# Magnetic Measurement of Rare Earth Ferromagnet Gadolinium Under High Pressure

Tomoharu Iwamoto [a], Masaki Mito [a] Masako Hidaka [a] Tatsuya Kawae [a] Kazuyoshi Takeda [a]

[a] *Department of Applied Quantum Physics, Kyushu University, Fukuoka 812-8581, Japan*

## Abstract

Magnetic property of rare earth ferromagnet gadolinium(Gd: $Tc = 293$ K) has been observed under pressures up to 15 GPa, using a miniature diamond anvil cell (DAC) installed in a SQUID system. Pressurization suppresses both the ferromagnetic moment and the transition temperature with increasing pressure. In the pressure region above 6 GPa, the ferromagnetic signal has disappeared. The structural analysis, however, suggests that the crystal symmetry does not change in the pressure region up to 9 GPa. The results will be discussed on the exchange interaction among the isotropic 4f-metallic system.

*Key words:* Gd, magnetization, transition temperature, pressure, DAC

## 1. Introduction

The physical measurements at high pressure have been atracting much attention from the interest of searching new physical phenomema. For example, in the case of iron, the ferromagnetic $\alpha$-phase transfroms into the nonmagnetic $\epsilon$ phase at around 13 GPa [1,2]. Recently, in the pressure range of 15 - 30 GPa, the pressure-induced superconductivity has been observed in the temperature below 2 K by Shimizu *et al.* [2]. This experimental finding gives the another variety to the study of ferromagnet. In this paper, we report the pressure effect on the rare earth metal ferromagnetic Gadoliniumu (Gd) through the magnetic measurements. The Gd is an f-electron ferromagnet with the transition tempreature Tc = 293.2K. Below Tc, the magnetization saturates in the magnetic field ($H$) region above 1 Tesla, and its saturation moment is 7.55 $\mu_B/atom$. The magnetic anisotropy of Gd is very small due to the quenching of the orbital angular momentum.

The study of magentism of Gd under pressures has been investigated using the ac-method by some groups [3,4]. Bartholin and Bloch have reported that the ferromagnetic transition temperature ($T_c$) shows the negative pressure effects such as $dT_c/dP$ = -14.8 K/GPa in the pressure region up to 0.5GPa [3]. They have suggested that the pressure effects on the exchange interaction along the c-axis plays an important role [3]. On the other hand, McWhan and Stevens have measured the magnetic susceptibility in the pressure region up to 5GPa, and there are two transitions above 2.5GPa [4]. The crystal structure of Gd under pressures has been studied by some groups [4–6]: Grosshans and Holzapfel have shown that the crystal structure changes hcp $\rightarrow$ Sm-type $\rightarrow$ d-hcp $\rightarrow$ fcc with increasing pressure [5]. Takemura and Syassen, however, have pointed out that hcp-Sm transition is not convincing.

## 2. Experimental

The used sample of Gd is the powdered one of 99.9 % purity. The magnetic measurement was performed using the SQUID magnetometer (Quantum Design MPMS-XL7TZ), into which the miniature diamond anvil cell (DAC) made of nonmagnetic hardened CuBe was installed. This miniature DAC is shown in detail in Ref. 7. The top-diameter of diamond anvils is 0.6 mm. The used gasket is the plate of CuBe, whose initial thickness is 0.2mm. As for the pressure transmitting medium, we used the alcohol mixture methanol/ethanol/water in the ratio 16:3:1. The ruby fluorescence technique has been used for pressure calibration in m-DAC at room temperature [8].

We perfomed the precise measurement of magnetization ($M$) of Gd at $H = 0.5$ Tesla in the pressure region up to $P = 15$ GPa, to the investigate whether the magnetic moment of Gd survives or not under high pressures.

## 3. Experimental Results

Three runs of measurement were carried out with different speciments. Fig. 1 shows the results of the first run for the temperature dependence of $M$ of Gd at $H = 0.5$ Tesla in the temperature region below 320 K. As pressure increases, the ferromagnetic behavior shifts toward low temperatures, and furthermore the magnitude of the moment is suppressed. In the pressure region above 6 GPa, the ferromagnetic signal cannot be detected. There is no magnetic behavior indicating the two transitions.

The $T_{\mathrm{c}}$ is defined as the temperature below which $M$ rapidly increases. Fig. 2 shows the pressure dependence of $T_{\mathrm{c}}$, which was estimated from three runs of experiment. Our results are consistent with the result by McWhan and Stevens, except for the splitting of $T_{\mathrm{c}}$. McWhan and Stevens have used the ring-like sample with the outer diameter of about 14 mm and the height of 2-3 mm. We assume that there may be uniaxial stress and large pressure distributuin in their measurent.

## 4. Conclusion

The pressure effects on Gd was investigated through the presice magnetic measurement using the SQUID magnetometer system, into which the miniature DAC was installed. The $T_{\mathrm{c}}$ value of decreases according to $dT_{\mathrm{c}}/dP = $ -12.2 K/GPa, and the ferromagnetic signal is not deteced in the pressure region above 6 GPa. Our reslus is partially consistent with the previous repots.
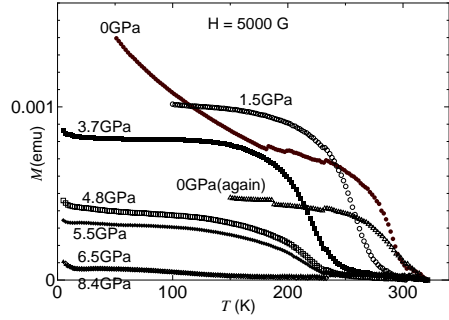


Fig. 1. Temperature dependence of magnetization ($M$) of Gd under $H = 0.4$T in the pressure region up to 8.4GPa. The data are taken in the oreder of $P = $ 0GPa → 1.5GPa → 3.7GPa → 4.8 → 5.5GPa → 6.5GPa → 8.4GPa → 0GPa(again).
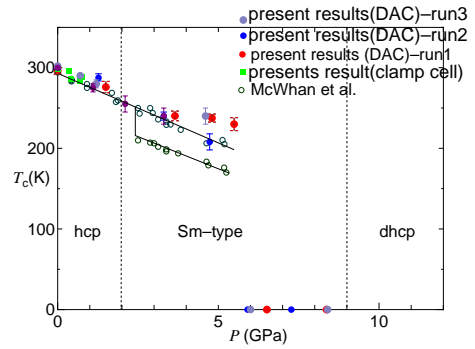


Fig. 2. Pressure dependence of transition temperature($Tc$) of Gd. About 6GPa, magnetic morment has quenched.

In order to confirm whether state above 6 GPa is non-magnetic or not, we have been measuring the magnetization curve of Gd up to 7 Tesla under pressures. Furthermore the powder X-ray structural analysis using the Rietveld method and the measurement of electric resistance are now in progress.

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