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Magnetic structure of $NpTGa_5$ (T: Fe, Co, Ni)

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Abstract

We have succeeded in growing single crystalline samples of $NpTGa_5$ (T: Fe, Co, Ni). Magnetic structures of these compounds have been studied by neutron diffraction. We summarize the results of the unusual variety of magnetic structure occurring in $NpTGa_5$ and discuss them in terms of their electronic structural point of view.

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Keywords: $NpTGa_5$; Magnetic structure; Neutron scattering

After the discovery of superconductivity above 18 K in $PuCoGa_5$, actinide based '115' compounds have received increasing attention [1]. It is a great advantage of the '115' system that single crystals of Ce ($4f^1$), U($5f^3$), Np($5f^4$) and Pu($5f^5$) can be grown with various transition metal elements. Thus, the '115' is an excellent candidate for studying the multiple 5f electron system. The appearance of superconductivity in Ce and Pu compounds and its absence in U and Np compounds are theoretically studied and discussed based on band structure calculation and the *j–j* coupling scheme [2]. It might be due to strong itinerant character of 5f electrons in U-system, whereas magnetism is rather stable in Np-system. In this paper, we summarize the magnetic structure of $NpTGa_5$ (T: Co, Fe, Ni), as revealed by neutron diffraction measurements.

Very recently, high-quality single crystalline samples of $NpTGa_5$ (T: Fe, Co, Ni) have been

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grown by the self-flux method. Np metal was prepared by the electrolysis from the aqueous solution [3]. Magnetic susceptibility measurements revealed the antiferromagnetic (AFM) transition in $NpCoGa_5$ [4,5] and $NpFeGa_5$ [6] below $T_N =$ 47 and 118 K, respectively. On the contrary, $NpNiGa_5$ shows successive ferromagnetic (FM) transitions at 18 and 30 K.

AFM reflections with the propagation vector $q = (0\,0\,1/2)$ have been found below T_N in $NpCoGa_5$ [7]. Fig. 1 is the (1 1 1/2) AFM peak measured at $T = 3$ K, which disappears at $T = 50$ K. The absence of the (0 0 1/2) peak indicates the moment direction to be parallel to the *c*-axis. The integrated intensities of the AFM reflections (Fig. 2) are well explained with model calculation, assuming the magnetic structure as shown in the inset of Fig. 2. In this calculation, the magnetic form factor of Np^{3+} ion was used. No magnetic moment was assumed on the Co site. The magnetic structure is the same as that for $UPdGa_5$ and $UPtGa_5$ [8–10].

In $NpFeGa_5$, AFM reflections with $q = (1/2\,1/2\,0)$ have been observed as shown in Fig. 3 [11]. The integrated intensities of the $(1/2\,1/2\,l)$ AFM peaks are plotted as open circles

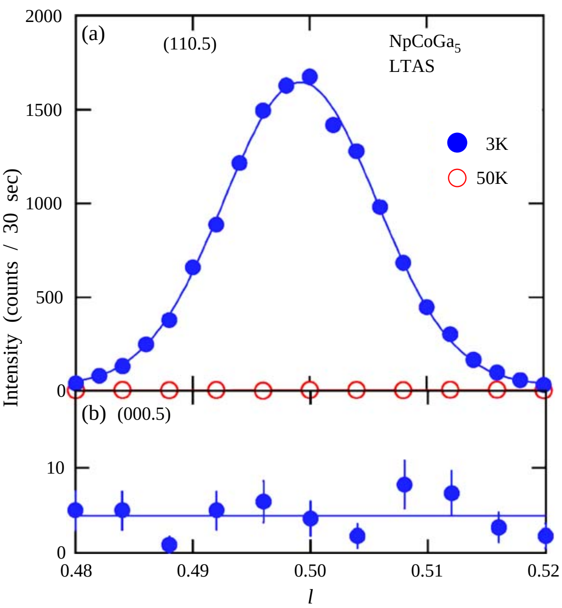

Fig. 1. The line scan in $NpCoGa_5$ at 3 and 50 K.

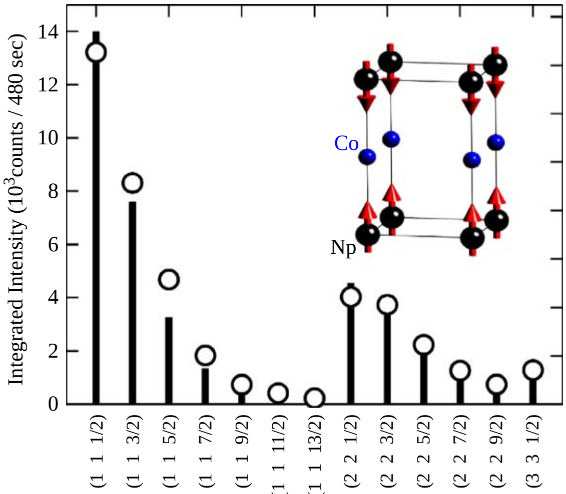

Fig. 2. The integrated intensity of AFM reflections of $NpCoGa_5$.

