  $1/T_1T$  above 90 K predicted the AF fluctuation. Below 90 K, although  $1/T_1T$  deviates from Curie-like behavior, AF fluctuation remains at low temperature. In addition, linewidth of NMR spectra broadens below 20 K. This result suggests the inhomogeneity of local spin susceptibility, which can be understood through the charge

within disproportionation the non-centrosymmetric dimer of  $\lambda$ -modification. We conclude that the superconductivity in  $\lambda$ -(BETS)<sub>2</sub>GaCl<sub>4</sub> salt is realized under an AF inhomogeneous with system fluctuation.

M. A. Tanatar *et al.*, PRB **66**, (2002)
 134503, W. A. Coniglio *et al.*, PRB **83**,
 (2011) 224507, S. Uji *et al.*, JPSJ **84**,
 (2015) 104709.

[2] S. Imajo *et al.*, JPSJ **85**, 043705(2016)

[3] Y. Saito *et al.*, to be published.



Fig. 1: Temperature dependence of  $1/T_1T$ . Solid line shows the temperature dependence of Curie–Weiss expression.

# Non-linear electric conductivity in the Spin-Density-Wave state of (TMTTF)<sub>2</sub>PF<sub>6</sub>

## Dept. of Phys., Hokkaido Univ. D. Chiba, N. Matsunaga, K. Nomura, and A. Kawamoto

Quasi-one-dimensional organic conductor  $(\text{TMT }C\text{F})_2X$  shows various electric properties such as spin-Peierls, spin-density-wave (SDW), and superconducting phase by applying physical and chemical pressure. In the SDW phase of TMTSF salts, which are located in higher pressure range of the phase diagram than TMTTF salts, the non-linear electric conductivity without temperature dependence was observed [1]. It can be described by the Zener-type expression  $j = j_0 \exp(-E_0/E)$ .

To investigate the dynamics of SDW and to clarify the differences between TMTSF salts and TMTTF salts, we measured I-V characteristic in the SDW phase of  $(TMTTF)_2PF_6$ and observed the non-linear electric conductivity. In high current region, we observed negative differential resistance. Moreover, in higher current region, negative differential resistance disappears and temperature independent resistance was observed. These results imply that I-V characteristic of  $(TMTTF)_2PF_6$  in high current region is understood as well as the Zener-type current of TMTSF salts.



[1] G. Mihály, Yong Kim, and G. Grüner, Phys. Rev. Lett. 67, 2713 (1991)

#### High-pressure synthesis of new filled skutterudite compounds $SrT_4As_{12}$ (T=Fe, Ru, Os)

K. Nishine, J. Sirimart, R. Nakajima, Y. Kawamura, J. Hayashi and C. Sekine *Muroran Institute of Technology, 27-1 Mizumoto-cho, Muroran, 050-8585, Japan.* 

Filled skutterudite compounds  $AT_4X_{12}$  (A = alkali metal, alkaline earth metal, lanthanide (Ln), and actinide; T = Fe, Ru, Os, and Pt; X = P, As, Sb, and Ge) crystallize in a body-centered cubic structure with a space group  $Im\overline{3}$  ( $T_{h}^{5}$ , No. 204) [1] are expected as potential thermoelectric materials. The compounds also exhibit various physical properties depend on combinations of elements. While the physical properties of P and Sb-based compounds have been investigated intensively, few studies of As-based filled skutterudite compounds have been conducted. One of the reasons is that the compounds are quite difficult to prepare at ambient pressure. High-pressure synthesis is a powerful technique for preparing As-based filled skutterudite compounds. In this study, we focused on As-based filled skutterudite compounds including alkaline earth metal as part of our search for new materials using a high-pressure synthesis technique. Polycrystalline  $SrT_4As_{12}$  (T=Fe, Ru, and Os) were prepared at high temperatures and high pressures using a Kawai-type double-stage multi-anvil high-pressure apparatus. The samples were prepared by reacting stoichiometric amount of 3N (99.9% pure)-Sr chips, 4N-Fe, 4N-Ru, 4N-Os and 6N-As powder at 4 GPa. The reaction temperature was 830-900 °C. The prepared samples were characterized by powder x-ray diffraction (XRD) using Co  $K\alpha_1$  radiation and silicon as a standard. Resistivity was measured by a standard dc four-probe method. Magnetization and dc magnetic susceptibility were measured by a superconducting quantum interference device magnetometer (Quantum Design MPMS). Specific heat measurement was carried out by a thermal relaxation method (Quantum Design PPMS). The XRD results indicate new skutterudite compounds  $SrT_4As_{12}(T=Fe,Ru,Os)$  with lattice constant of 8.351Å, 8.521Å, and 8.561Å, respectively. Resistivity and magnetic susceptibility measurements indicate  $SrOs_4As_{12}$  is a new superconductor around 4.8 K. The magnetic susceptibility of  $SrFe_4As_{12}$ shows a broad peak around 50 K. A large electronic specific heat coefficient is observed. The results suggest that  $SrFe_4As_{12}$  is a nearly ferromagnetic metal with spin fluctuations of Fe 3d electrons.

