Study of 2D Heavy Fermion Compounds $Ce(Te_{1-x}Se_x)_3$

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Orthorhombic $CeTe_3$-type (space group $C2cm$) $CeTe_3$ may be the best sample to study 2D quantum critical phenomena in heavy fermion system. Rare-earth tritelluride $CeTe_3$, which belongs to the family of quasi-2D compounds RTe3 (where R = Y, La-Sm, Gd-Tm), has highly 2D crystal structure; RTe-slabs and two square Te-sheets are stacked along the b-axis[1,2]. RTe-slabs contribute to magnetism[1,3] and square Te-sheets induce 2D conducting bands, which give strongly anisotropic transport properties[2]. First-principles band-structure calculations revealed that the Fermi surface consists of inner and outer square sheets, large regions of which are nested by a single incommensurate wave-vector corresponding to the observed lattice-modulation[4,5]. Because of the characteristic quasi-2D nature of the Te sheet, the charge density wave (CDW) is formed with an extremely large gap of the order of 100 meV [6-9]. Bulk measurement studies using specific heat, electrical resistivity, and magnetic susceptibility clarified that $CeTe_3$ show successive antiferromagnetic(AFM) transition at T_{N1} = 3.1 K and T_{N2} = 1.3 K with electrical specific heat coefficient $\gamma = 0.9$ J/molK^2, which indicates that $CeTe_3$ forms heavy quasi-particles at low temperature although the ground state is still AFM order[10]. Very recently, our group has succeeded in growing single crystals of $Ce(Te_{1-x}Se_x)_3$ system and has studied x dependence of physical properties. T_{N1} and T_{N2} decrease with the increase of x and both disappear around x = 0.1. In addition, the γ value increases with the increase of x. These results indicate that the chemical pressure effect coming from Se substitution suppresses magnetic order and enhances Kondo effect due to the increase of c-f hybridization. The x = 0.1 sample may realize 2D quantum criticality at low temperature. Despite the extensive studies, there is no information about magnetic structure of $CeTe_3$ and its Se-substitution system. The determination of magnetic structure is necessary to understand 2D quantum criticality in the system. Additionally, the relation between CDW and AFM transition is also important to unveil how fermiology connects magnetism in the system. Therefore, the aim of this proposal is to determine magnetic structures in two different AFM phase (L-phase: $T < T_{N2}$, I-phase: $T_{N2} < T < T_{N1}$) and clarify how these AFM transition affect CDW phase. We also expect to detect diffuse scattering parallel to b-axis. The anomaly at T_{N1} in the specific heat measurements looks very broad, which implies the existence of 2D-like AFM order in I-phase.

Neutron scattering is suitable to study the structure of both CDW and AFM order in the same reciprocal lattice unit. Previous electron and neutron studies implied the existence of the nuclear propagation vector $k_0 = (0.71, 0, 0)$ and two different magnetic propagation vectors; one is $k_1 = (0.5, 0, 0.4)$, the other one is $k_2 = (0.18, 0, 0.68)$ [11]. However, observed magnetic peaks were not many. It is difficult to determine these magnetic structures from these peaks only.

In this experiment, we focused on $CeTe_3$ single crystal samples because of the machine time limitation. We have performed the experiments using the WOMBAT diffractometer at the OPAL reactor in ANSTO. The experiments used thermal neutron with a 1.54 Å and 2.95 Å wavelengths, which were monochromatized by a vertically focusing Ge-115 monochromator. The scattering planes of $CeTe_3$ single crystals were set on the $h0l$ scattering plane, where magnetic peaks were observed in a previous study[11]. A dilution refrigerator was used to cool the samples, and the measurements were made in the temperature range of 50 mK   8.5 K.

Figure 1 shows the contour map of nuclear Bragg intensity in the h0l scattering plane at T = 8.5 K. All the observed nuclear scattering peaks can be explained by the space group of *Cmcm* and the lattice parameter of $CeTe_3$ consistently. Additionally, satellite nuclear peaks associated with the CDW order were also observed at the locations reported by ARPES measurements, which are in good agreement with the results of previous studies. Figure 2 (a,b,c,d) show contour plots of the Bragg scattering at 50 mK, and 1.5 K. Figure 2 (e,f) shows One-dimensional plots of the contour map integrated into Q direction. In the previous study, magnetic scattering peaks were observed in the region indicated by the blue dotted square in figure 2 (a,b). In the present study, however, no magnetic scattering peak was observed in this region. On the other hand, a ring-shaped weak Bragg scattering signal was observed in the low-Q region, as shown in figure 2 (c,d,e,f). This ring-shaped anomaly disappears above the antiferromagnetic transition temperature. Therefore, it is unlikely to be caused by polycrystalline impurities. We are planning to perform a follow-up experiment to investigate this ring-shaped anomaly with another spectrometer in the future.

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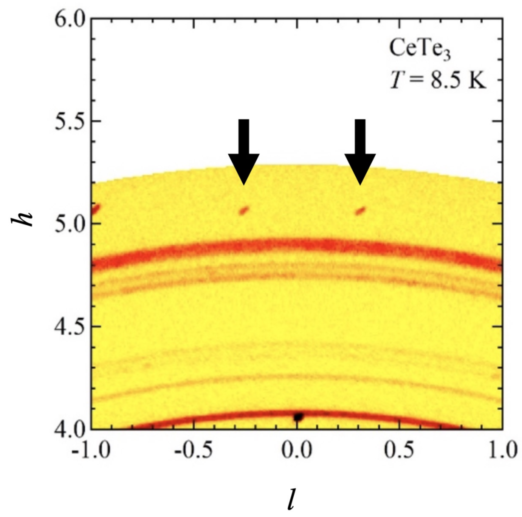

Fig. 1. Contour plot of the nuclear Bragg intensity in the (h, 0, l) scattering plane at T = 8.5 K. The black arrows indicate the satellite peaks coming from CDW order. These results are in good agreement with the results of the ARPES measurements.