PCP2-1

Effects of 800 MeV Xe Irradiation on 2H-NbSe2 Single Crystals

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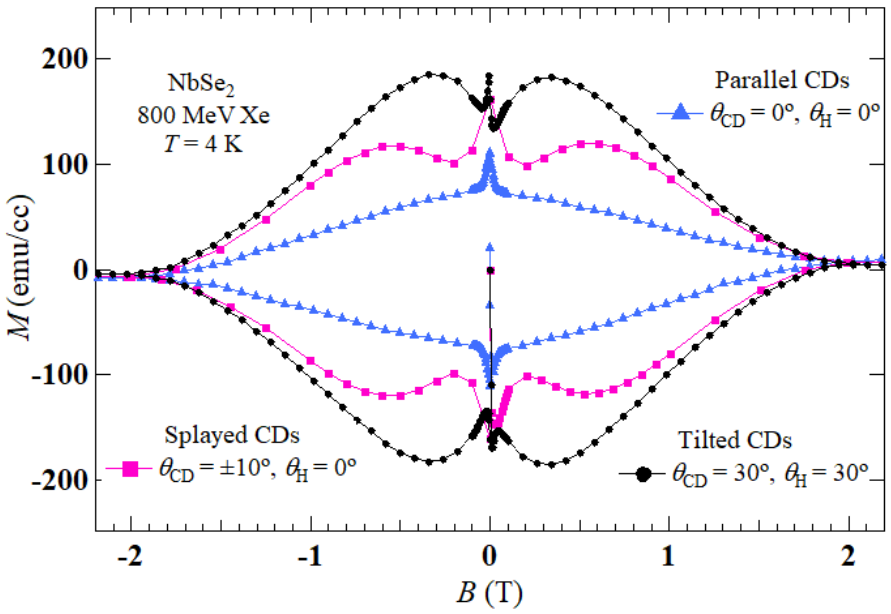
Introduction of columnar defects in a clean single crystal of superconductor strongly enhances the critical current density (Jc). This has been confirmed by many experiments [1,2] and explained by theoretical analyses. Several conditions of heavy-ion irradiation, such as the energy, density, and the incident direction of heavy ions strongly affect the structure of columnar defects and enhancement of Jc. An anomalous peak effect has been observed in iron-based superconductors at ~1/3 of the dose equivalent matching field, BΦ, when the columnar defects are introduced from two symmetric directions with respect to the c-axis at angles of ~±20° [3]. Actually, a similar peak effect has been observed in YBa2Cu3O7 with tilted columnar defects but with natural splay [1]. Despite these extensive research on iron-based superconductors and cuprate superconductors, there have been few studies on the effect of columnar defects in conventional superconductors. Recently, a peak effect has been observed in NbSe2, which is a canonical conventional layered superconductor, with tilted columnar defects [4]. To understand how the configuration of columnar defects affects the Jc in NbSe2, effects of 800 MeV Xe irradiation on NbSe2 single crystals have been investigated. We introduced three kinds of columnar defects (parallel, tilted, and splayed columnar defects with respect to the c-axis) in NbSe2 single crystals. Pronounced peak effects in M-H loops have been observed in the case of samples introduced tilted or splayed columnar defects when the field is applied to the average direction of columnar defects (Fig. 1). It should be noticed that with a large matching field of BΦ = 8 T, the superconducting transition temperature hardly changes. We will discuss the origin of the anomalous peak effect in NbSe2 with tilted or splayed columnar defects.



[1] L. Civale et al., Phys. Rev. Lett. 67, 648 (1991).
[2] T. Tamegai et al., Supercond. Sci. Technol. 25, 084008 (2012).
[3] A. Park et al., Phys. Rev. B 97, 064516 (2018).
[4] S. Eley et al., Sci. Rep. 8, 13162 (2018).

