Investigation of SDW/CDW State in UCu_2Si_2 using Non-resonant X-ray Scattering

Actinides attract strong interests in the field of condensed matter physics from the rich variety of unusual properties in magnetism, multipole ordering and unconventional superconductivity, among others. Actinide has unfilled 5*f* electrons in the outermost shell. The 5*f* electron has a magnetism dominated by its orbital contribution and multipolar degree of freedom due to LS coupling. On the other hand, the 5*f* wave function is expanded due to the large relativistic effect, which leads to hybridization with the valence states of neighboring atoms. The itinerant 5*f* electron appears in valence and conduction bands, which plays an important role in bringing about the unusual properties. The strongly correlated many body *f* electron system is realized only in a light actinides 5*f* system. Therefore, there is an open field for investigating actinides in the area of condensed matter physics.

Recently, we have determined the magnetic structure of UCu_2Si_2 by neutron scattering as shown in Fig. 1(a) [1]. This compound shows the longitudinal amplitude modulation of the magnetic moment with a long periodicity Λ = 85.7 Å corresponding to ~17 uranium layers along the tetragonal *c*-axis. The opening gap accompanied by the spin density wave (SDW) state indicated by the BCS-type magnetic order parameter [1] reminds us of the nesting origin of the itinerant magnetism in 3*d* transition metals such as chromium [2], in which the charge density wave (CDW) state coexists with SDW.

We succeeded in revealing the SDW/CDW state of an itinerant 5*f* electron system for the first time in UCu_2Si_2 by performing a non-resonant X-ray scattering (NRXS) experiment at beamline **BL46XU**. Figure 2 shows the observed CDW peak at the second-order satellite, whose intensity is in the order of 10^{-7} of the (0 0 8) fundamental reflection.

The charge origin was unambiguously confirmed by the polarization analysis, where we utilized the variable scattering plane method [3]. Also, the inclination angle dependence of the signal intensities of fundamental reflection and that of satellite reflection is well explained in terms of the charge origin peak as denoted by a solid line in Fig. 3, whereas an almost flat dependence is expected for the SDW origin peak as shown by a dashed line. The polarization analysis of such a subtle reflection is the great advantage of the six-circle diffractometer installed at BL46XU.

Figure 1(b) shows schematic pictures of the charge density modulation. The NRXS intensity of the observed satellite comes from the lattice strain in the order of 10^{-4} Å. This is consistent with the contraction of the lattice parameter of the *c*-axis around the magnetic transition. Thus, we suppose that the lattice spacing around the node of the CDW is slightly larger than the loop where a large U moment appears in the modulation. Besides the strain wave, we expect charge modulation of the 5*f* component in connection with exchange splitting. This charge modulation could be directly observed by resonant X-ray scattering, which is now under consideration.

A similar but rather short periodicity incommensurate modulation has been reported in UPd_2Si_2 and UNi_2Si_2. The magnetic structures were

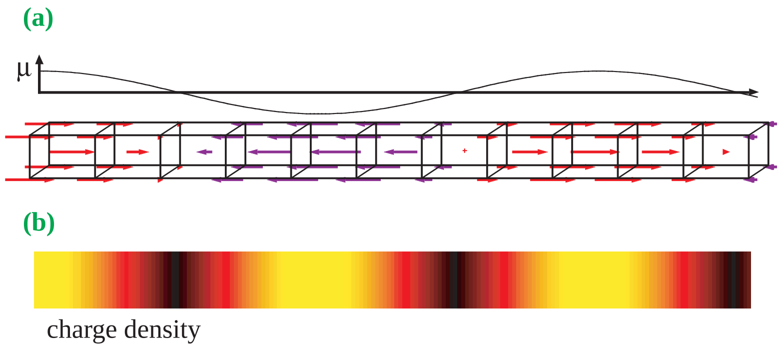

Fig. 1. **(a)** Antiferromagnetic structure of UCu_2Si_2 and magnetic amplitude modulation. **(b)** Charge density distribution in UCu_2Si_2.

