Magnetic properties of the UNiGe$_2$ at low temperature

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Abstract. We report on the magnetic characterization of a novel ternary uranium intermetallic UNiGe$_2$. When we assume that UNiGe$_2$ has the orthorhombic structure of CeNiGe$_2$-type which is same as that of UNiSi$_2$, the lattice constants were obtained to be $a = 3.97$ Å, $b = 16.48$ Å, and $c = 4.08$ Å. The unit cell volume of UNiGe$_2$ is larger than that of UNiSi$_2$. It comes from the fact that the atomic radius of Ge is larger than that of Si. The temperature dependence of the magnetic susceptibility shows two peaks at $T_N = 45$ K and $T'_N = 65$ K. Taking an account that UNi$_2$Ge$_2$ secondary phase exists in the compound, UNiGe$_2$ is an antiferromagnet below $T_N$ while $T'_N$ may come from the antiferomagnetic order of UNi$_2$Ge$_2$. At 5 K, the slope of the magnetization curve increases as increasing the magnetic field up to 5 T, indicating the presence of a metamagnetic transition. The residual magnetization remains on the magnetization curve at 5 K, which may come from a week ferromagnetism of UNi$_2$Ge$_2$ at low temperature.

1. Introduction
Intermetallic compounds including Ce or U atoms have been investigated extensively because these compounds give important information for studying the role of strong electron correlations in metallic systems[1, 2, 3, 4]. In these compounds, the ferromagnetic/antiferromagnetic interaction and Kondo effect compete each other.

The ternary compounds CeTX$_2$ (T = transition metal and X = Si, Ge, Sn) form a large family having the orthorhombic CeNiSi$_2$-type layered structure, which is constructed from deformed fragments of the CeGa$_2$Al$_2$ and α-ThSi$_2$ structures[5]. The lattice parameter along $b$-axis is extremely large compared to those along $a$- and $c$- axes, and it is expected that highly anisotropic magnetic property exists. Indeed, these compounds have received considerable interest of a great variety of magnetic behaviors[6, 7, 8].

UNiSi$_2$ also crystallizes in orthorhombic CeNiSi$_2$-type layered structure, and is a ferromagnet at $T_C = 95$ K[9, 10]. Single crystals can be brown by Czochralski pulling method because UNiSi$_2$ melts congruently. The large anisotropic behavior is observed in the measurement of the magnetization of UNiSi$_2$ single crystal at low temperature ferromagnetic phase. The easy
2. Experimental
Polycrystalline sample of UNiGe$_2$ was synthesized by arc melting with a stoichiometric composition in an Ar gas atmosphere. Weight losses were less than 0.3%. To improve homogeneity, the sample was turned over and re-melted several times. The sample was characterized by X-ray powder diffraction experiments using a Rigaku MiniFlex II diffractometer with Cu-K$_\alpha$ radiation. The dc magnetization was measured by using a Quantum Design MPMS-5 superconducting quantum interference device magnetometer.

3. Results and Discussion
3.1. X-ray diffraction
Figure 1 shows the X-ray diffraction pattern of UNiGe$_2$ at room temperature. Here we assumed that UNiGe$_2$ has the same crystal structure as UNiSi$_2$ and indexed the Bragg peaks as the orthorhombic CeNiSi$_2$ type structure with the space group of $Cmcm$. The lattice constants were obtained to be $a = 3.97$ Å, $b = 16.48$ Å, and $c = 4.08$ Å for UNiGe$_2$. The unit cell volume is calculated to be 266 Å$^3$, which is larger than that of UNiSi$_2$, 258.83 Å$^3$[11]. It comes from the fact that the atomic radius of Ge is larger than that of Si. On the other hand, several unknown peaks are also observed in the X-ray diffraction pattern, and may correspond to the diffraction of UNi$_2$Ge$_2$ as a secondary phase[13]. Such behavior has been also observed in the previous report, in which it is suggested that a new dominant phase and UNi$_2$Ge$_2$ secondary phase exist in the compound[12].
3.2. Magnetic Properties

Figure 2 shows the temperature dependence of $M/H$ of UNiGe$_2$ between 2 and 300 K in a magnetic field of 1 kOe. The ZFC $M/H$ curve is obtained by cooling in zero field from a high temperature while the FC one by cooling at small applied field. $M/H$ increases as temperature decreases and two peaks are visible on the $M/H(T)$ curve at $T_N = 45$ K and $T_{N'} = 65$ K. At low temperature below $T_N$, on the other hand, $M/H$ in the FC curve tends to increase as decreasing temperature while that in the ZFC one approaches to zero. It suggests that a dominant phase of UNiGe$_2$ is an antiferromagnet below $T_N$. Taking account that UNi$_2$Ge$_2$ is an antiferromagnet below 74 K and that a weak ferromagnet moment is also present at low temperature[13, 14], $T_{N'}$ and the residual magnetization in the FC curve may also come from a secondary phase in the sample.

Figure 3 displays the behavior of the magnetization $M$ of UNiGe$_2$ as a function of magnetic field $H$ up to 50 kOe at 5 K. $M$ increases as increasing magnetic field, and reaches 0.139 $\mu_B$, which is much smaller than the saturation magnetization $M_s = 1.12$ $\mu_B$ of UNiSi$_2$[9]. Since the slope of magnetization $\partial M/\partial H$ increases up to 50 kOe, a magnetic phase transition such as metamagnetism is expected at a high magnetic field below $T_N$. Moreover, hysteresis loop is also observed in the magnetization curve at 5 K, suggesting the the presence of some magnetic ordering phase such as weak ferromagnetism or canted magnetism. Taking account that UNi$_2$Ge$_2$ a weak ferromagnet moment is also present at low temperature[13], pure samples are needed to discuss the ground state of UNiGe$_2$.

4. Summary

In this study, we prepared a novel ternary uranium intermetallic UNiGe$_2$ during our investigation of UNiX$_2$ with the CeNiSi$_2$-type orthorhombic structure. The unit cell volume of UNiGe$_2$ is larger than that of UNiSi$_2$. Our preliminary result of the magnetization indicates that UNiGe$_2$ is an antiferromagnet of 45 K. Further experiments are in progress to synthesize UNiSn$_2$ and UNiC$_2$ to investigate magnetic properties of UNiX$_2$ (X = C, Si, Ge, Sn) series.
Figure 3. The field dependence of the magnetization of UNiGe$_2$ at 5.0 K.

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