Keywords: NbSe2, columnar defects, peak effect

PCP2-2

Spectroscopy of exfoliated $NbSe_2$ thin films using $NbSe_2/MoS_2$ superconductor-semiconductor heterostructures

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Owing to the rapidly developing technology of mechanical exfoliation of layered materials and transfer/stacking of atomic layers, first developed in the graphene research, atomically thin superconducting transition metal dichalcogenide $NbSe_2$ has attracted much attention. Peculiar features such as superconductivity in high-quality monolayer with suppressed superconducting energy gap and two-band superconductivity have been reported.[1,2] In such measurements, so-called van der Waals tunnel junctions (stacked superconductor-semiconductor heterostructures) were used. However, it is known that reproducing the above results is quite difficult. Thus, here we focus on the transport property of such van der Waals superconductor-semiconductor heterostructures.

In our experiment, van der Waals $NbSe_2/MoS_2$ heterojunctions were made in a glove box, and Ti/Au electrodes are connected to them to perform tunnel spectroscopy of $NbSe_2$. We find that the superconducting energy gap of $NbSe_2$ derived from the tunnel conductance is generally smaller than the value expected from the BCS theory, and it strongly depends on the thickness of MoS_2 layers, indicating that the tunnel conductance does not correspond to the density of states of $NbSe_2$. Origin of the disagreement will be discussed in the presentation.

PCP2-3

Intercalation of alkaline earth metals and rare-earth ions into 2H-$NbSe_2$

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The intercalation of alkali and alkaline earth metals with liquid ammonia or organic solvents into the FeSe superconductor results in a significant increase in the superconducting transition temperature (T_c).[1,2] Although the mechanism of the increase of T_c has not been known, this study indicates that intercalation with liquid ammonia or organic solvents is a technique effective for increasing T_c. Meanwhile, transition metal dichalcogenide compounds (TMDC) are known to have the layered structure which resembles that of FeSe. In particular, 2H-$NbSe_2$, one of TMDC, exhibits superconductivity below 7 K [3] and can be a material suitable for the intercalation. In this study, we report on the synthesis of $(NH_3)_yA_xNbSe_2$, where A is an alkaline earth metal element or Yb (x is a nominal value), by intercalating alkaline earth metals into $NbSe_2$ with liquid ammonia as a solvent. We also present the synthesis of $(C_2H_8N_2)_y A_xNbSe_2$ by the ethylenediamine $(C_2H_8N_2)$ solvent. Physical properties of intercalated samples were measured. Magnetization of the samples indicates that all the samples exhibit superconductivity and different T_c values. Powder x-ray diffraction patterns (Fig. 1) show changes in the c-axis associated with intercalation for the samples. We discuss a relation between T_c and the c-axis length. Its implication in charge-density-wave is also discussed. The details will be explained in the presentation.

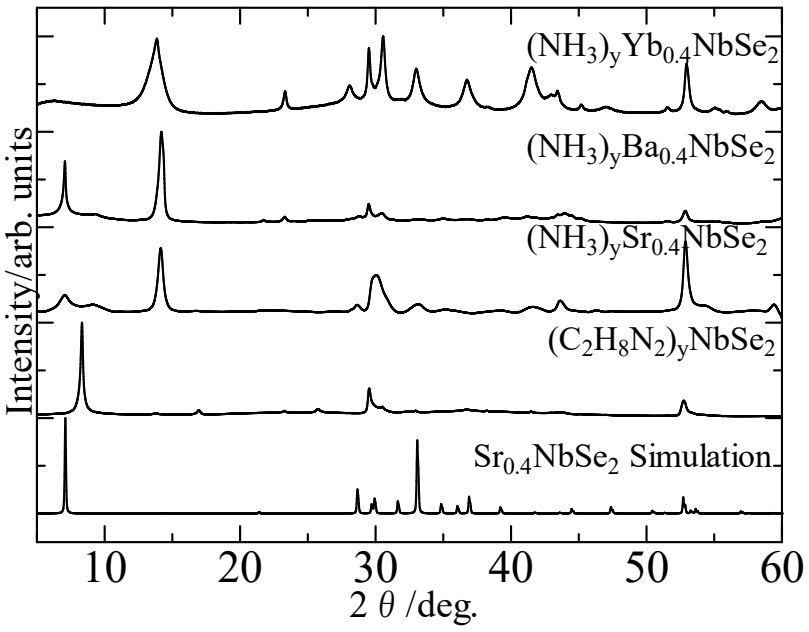

Fig. 1 Patterns of powder x-ray diffraction for samples

[1] T.P.Ying et al., Sci. Rep. 2 (2012) 426.
[2] T. Hatakeda et al., J. Phys. Soc. Jpn. 82, 123705 (2013)
[3] E. Morosan et al., Nature Phys. 2, 544 (2006).