[1] W. Jeitshko and D. Braun 1977 Acta Crystallogr., Sect. B 33 3401 (1977).

## Electrical transport study of Sn-doped α-Fe<sub>2</sub>O<sub>3</sub>

Taewon Min, Sehwan Song, Sungkyun Park, Jaekwang Lee\*

Department of Physics, Pusan National University, Busan 46241, Korea

#### Abstract

 $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> has been known as a promising photo-anode material due to its efficient visible light absorption, appropriate band edges and strong stability in aqueous electrolyte. However, its solar to hydrogen conversion efficiency is strongly limited by slow charge transport governed by the polaron hopping conduction. Here, using density functional theory calculations, we find that the polaron hopping barrier in Sn-doped  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> is reduced by about 0.3 eV compared to that in bare  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> with oxygen vacancy, which corresponds to around 10<sup>10</sup> times enhancement in electrical conductivity at room temperature. Such a remarkable effect is achieved by only 2% Sn substitution and clearly confirmed by the 4-probe measurement. Our combined studies provide essential information for developing novel  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>-based photoelectrochemical(PEC) cell with high efficiency.

#### RIETVELD ANALYSIS OF NANOCRYSTALLIN BARIUM M-HEXAFERRITE WHICH SYNTHESIZED USING CO-PRECIPITATION METHOD Irwan Ramli

Department of Condensed Matter Physics, Hokkaido University

Nanocrystallin Barium M-Heksaferrite has been successfully synthesized using Co-precipitation Method. The Precursor were calcined at varied temperature to obtain good crytallin BaM. The nanocrytallin powder BaM were characterized by X-ray diffraction techniques and Tunneling Electron Microscopy (TEM) and its magnetic properties measured by Vibrating Sample Magnetometer (VSM). The Analyse crystalline phase composition in the samples performed by rietveld method using Software Rietica and MAUD. The results of your analysis of the diffraction pattern showed that the highest percentage of crystalline phase of BAM 94.3 (2.9)% with a crystal size of 87 (3) nm. The estimate crystalline size usinng diffraction data agreed with TEM observation. Characterization of the magnetic properties showed that BAM is a hard magnetic with coercivity field 46.0 tesla and remanence 29.3 emu/g

Keywords: co-precipitation, Rietveld, rietica, X- Ray Difraction, MAUD, TEM



Fig 2. Crystal size from TEM observation and Rietveld Analysis

**References:** 

- [1] R. C. Pullar, Progress in Materials Science, vol. 57, no. 7, pp. 1191–1334.
- [2] D. L. Bish and S. A. Howard, Journal of Applied Crystallography, vol. 21, no. 2, pp. 86–91.
- [3] E. H. Kisi, Materials Forum, vol. 18, pp. 135–153.
- [4] K. S. Martirosyan, et.al, *Materials Science and Engineering: B*, vol. 176, no. 1, pp. 8–13.