Observation of Spin Reorientation in $TbCu_2Ge_2$ from Resonant and Nonresonant Magnetic X-ray Scattering

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Introduction

Previous powder neutron scattering measurements of magnetic ordering in the tetragonal $TbCu_2Ge_2$ compound revealed a single transition, below approximately 12.5K, to an antiferromagnetic state characterized by a wave vector of (1/2 0 1/2) with the moments directed along the [110] direction. More recent bulk magnetization measurements on small single crystals grown by the high-temperature flux method, however, revealed the presence of a second transition below approximately 9.8K. It was suspected that this second transition involved the reorientation of the spin in the antiferromagnetic structure, a feature that was not clearly observed in the neutron powder measurement. Resonant and nonresonant magnetic x-ray scattering measurements were undertaken to resolve the nature of the second transition, denoted T_t at 9.8K.

Methods and Materials

Single crystals of $TbCu_2Ge_2$ were grown at Ames Laboratory using a high-temperature flux-growth method. The scattering experiment was carried out on the MU-CAT undulator beamline 6-ID, using a double-bounce Si(111) monochromator and a pyrolitic graphite analyzer in the horizontal scattering geometry. The sample was mounted on the cold finger of a closed-cycle cryostat and wrapped with Al foil (15 μm) to reduce local heating. The sample was oriented with the (*h0l*)-zone in the scattering plane with s incoming photon polarization. The resonant scattering was performed at LIII edge of Tb, where, using the PG(006) reflection, scattering in the s polarization channel was effectively suppressed. In this geometry, for electric dipole resonant scattering, the component of the magnetic moment in the scattering plane is probed. Nonresonant scattering measurements were done at 7 keV using the PG(002) reflection to pass both the σ and π-polarized scattered radiation. In this configuration, and at this low energy, all components of the magnetic component contribute to the scattering, but we are primarily sensitive to the component out of the scattering plane along (*0k0*).

Results and Discussion

The temperature dependence of the magnetic scattering is shown in Fig. 1 for both the resonant and nonresonant measurements. We note that the resonant scattering all but disappears above 9.8K indicating that the moment direction above 9.8K, but below TN, is along [010]. This was confirmed by a simple model of the temperature dependence that uses a Brillouin function to model the temperature dependence of the magnetization and takes into account a reorientation of the magnetic moments from the [110] direction below 9.8K to the [010] direction above 9.8K. The temperature dependence of this rotation angle is displayed in the bottom panel of Fig. 1.

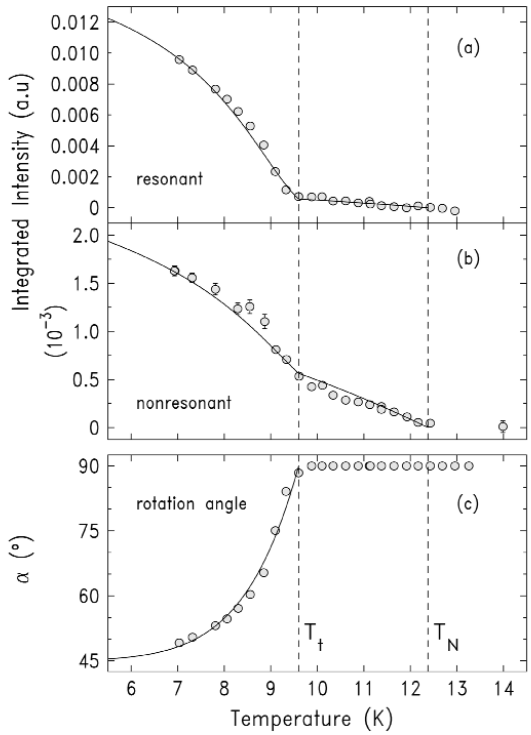

FIG. 1. (a) Integrated intensity at (1/2 0 15/2) magnetic Bragg peak at LIII edge of Tb ion. (b) Nonresonant integrated intensity with photon energy at 7 keV. (c) Angle of moment direction with respect to the [100]. Solid lines are fits.

Ackowledgments

Ames Laboratory-U.S.DOE is operated by Iowa State University under contract W-7405-ENG-82. This work is supported by the Director for Energy Research, Office of Basic Science. Synchrotron work was performed at the Midwest University Collaborative Access Team (MU-CAT) sector at the Advanced Photon Source, supported by U.S.-DOE, Office of Science, Office of Basic Energy Sciences under contract W-31-109-ENG-38.

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C. Song, D. Johnson, D. Wermeille, A. I. Goldman, S. L. Bud'ko, I. R. Fisher, and P. C. Canfield, (submitted).