PCP2-4

Observation of surface structure in Hf doped $ZrTe_3$ by STM

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In transition metal trichalcogenide $ZrTe_3$, one dimensional charge density wave (CDW), which have the wave vector $q_{CDW} \cong (0.07, 0, 0.333)$ appears along the a-axis at about 63K, and filamentary superconductivity appears at 2K [1].STM measurements at 4.2K in $ZrTe_3$ have revealed not only the CDW but also black streaks extending along the a-axis. The number of the streaks was found to increase when $ZrTe_3$ was grown at high temperature [2]. Since changes in physical properties due to crystal growth temperature has been reported in $ZrTe_3$[3], the streaks seems to greatly affect the physical properties in this material.

Transition metal trichalcogenide $HfTe_3$ also exhibits quasi-one-dimensional properties. In $HfTe_3$, it has been reported that a one-dimensional CDW along the a-axis at about 82K and superconductivity appears at about 1.4K [4,5]. However, in $HfTe_3$, the details of the CDW or existence of the streaks observed in $ZrTe_3$ have not been reported. This seems to be due to the fact that $HfTe_3$ is unstable against humidity in atmosphere unlike $ZrTe_3$.

In this study, the sample $Hf_xZr_{1-x}Te_3$, in which the Zr site of $ZrTe_3$ is partially substituted for Hf, was synthesized and STM observations were performed to observe the existence of the streaks and change in the CDW due to Hf substitution. Electrical resistivity measurements showed that the CDW transition temperature increased with Hf substitution. STM observations at 4.2K revealed the existence of the similar streak to those observed in $ZrTe_3$. Furthermore, in addition to the CDW inherent to $ZrTe_3$, additional harmonic-like structure was observed. In this presentation, we will discuss the details of the change in STM images due to Hf substitution on the Zr site of $ZrTe_3$.

[1] D.J. Eaglesham et al., Journal of Physics C: Solid State Physics 17 (1984) L697
[2] S. Kobayashi et al, The Annual Meeting of JPSJ 2019 (Tokyo univ of science)
[3] X. Zhu et al., PHYSICAL REVIEW B 87, 024508 (2013)
[4] Jing Li et al., PHYSICAL REVIEW B 96, 174510 (2017)
[5] S. J. Denholme et al., Scientific Report 7, 45217 (2017)

Keywords: HfxZr1-xTe3, ZrTe3, CDW, STM

PCP2-5

Evaluation of the physical properties and the real space observation in 2*H*-TaS_2 synthesized with flux method

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The physical properties of the layered compounds can be changed by the intercalation of the metal ion, organic molecules, and so on. In transition metal dichalcogenide (TMDC) 2*H*-TaS_2, which shows superconductivity and charge density wave (CDW) state, the intercalation of the metal ion increases the superconducting transition temperature and changes the superstructure. Although intercalation is useful to tune physical properties of TMDC, up to present, the intercalation technique in TMDC is restricted to a few methods, such as electrochemical or vapor transport technique, and intercalants are also restricted. Thus, it is necessary to find the more methods of the intercalation.
In this study, we tried to grow single crystal 2*H*-TaS_2 with flux method to intercalate elements which are included in the flux. NaCl and KCl were used as flux. It was found that the potassium is included in the single crystals grow by the flux method from the EDX measurements. The measurements of the electrical resistivity showed the transition temperature to the superconducting state became higher than that in the pristine crystal. Scanning tunneling microscopy / spectroscopy (STM/STS) measurements at 4.2 K revealed the superstructure which is different from that of the CDW in the pristine 2*H*-TaS_2. Considered these results, it is concluded that the potassium included in the flux is intercalated with 2*H*-TaS_2 by single crystal growth with flux method. In the presentation, how the potassium is intercalated with 2*H*-TaS_2 will be discussed.

