Modulated Structure and Ferromagnetic Insulating State in a Nine-layer $BaRuO_3$

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It is well known that the formation of CDWs modulation is accompanied by the lattice distortion which can be observed by x-ray spectroscopy measurements. Furthermore, it has been suggested that a distorted lattice should play an important role in the ferromagnetic insulating state in hole-doped manganese oxides and $YTiO_3$. Up to date, experimental evidence showing the CDWs modulation and the interplay between the lattice distortion and the magnetism in $BaRuO_3$ is still lacking. It is probably due to the unknown q vector and the relatively weak diffraction intensities associated with the CDWs modulation. In this work, a combination of using x-ray scattering along with the image plate and magnetic measurements was performed on a high quality single crystal of nine-layer $BaRuO_3$. It provides experimental evidence for the presence of a ferromagnetic insulating state, strongly coupled to a complicated lattice distortion associated with the CDWs modulation, at low temperatures.

A metal-insulator transition observed at T~ 90 K below which $d\rho/dT$ is less than zero in resistivity measurements. This non-linear transport is ascribed to the formation of a CDW modulation which distorts the Fermi surface resulting in a gap opening at the Fermi level. Furthermore, the temperature dependence of magnetization with a field of 100 G along the *c*-axis also reveals a weak ferromagnetic transition along the *c*-axis at T~ 90 K. These measurements confirm the coexistence of a weak ferromagnetic state and an insulating state in a 9-layered (9R) $BaRuO_3$ at low temperatures.

In order to precisely locate the satellites below the transition temperature, we took the diffraction images above and below the transition temperature using an *in-vacuum* camera on the beamline BL02B1 at SPring-8. Images taken at T= 200 K and 30 K. Some extra satellites were observed at T= 30 K. These satellites were indexed to double the unit cell along the *c*-axis. Further studies were carried out by measuring the peak profiles of these satellite reflections as a function of temperature on the bending magnet beamline BL12B2. The incident x-rays were selected to be 1 Å by a pair of perfect single crystal Si(1 1 1). The high-order contaminations were rejected by the use of the collimating mirror and the focusing mirror. The sample used for the image study was glued on a cryostat mounted on a 6-circle diffractometer. The use of a multi-circle diffractometer allows the scans to be performed along any crystallographic axis in the reciprocal space. In order to improve the spatial resolution, a perfect crystal Si(1 1 1) was used as an analyzer. The crystal was aligned with a hexagonal lattice parameter at room temperature and then cooled down to 10 K for x-ray scattering measurements. Many satellite reflections were located at positions such as (0 0 7.5), (0 0 10.5), (0 0 13.5), (0 1 9.5), and (0 1 12.5), suggesting that the modulation occurs along the c^* direction and doubles the unit cell along the *c*-axis. Scans through the three crystallographic axes also show that the modulation possesses the character of anisotropic ordering at low temperatures. Surprisingly, using meshing scan around the satellite reflection, we observed the splitting of the satellite reflection at about 55 K as showing in Fig. 1. This is can be explaind by a lattice distortion.

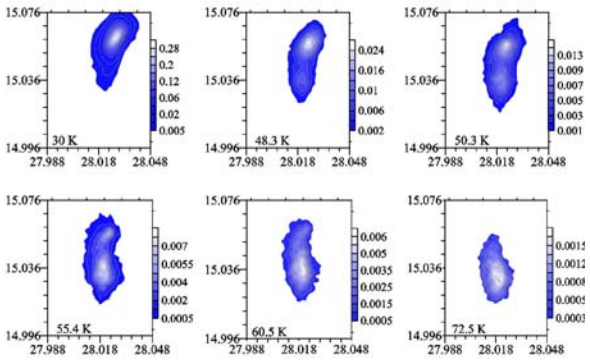

Fig. 1: Mesh-scans around the CDW satellite (0 0 10.5) at different temperatures (30 K, 48.3 K, 50.3 K, 55.4 K, 60.5 K, 72.5 K). The *x*-axis presents the 2θ and the *y*-axis is the θ. It is clear to see the splitting of CDW satellite along the θ-axis at around T= 55 K.