Proceedings of the 15th Czech and Slovak Conference on Magnetism, Košice, Slovakia, June 17–21 2013

Pressure Influence on Magnetic Properties of TbNiAl

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We have investigated the effect of hydrostatic pressure on magnetic properties of TbNiAl, crystallizing in hexagonal ZrNiAl-type structure. TbNiAl orders antiferromagnetically below $T_N = 45$ K and undergoes further magnetic phase transition to another AF phase at $T_1 = 23$ K. The magnetic field of $B_c \cong 0.3$ T applied along the c–axis at 2 K leads to the transition to ferromagnetic order. By applying the hydrostatic pressure, both T_N and T_1 remain almost unaffected whereas B_c shows a strong increase. The hydrostatic pressure stabilizes the antiferromagnetic state which can be related to development of structural parameters.

DOI: 10.12693/APhysPolA.126.280

PACS: 75.50.Ee, 75.30.–m

1. Introduction

TbNiAl belongs to a rather large group of rare–earth intermetallic compounds crystallizing in the hexagonal ZrNiAl–type structure. TbNiAl orders antiferromagnetically below $T_N = 45$ K and undergoes an additional magnetic phase transition at $T_1 = 23$ K. Neutron diffraction studies reveal that the magnetic order is characterized by a propagation vector (1/2, 0, 1/2) with Tb magnetic moments oriented along the hexagonal c-axis in both magnetic phases [1, 2]. One third of the moments is strongly reduced between T_N and T_1 due to a geometrical frustration originating in triangular arrangement of Tb atoms within the basal planes. The strong frustration is removed below T_1 and all Tb moments reach the same value at 2 K [1]. The antiferromagnetic order can be easily disrupted by a small (~ 0.3 T at 2 K) magnetic field applied along the c-axis [1, 3, 4] or by substitutions like in the TbNi(Al,In) series [4], leading to a collinear ferromagnetic structure.

Previous results indicated that TbNiAl is a rare example of a localized system in which the magnetic properties seem to be very sensitive to structural changes caused by substitutions [5]. One can expect that similar effects can be thus achieved by applying external pressure. Here we present the effect of hydrostatic pressure on the magnetic phase transitions as observed on electrical resistivity measurements. Surprisingly, the electrical resistivity of TbNiAl was not published up to now even in zero pressure.

2. Experimental

The single crystal of TbNiAl was grown by Czochralski method as described elsewhere [3]. The electrical resistivity was measured by a standard four–probe method with the PPMS (Quantum Design) instrument. The pressure measurements were realized using the double–layered pressure cell (outer CuBe bronze + inner NiCrAl alloy) CuBe–bronze pressure cell. The Daphne oil 7373 was used as the exchange pressure medium and the thermally stabilized manganin wire was used to determine the pressure inside the pressure cell.

3. Results and discussion

The temperature dependence of electrical resistivity measured at ambient pressure on TbNiAl single crystal is shown in Fig. 1. Two clear kinks on the $R(T)$ curve (seen well as maxima of the temperature derivative) correspond to the magnetic transitions at T_N and T_1, well in agreement with other experimental techniques [1–4].

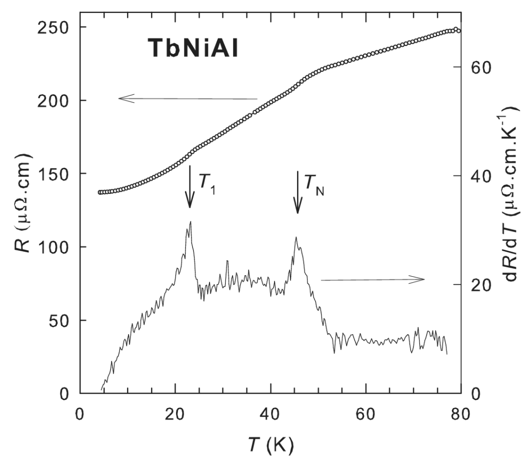

Fig. 1. Temperature dependence of resistivity measured at ambient pressure and its temperature derivative.