Keywords: intercalation, CDW, 2H-TaS2, STM/STS

PCP2-6

Synthesis and physical property measurements of misfit transition-metal dichalcogenide $(SbS)(TaS_2)$

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The misfit layered compound $(MS)(TX_2)_n$ (n = 1, 2, 3) has a layered crystal structure in which a MS layer (M = Bi, Pb, Sb, Sn or lanthanide) forming a square lattice is inserted between transition metal dichalcogenide TX_2 (T = Ta, Nb, Ti, V, Cr　X = S, Se) which has a triangular lattice. Because the stacking of the triangular and the square lattice breaks spatial inversion symmetry, the spin orbit interaction affects the electronic states in the misfit layered compounds. Furthermore, because of the low dimensionality of the crystal structure, the appearance of charge density wave (CDW) and superconductivity has been reported. However, understanding of the difference of the CDW and the superconducting transition temperatures between the misfit layered compounds has not been fully understood.
In one of misfit compound, $(SbS)(TaS_2)_1$, there are reports on poly crystal synthesis. However, there are no reports on single crystal synthesis and measurements of physical properties such as the CDW and the superconducting transition[1]. Furthermore, there have been no reports of real space observations of this compound so far. In this study, we investigated single crystal $(SbS)(TaS_2)_1$, whose CDW or superconducting transition has not been studied.
We found that single crystal of $(SbS)(TaS_2)_1$ can be synthesized by flux method. The structural analysis by X-ray diffraction and electric resistivity measurements down to 1.4K, and scanning tunneling microscopy measurements were performed in the single crystal. We found this material undergoes both CDW and superconducting transition, and transition temperature was 70K and 2.14K, respectively. In STM measurements, only triangular lattice layer was imaged with superlattice due to the effect of underlying square lattice layer and the CDW. In the presentation, CDW and superconducting transition temperature is compared to those of other misfit materials.

[1] Yoshito Gotoh et al. Jpn. J. Appl. Phys. **30** L1039 1991

Keywords: Superconducter, Charge Density Wave, Scanning Tunneling Microscopy, Transition metal dichalcogenide

PCP2-7

Local Density of States in Two-Dimensional Nano-Structured Superconducting Systems with Superconductor–Normal Metal Interfaces

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Osaka Prefecture University[2]

Superconductor–normal metal (SN) interfaces occur important phenomena such as the Andreev reflection and a proximity effect. Also, superconductor–normal metal–superconductor (SNS) junctions are expected as many applications, for example, a SQUID, a single flux quantum logic, and so on. In recently developments, high-quality junctions with nano-structured superconducting films are made. In nano-structured systems, movements of electrons are restricted strongly and the quantum confinement effect occurs. Also, it is known that superconducting properties such as a critical temperature and a density of state oscillate as a function of a thickness of the superconducting film [1]. The other feature of the quantum confinement effect is a discreteness of energy levels. The quantum confinement effect in the superconductor is investigated actively, while in the case of superconductors with SN interfaces, effects of the quantum confinement effect on various properties are not investigated very much.

We investigate superconducting properties in nano-structured superconductors with SN interfaces, in particular, in the region of the quantum confinement effect. In this research, we focus on the discreteness of energy levels. The discreteness of energy levels affects a local density of state (LDOS), and the LDOS as a function of the energy has some peaks. Then, we investigate behaviors of the LDOS in nano-structured systems with the SN interface and SNS junctions theoretically. Experimentally, the LDOS can be measured through a differential conductance with the STM / STS measurement, so an electronic structure of a surface in the system is important. Then, we consider two-dimensional systems. In order to obtain the electronic structure in this system, we solve the Bogoliubov-de Gennes equations self-consistently with a two-dimensional finite element method [2]. Using solutions, we report dependences of sizes, shapes, potential barriers in SN interfaces, and widths of each metals on the LDOS.