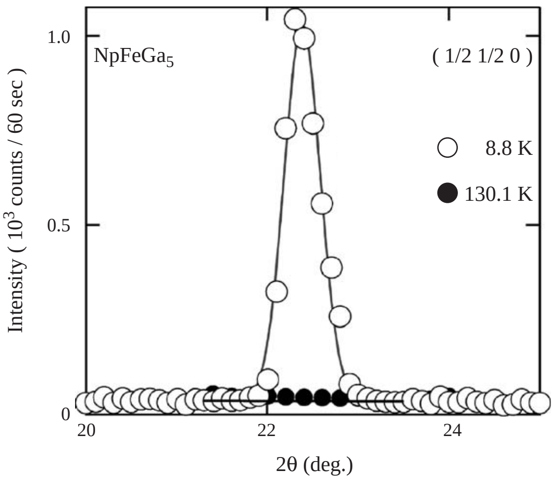

Fig. 3. The radial scan at (1/2 1/2 0) in $NpFeGa_5$.

as shown in Fig. 4. It is notable that the integrated intensity is strong for odd *l* and weak for even *l*. This feature cannot be explained from a simple collinear magnetic structure with the magnetic moment only on Np site. But this can be reproduced assuming a ferrimagnetic structure on Np and Fe magnetic sublattices. Note that the magnetic structure factor is proportional to the sum and the difference of the Np and Fe moment for even *l* and odd *l*, respectively. Thus, the Fe moment should be opposite to the moment of

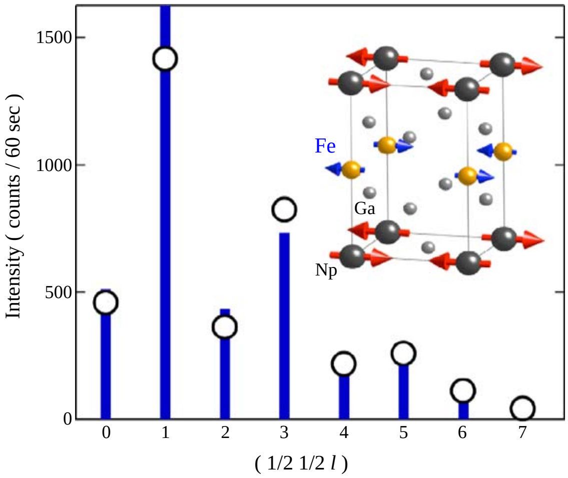

Fig. 4. The integrated intensity of AFM reflections of $NpFeGa_5$.

neighboring Np. One may explain the experimental data with the model calculation assuming the ferrimagnetic structure shown in the inset of Fig. 4. The in-plane moment direction cannot be determined because of the multi domain structure. The magnetic moment was derived as $0.24\mu_B$/Fe and $0.86\mu_B$/Np, respectively. In our model calculation we used the magnetic form factor of Np^{3+} free ion and j_0 (zeroth order Bessel function) for Fe. The magnetic structures of $NpCoGa_5$ and $NpFeGa_5$ are significantly different. $NpCoGa_5$ exhibits in-plane FM and inter-plane AFM interaction, whereas the ones for $NpFeGa_5$ are opposite, namely in-plane AFM and inter-plane FM. The magnetic propagation $q = (1/2\,1/2\,0)$, C-type structure, is found for the first time in $NpFeGa_5$ in '115' system. The moment direction is also different.

The existence of Fe moment indicates that the 5f–3d hybridization is rather important in Np system. In the U-'115' system, however, the transition metal d-bands are fully occupied, thus no magnetism is expected. The uranium 5f and Ga 4p hybridization band plays a dominant role for the transport and magnetic properties in the U-'115' system.

We briefly mention the preliminary results on $NpNiGa_5$ [11]. The two successive FM transitions at $T_{C1} = 30\,K$ and $T_{C2} = 18\,K$ were confirmed by means of neutron diffraction. Surprisingly, however, we observed a clear (1/2 1/2 1/2) AFM peak which starts to increase below $T_{C2} = 18\,K$. This propagation vector has been reported in $UNiGa_5$ [8] but appeared neither $NpCoGa_5$ nor $NpFeGa_5$. The presence of the (1/2 1/2 1/2) AFM peak indicates that a canted AFM structure appears below T_{C2}.

We have two models to explain the successive transition in $NpNiGa_5$, (i) Np sublattice exhibits the FM and a canted structure below T_{C1} and T_{C2}, respectively or (ii) Np (Ni) sublattice shows a FM order below T_{C1} and a canted AFM order appears on Ni (Np) sublattice below T_{C2}. Spin polarized neutron diffraction experiment are planned to clarify the magnetic structure in $NpNiGa_5$.

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