The Non-linear Susceptibility at Metamagnetic Transition in TbNiSn

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Abstract

The linear and non-linear AC-susceptibility of TbNiSn single crystals for b-axis has been measured under DC magnetic field at 4.2 and 1.8 K, below Neel Temperature. The divergence of the third higher-harmonic susceptibility was observed at the critical fields of metamagnetic transitions. This result suggests the spin relaxation time extremely increase around the critical field.

Key words: TbNiSn; AC susceptibility; metamagnetic transition

1. Introduction

The TbNiSn compound has the orthorhombic (Pnma) TiNiSi type structure and isostructural Kondo semiconductor CeNiSn is most extensively investigated material in RNiSn series (R:rare earth element). However, only few studies have been made for TbNiSn, so far.

Recently, we have presented the detailed magnetic and transport properties of TbNiSn single crystal [1–3]. It is characterized by the four successive magnetic phase transitions at $T_N = 18.5$, $T_3 = 7.6$, $T_2 = 6.0$ and $T_1 = 2.2$ K and the four multistep metamagnetic transitions along the easy axis(b-axis): critical field of $H_{c1} = 0.6$, $H_{c2} = 1.5$, $H_{c3} = 4.3$ and $H_{c4} = 5.3$ T at 1.5 K. Furthermore, the magnetic Tb^{3+} ion has localized Ising spin character [4,5]. Moreover, TbNiSn single crystal shows remarkable changes in magnetoresistance at magnetic field correspond to the metamagnetic phase transition. This remarkable behavior is presumably due to spin fluctuation related to the magnetic phase. In order to investigate this fluctuation, we have carried out the non-linear AC susceptibility measurement.

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2. Experimental

High quality single crystals of TbNiSn were prepared by one of the present authors. The procedure of sample preparation was same as presented elsewhere [1]. The linear and non-linear susceptibility was measured using a non-balanced mutual inductance bridge. Focusing on the nonlinear term, The magnetization in the presence of the magnetic field can be generally expressed as

$$m = \chi_0 H + \chi_2 H^3 + ...$$

In the presence of a DC magnetic field H_0 and AC magnetic field $h = h_0\cos(\omega t)$ the linear susceptibility χ_0^t and non-linear susceptibility $3/4\chi_2^t {h_0}^2$ is expressed as

$$\chi_0^t = \chi_0 + 3\chi_2 {H_0}^2 + ... + 3/4\chi_2 {h_0}^2 + ...$$

$$3/4\chi_2^t {h_0}^2 = 3/4\chi_2 {h_0}^2 + ...,$$

where the linear term χ_0 is expressed as in-phase and quadrature components, *i.e.*

$$\chi_0 = \chi_0' + \chi_0''.$$

There was no frequency dependence on χ_0^t in the frequency range between 10 Hz and 1 KHz in our experiment except the vicinity of the critical field.

3. Results and Discussion

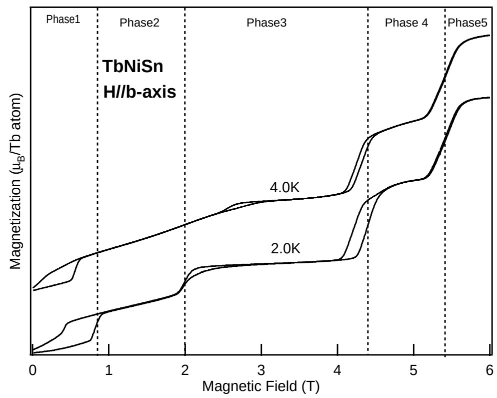

Fig. 1. Magnetization process of TbNiSn at 1.8 and 4.2 K

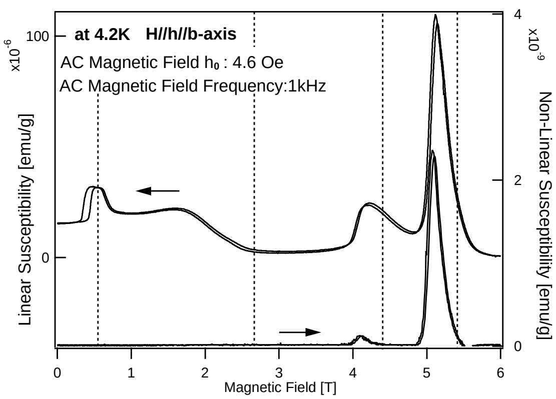

Fig. 2. Magnetic field dependence of linear and nonlinear AC susceptibility of TbNiSn at 4.2K

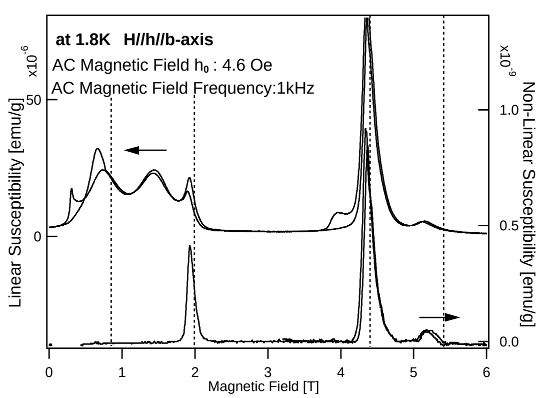

Fig. 3. Magnetic field dependence of linear and nonlinear AC susceptibility of TbNiSn at 1.8K

Fig. 1 shows the magnetization process measured using vibrating sample magnetometer (VSM) in the magnetic field along the *b*-axis at 2.0 and 4.0 K. Fig. 2 and Fig. 3 shows magnetic field dependences of the in-phase linear AC susceptibility and the third-order harmonic non-linear AC susceptibility at 1.8 and 4.2 K. These non-linear susceptibility clearly show the divergences just below critical phase transition fields. The divergence of linear susceptibility was also observed, because linear susceptibility includes non-linear susceptibility.

It should be noted that the divergence at H_{c4} is very small and the divergence at H_{c3} is very large at 1.8 K, although each intensities are exchanged at 4.2 K. AC susceptibility in DC magnetic field can be simply expressed by differential of the magnetization processes. However, both static magnetization process are quite similar above 3 T(includes H_{c3} and H_{c4}). Thus the divergences are not due only to the effect of non-linear magnetization process accompanied by metamagnetic phase transition.

It seems that the divergences are the critical behavior involved with phase transition. However, in this magnetization process all phase transitions show hysteresis. Thus these phase transitions are 1st order phase transition. Usually 1st order phase transition doesn't exhibit large fluctuation. Moreover, as mentioned above, the divergences always little shift from critical point to lower field. It might be an error to assume that the divergences are critical behaviors of the phase transitions. It seems rather reasonable to suppose that the antiferromagnetic domain structure was formed at critical point, and magnetic soliton was excited at H_{c4}. In fact, H_{c4} is phase transition point from antiferromagnetic state (AF) to forced ferromagnetic state (FM). If the magnetic domains were formed, magnetic state above H_{c4} is considered to be mixed AF and FM domain states.

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