[1] A. A. Shanenko, et al., Phys. Rev. B, **75**, 014519 (2007)

[2] H. Suematsu, et al., Physica C, **412-414**, 548 (2004)

Keywords: superconductor-normal metal interface, Bogoliubov de Gennes equations

PCP2-8

Angular dependence of the upper critical field in the high-pressure 1T' phase of $MoTe_2$

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Superconductivity in the type-II Weyl semimetal candidate $MoTe_2$ has attracted much attention due to the possible realization of topological superconductivity. In this work, we constructed a temperature-pressure phase diagram, as shown in Fig.(a). The magnetoresistance (MR) and Hall coefficient of MoTe2 are found to decrease with increasing pressure. The Kohler's scalings for the MR data above ~11 kbar show a change of exponent whereas the data at lower pressure can be well scaled with a single exponent. These results are suggestive of a Fermi-surface reconstruction when the structure changes from the T_d to 1T' phase. We have performed a detailed study of the upper critical field H_{c2} of MoTe2 at 15 kbar, which is in the 1T' phase. The H_{c2}-temperature phase diagram are constructed with magnetic field B // ab and B $\perp$ ab. The data can be satisfactorily described by the Werthamer–Helfand–Hohenberg model with the Maki parameters α ~ 0.77 and 0.45, respectively. The surprisingly enhanced α may stem from a small Fermi surface and a large effective mass of semimetallic $MoTe_2$. The angular dependence of H_{c2} at 15 kbar can be well fitted by the Tinkham model, as shown in Fig.(b), suggesting the two-dimensional nature of superconductivity in the high-pressure 1T' phase. Furthermore, the calculations and experimental results of the electronic structure of $MoTe_2$ under pressure will also be discussed.

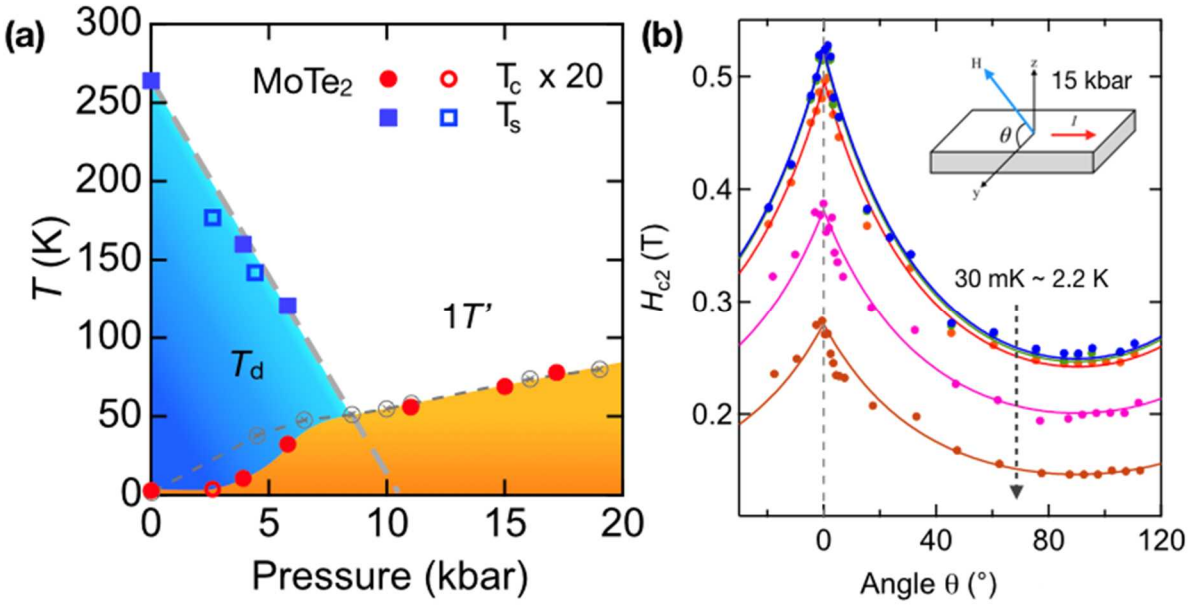

Figure: (a) The temperature-pressure phase diagram of $MoTe_2$. (b) Angular dependence of upper critical field of $MoTe_2$ at 15 kbar. The markers are data and the lines are fitting.