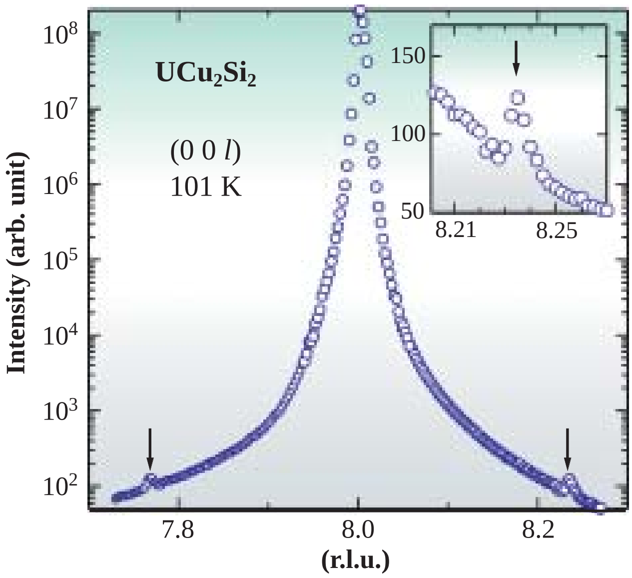

Fig. 2. Line scan along (0 0 8) at 101 K measured by non-resonant X-ray scattering.

interpreted with an axial next nearest neighbor ising (ANNNI)-type model based on a frustrated short-range interaction between localized 5*f* electrons [4]. There is no way to explain such a long sinusoidal modulation in UCu_2Si_2 with the ANNNI model unless the long-range interactions for up to the ~9th nearest neighbors are taken into account. Since the electronic properties of these three compounds are similar, we suggest the strong intinerant character of 5*f* electrons in these compounds as the origin of the SDW state.

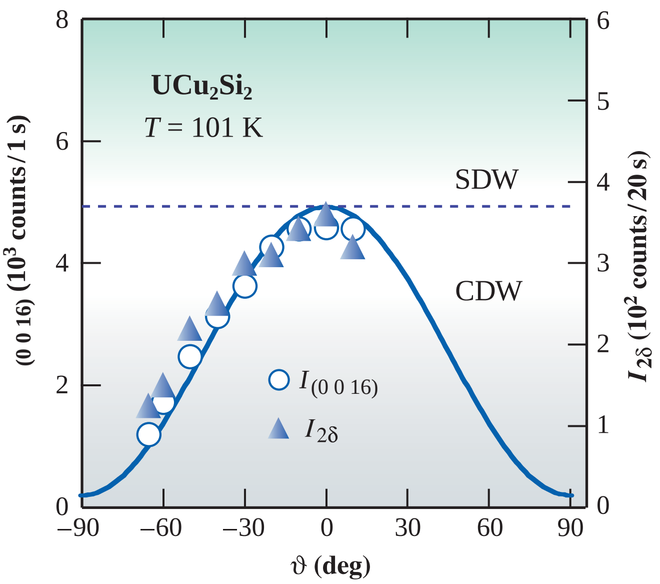

Fig. 3. Scattering intensity as a function of inclination angle, ϑ. The open circles and closed triangles are the observed data at the (0 0 16) fundamental and satellite reflections, respectively. The solid and dashed lines indicate the calculated results for charge and magnetic peak.

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References

[1] *F. Honda, N. Metoki, T.D. Matsuda, Y. Haga and Y. Onuki: J. Phys. Condens. Matter* ***18*** *(2006) 479.*
[2] Y. Tsunoda *et al.*: Solid State Commun. **14** (1974) 287.
[3] H. Ohsumi: SPring-8 Research Frontiers 2003, p.121.
[4] V. Sechovsky and L. Havela: Handbook of Magnetic Materials, ed. K.H.J. Buschow (Amsterdam: Elsevier Science B.V.) **11** (1998) 1; and references therein.