The magnetoresistivity curves measured at three different temperatures in the ordered state (below and above T_1) under several values of hydrostatic pressure are

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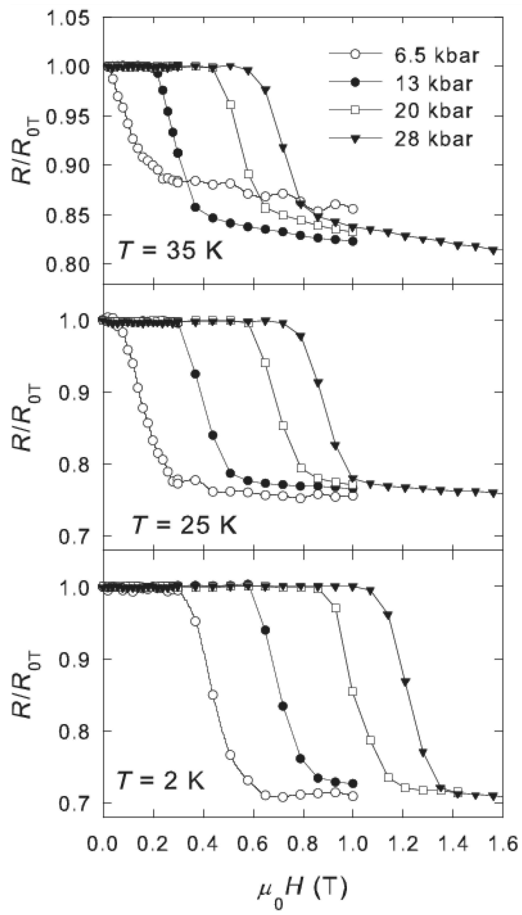

Fig. 2. Magnetoresistivity of TbNiAl measured under several hydrostatic pressures at three different temperatures. Magnetic field was oriented along the hexagonal c-axis.

shown in Fig. 2. The metamagnetic transition between the antiferromagnetic ground state and the induced ferromagnetic state is clearly reflected as a large drop of resistivity by ∼30% at 2 K. The observed critical field of about 0.4 T at 2 K is in a good agreement with previous magnetization measurements on the same crystal [3]. At higher temperatures, this metamagnetic transition shifts to lower magnetic fields, the strength of the antiferromagnetic exchange weakens. Nevertheless, it is present also at 35 K, i.e. in the magnetic phase between T_1 and T_N.

When applying the hydrostatic pressure, the metamagnetic transition shifts considerably to higher magnetic fields. The overall trend is the same below T_1 as well as above T_1. We can thus conclude that the antiferromagnetic structure in TbNiAl is clearly more stable under applied hydrostatic pressure. Such conclusion is in agreement with the neutron diffraction experiment which showed similar trend on polycrystalline $Tb_{0.95}Y_{0.05}NiAl$ sample [6]. $Tb_{0.95}Y_{0.05}NiAl$ orders ferromagnetically in zero pressure, but the antiferromagnetic order is re-established by applying external pressure [6].

The observed results can be discussed in relation with crystal structure of TbNiAl. By applying the hydrostatic pressure, both lattice parameters decrease, the volume decreases and c/a ratio decreases as well due to higher compressibility along the c axis [7]. The values of c and c/a thus show the same trend as for the In–Al substitution in the TbNi(Al,In) series [5], whereas the a parameter shows the opposite trend. As the effect on magnetic properties is opposite – strengthening the antiferromagnetic ground state, one can draw a hypothesis that mainly the Tb–Tb distances within the basal plane, which are related to the a parameter and represent the shortest Tb–Tb distance, affect the nature of the magnetic ground state in TbNiAl.

4. Conclusions

The resistivity of TbNiAl measured under hydrostatic pressure showed that the antiferromagnetic structure becomes more stable with applied pressure. The Tb–Tb distance within the basal planes seems to be the main parameter which determines the nature of the ground state.

Acknowledgments

The experiments were performed in MLTL (http://mltl.eu/), which is supported within the program of Czech Research Infrastructures (project no. LM2011025). The work of M.K. and J.K. was also supported by the grant SVV-2014-260091.

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