Keywords: Weyl semimetal, Superconductivity, Angular dependence, Electronic structure

PCP2-9

Bogoliubov–de Gennes Approach to Inhomogeneous Superconducting Gap in Nanowires and Nanotubes

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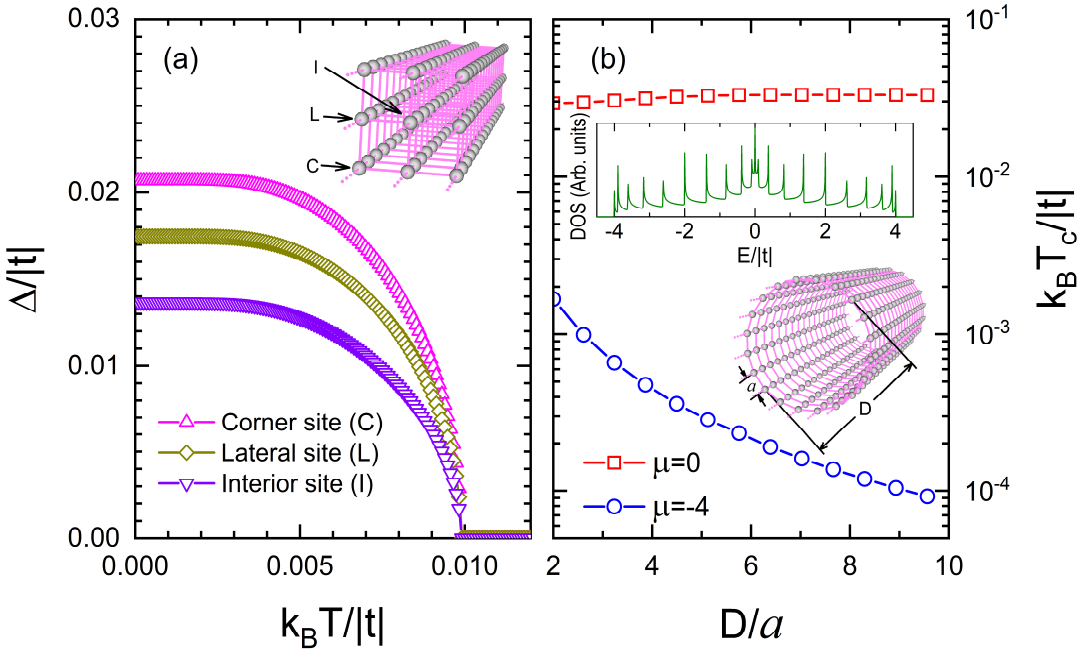
Traditional theories of superconductivity have been developed in the reciprocal space based on the translational symmetry. Such symmetry is absent in many inhomogeneous superconductors that contain structural grains or interfaces, whose study requires a real space theory of superconductivity [1]. In this work, we study the inhomogeneity of superconducting gap in nanostructures by using the Bogoliubov–de Gennes equations and an attractive Hubbard model [2]. In Fig. 1(a), the superconducting gap (Δ) versus temperature (T) is shown for a nanowire of an infinite–length and a cross section of 9 atoms (illustrated in the inset) with an on–site interaction of $U=-|t|$ and the chemical potential at μ=0, while the critical temperature (T_c) as a function of diameter (D) is exposed in Fig. 1(b) for an infinite–length nanotube (illustrated in its inset) with $U=-|t|$, μ=0 (red squares) and $\mu=-4|t|$ (blue circles), being t the single electronic hopping integral. Observe the appearance of a unique critical temperature at $k_BT_c\approx0.01|t|$ in Fig. 1(a), in spite of different Δ at non–equivalent sites. Notice also in Fig. 1(b) both slight increase and decrease behaviors of calculated T_c, in consistence with those observed in WS_2 [3] and carbon [4,5] nanotubes.

This work was partially supported by *UNAM-IN106317 and CONACyT-252943*. Computations were performed at Miztli of DGTIC, UNAM. G.E.L. thanks the support from UNAM-PAEP 2019.

