Evidence of the Non-Magnetic Ordering in TmRu$_2$Si$_2$ at Low Temperatures

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The neutron powder diffraction measurements of the TmRu$_2$Si$_2$ compound in the temperature range 0.47–2.5 K have been performed. The obtained results confirm that this compound in low temperature has a tetragonal ThCr$_2$Si$_2$-type crystal structure (space group $I4/mmm$). The long range magnetic ordering was not detected up to 0.47 K.

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1. Introduction

TmRu$_2$Si$_2$ compound crystallizes in a tetragonal ThCr$_2$Si$_2$-type crystal structure [1]. In contrast to other RRu$_2$Si$_2$ (R = rare earth element) compounds which are antiferromagnets [2, 3], the magnetic properties of TmRu$_2$Si$_2$ are contradictory. The first magnetic data indicate the ferromagnetic order near 1 K [3] while the new complex measurements (magnetic, specific heat and electrical resistivity) indicate the paramagnetic behaviour down to 0.3 K [4]. The specific heat data (see inset in Fig. 3 in Ref. [4]) give the small intensity maximum at 0.6 K.

For the explanation of these differences the neutron diffraction experiment in mK temperature was performed.

2. Experimental

The experiment was performed on the sample whose preparation is described in Ref. [4]. The X-ray analysis at room temperature indicates that the sample has a tetragonal crystal structure with the lattice parameters $a = 4.138(4)$ Å and $c = 9.469(10)$ Å which are in good agreement with those reported in Ref. [4].

The neutron diffraction patterns are determined at temperatures 0.47, 0.6, and 2.5 K with the use of E6 diffractometer at BER II reactor (Helmholtz-Zentrum, Berlin). Low temperatures are obtained using a ILL-type cryostat with a $^3$He inset. The powdered samples were enclosed in a cylindrical copper container with a diameter of 8 mm. For better thermal contact a small amount of deuterated methanol was dropped into the container. The incident neutron wavelength was 2.443 Å. The data were analyzed using the Rietveld-type program FullProf [5].

3. Results and discussion

Typical diffraction pattern measured at 2.5 K and the differential patterns: 0.47–2.5 K and 0.6–2.5 K are shown in Fig. 1. The strong intensity peaks correspond to Cu container while the small intensity ones correspond to...
TmRu$_2$Si$_2$ sample and the cryostat (Al). Analysis of the peaks connected with the investigated sample confirm the tetragonal structure (space group $I4/mmm$) in which the atoms occupy the following positions: Tm atoms at 2$a$ site (0,0,0), Ru atoms in 4$d$ site (0,1/2,1/4) and Si atoms in 4$c$ site (0,0,$z$). Determined values of lattice parameters $a$ and $c$, $a/c$ ratio, unit cell volume $V$ and positional parameter $z$ are listed in Table I.

Presented in the work data indicate that the change of the crystal structure and existence of the magnetic order at low temperatures are not observed. In majority of TmT$_2$Si$_2$ compounds the Tm moments order at low temperatures [6]. Absence in Tm sublattice of magnetic order is detected in isostructural TmCr$_2$Si$_2$ [7] in which the electrical crystal field (CF) indicates a non-magnetic singlet as a ground state.

The obtained data indicate the large decrease of the unit cell volume between 0.47 K and 300 K equal to 3.81 Å$^3$ which corresponds to the ratio $\Delta V/V = 2.35\%$. This decomposition is larger than that in isostructural TmCu$_2$Si$_2$ (0.7%) [8] and TmNi$_2$Ge$_2$ (1.75%) [9].

The anomaly is hard to understand. Some explanation can give the comparison of the physical parameters for ordered and non-ordered compounds:

- quadrupole interaction ($\Delta E_Q$) at low temperatures is bigger in compounds with magnetic ordering compound, for example 140 mm/s in TmCu$_2$Si$_2$ [10] than in non-magnetic compounds TmCr$_2$Si$_2$ (70 mm/s) [7];
- energy gap between the ground state and first excited CF level is equal to 6.09 K in TmCr$_2$Si$_2$ [11] and nearly 20 K in TmRu$_2$Si$_2$ [4] and 13 K in TmCr$_2$Si$_2$ [7].

4. Conclusion

Above data suggest that anomalous properties of TmRu$_2$Si$_2$ are connected with the electronic properties of those compounds.

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References