[1] P. G. de Gennes, *Superconductivity of Metals and Alloys* (Westview Press, 1999).
[2] C. G. Galvan, J. M. Cabrera, L. A. Perez, C. Wang, *Phys. Status Solidi B* **253**, 1638 (2016).
[3] F. Qin, *et al.*, *Nano Lett.* **18**, 6789 (2018).
[4] Z. K. Tang, *et al.*, *Science* **292**, 2462 (2001).
[5] M. Kociak, *et al.*, *Phys. Rev. Lett.* **86**, 2416 (2001).



Keywords: Bogoliubov–de Gennes, Superconducting gap, Critical temperature, Nanostructures

PCP2-10

Crystal growth and conduction properties of Pb substituted La(O,F)BiS_2

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La(O,F)BiS_2 is a layered superconductor, which have LaO as a blocking layer and BiS_2 as a conducting layer. Recently, an anomalous hump in temperature dependence of electric resistivity was reported in Pb substituted La(O,F)BiS_2 single crystal with Pb concentration 6~9%.[1] These specimens showed higher superconducting transition temperature (Tc) than specimens without the hump. The appearance of the hump is thought to be related to a structural change, though the origin has not been elucidated yet. We tried to synthesize La(O,F)BiS_2 single crystals which have Pb concentration much more than that in the samples previously studied to elucidate the effect of Pb substitution in La(O,F)BiS_2. We synthesized Pb substituted La(O,F)BiS_2 single crystal with Pb concentration up to 75% with flux method. We carried out structure analysis by X-ray diffraction and temperature dependence of the electric resistivity measurements to evaluate the conducting property of the samples. We found that the lattice constant along the c-axis shrank largely when Pb concentration exceeded 10%, indicating possible structural change. In these samples, the superconductivity was suppressed and no Tc was observed down to 2 K. In the presentation, we also discuss the results of Seebeck coefficient measurements of these samples to investigate the electronic structure.

[1] S. Otsuki, et al. Solid State Communications 270 (2018) 17-21

Keywords: BiS2-based superconductor, layered material

PCP2-11

Synthesis and superconducting property evaluation of Pb-substituted BiS-based superconductor $LaO_{1-x}F_xBiS_2$

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BiS_2-based superconductor $LaO_{1-x}F_xBiS_2$ has a layered crystal structure composed of electron-supply layers of La (O,F) layers and conductive layers of two BiS_2 layers. Although superconductivity does not appear in $LaOBiS_2$, it shows superconductivity about 3K by replacing a part of O ions with F ions. In addition, the superconducting transition temperature of $LaO_{0.5}F_{0.5}BiS_2$ is increased by replacing a part of Bi ions with Pb ions, which is called as Pb substitution effect. [1] While Pb substitution effect was confirmed in $LaO_{0.5}F_{0.5}BiS_2$, it has not be known whether the same effect occurs in $LaO_{1-x}F_xBiS_2$ with different fluorine content so far.

Here, we performed Pb substitution to $LaO_{1-x}F_xBiS_2$ with various fluorine content to investigate the Pb substitution effect to superconducting properties of these materials. Polycrystalline samples used in this investigation were prepared by solid state reaction in evacuated quartz tube. The superconducting properties for the obtained samples were evaluated from X-ray diffraction, electrical resistivity, and magnetic susceptibility measurements. In this presentation, we will discuss the effect of Pb substitution for the superconducting properties in $LaO_{1-x}F_xBiS_2$ while comparing results of that of $LaO_{0.5}F_{0.5}BiS_2$.

[1] S. Otsuki *et al.*, Solid State Commun.,270 17-21(2018)

PCP2-12

Co-Intercalation of Li and Ethylenediamine into the Bi-based Chalcogenides with the Layered Structure by Solvothermal Technique

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We have reported that the co-intercalation of alkali metals or alkaline-earth metals and organic molecules into the transition-metal chalcogenides is effective to induce superconductivity or enhance the superconducting transition temperature T_c [1,2]. Through the co-intercalation, carriers can be doped and the electronic density of states at Fermi level is expected to increase due to the change of the electronic structure from three-dimensional to two-dimensional by the expansion of spacing between the conductive layers. It is reported that the topological insulator Bi_2Se_3 with the layered structure exhibits superconductivity with T_c ~ 2-4 K through the intercalation of several kinds of metals [3-5]. Therefore, the enhancement of T_c is expected by the expansion of spacing between the conductive Bi-Se layers through the co-intercalation. In this study, we have carried out the co-intercalation of Li and ethylenediamine (EDA) into the Bi-based chalcogenides with the layered structure of Bi_2Se_3 and $SnBi_2Se_4$.

Host materials were prepared by the solid-state reaction method. The co-intercalation was carried out at 180-190ºC for 7 days by the solvothermal technique using the Teflon-lined steel autoclave.

As for Bi_2Se_3, new Bragg peaks are observed through the co-intercalation, as shown in Figs. 1(a) and (b). It has been found that the new co-intercalation compound of $Li_x(EDA)_yBi_2Se_3$ is successfully synthesized. As for $SnBi_2Se_4$, it is not clear if the co-intercalated sample is obtained because only one new Bragg peak is observed as shown in Figs. 1(c) and (d). We will report whether superconductivity appears or not.

[1] T. Hatakeda *et al.*: J. Phys. Soc. Jpn. **85**, 103702 (2016). [2] K. Sato *et al.*: J. Phys. Soc. Jpn. **87**, 054704 (2018). [3] Y. S. Hor *et al.*: Phys. Rev. Lett. **104**, 057001 (2010). [4] Z. Liu *et al.*: J. Am. Chem. Soc. **137**, 10512 (2015). [5] Y. Qiu *et al.*: arXiv:1512.03519.

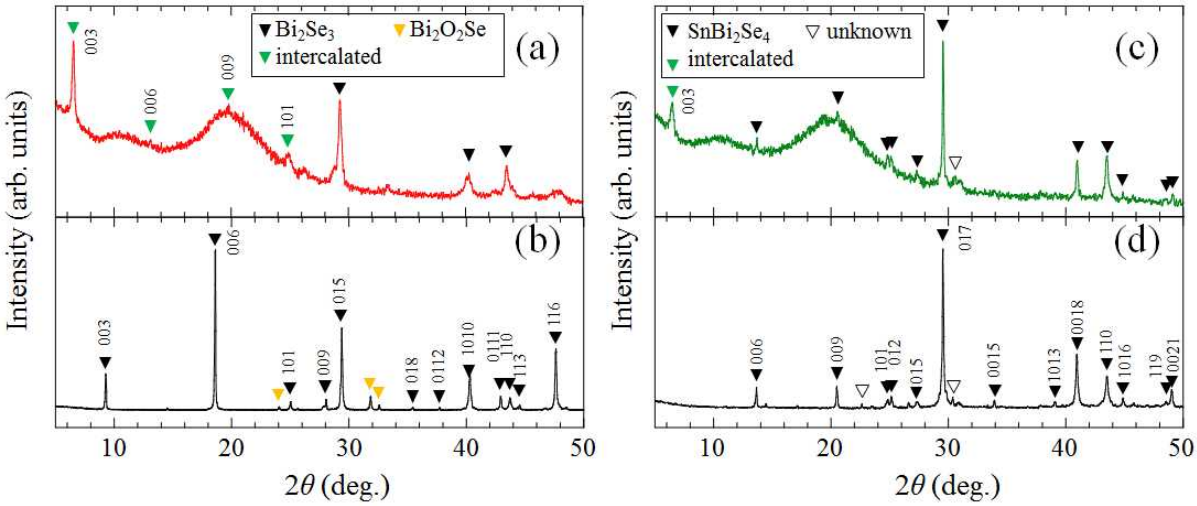

Fig.1. Powder X-ray diffraction patterns of samples obtained through the co-intercalation of Li and EDA for (a) Bi_2Se_3 and (c) $SnBi_2Se_4$. Those of host samples of (b) Bi_2Se_3 and (d) $SnBi_2Se_4$ are also shown for reference.

Keywords: Superconductor, Intercalation, Solvothermal Technique