De Haas-van Alphen effect in $GdAl_3$

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Abstract

We have succeeded in growing a high quality single crystal of an antiferromagnet of $GdAl_3$ with the hexagonal crystal structure, and carried out measurements of the de Haas-van Alphen effect at temperatures down to 0.4 K up to 14 T. A number of dHvA frequencies in the range from 160 T to 2300 T was observed. The largest frequency has the cyclotron effective mass of 0.72 m_0 along the [0001] direction.

Key words: $GdAl_3$, dHvA effect

The light rare earth trialuminide compounds, RAl_3 (R: La-Gd), crystallized in the hexagonal Ni_3Sn-type of crystal structure, show a variety of interesting physical properties. The role of 4f electrons in determining the physical characteristics of these materials is still under investigation. Among the RAl_3 compounds, $GdAl_3$ is simple model material with Gd^{3+} ion in the $^8S_{7/2}$ ground state, having no influence of crystal-field and Kondo effect. $GdAl_3$ orders antiferromagnetically at 18 K [1] and exhibits spin frustration [2-4]. But as far as we known there are no published measurements performed on single crystals. To clarify the Fermiology of $GdAl_3$ we have measured the de Haas-van Alphen (dHvA) effect.

High quality single crystals were grown using a flux technique. The starting materials Gd (3N) and Al (6N) were put into an alumina crucible and sealed in the quartz ampoule under vacuum. The single crystals have well-developed facets and a size of $4 \times 4 \times 10$ mm^3 for the largest one. The crystal structure and phase purity were confirmed by X-ray powder diffraction and the crystal orientation was determined by a usual Laue method. The dHvA experiment was done by the standard field-modulation method in magnetic fields up to 14 T and temperatures down to 0.4 K.

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Figure 1 (a) shows the typical recorder trace of the dHvA oscillation in the field range from 4.8 to 6.0 T at 1.4 K for the field along [0001] direction, and (b) is the corresponding fast Fourier transformation (FFT) spectrum. It contains two fundamental frequencies denoted by α and β with the dHvA frequencies of 2297 T and

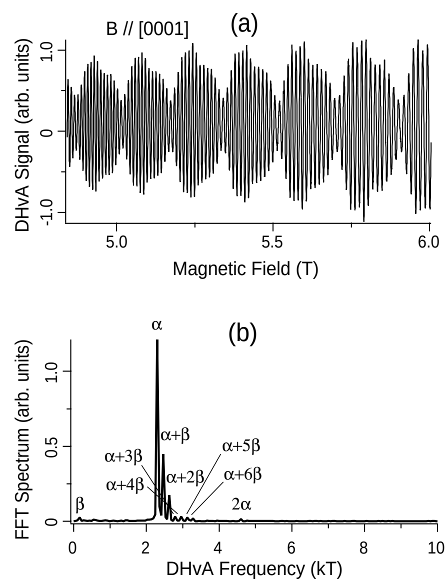

Fig. 1. (a) The typical dHvA oscillation for the field along the [0001] direction and (b) the corresponding FFT spectrum.

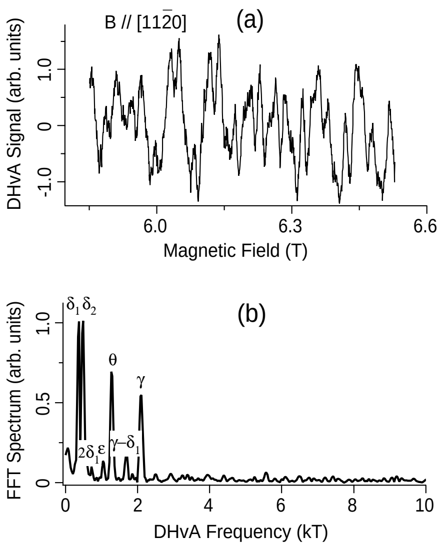

Fig. 2. (a) The typical dHvA oscillation for the field along th
[11$\overline{2}$0] direction and (b) the corresponding FFT spectrum.

168 T. The 2α is the second harmonic of fundamenta one and the α + nβ (n = 1 - 6) are the combination of the fundamental ones.

Figure 2 (a) shows the observed dHvA oscillation fo the field along [11$\overline{2}$0] direction in the field range fron 5.9 to 6.5 T at 1.4 K, and (b) is the corresponding FF spectrum. It contains five fundamental frequencies de noted by δ_1, δ_2, ϵ, θ and γ with the dHvA frequencie of 346, 462, 1038, 1280 and 2072 T, respectively. The harmonics and the combinations are also included.

The angular dependence of dHvA frequencies is shown in Fig.3 as a function of field angle from [11$\overline{2}$0] direction. The α branch with the largest frequency was observed in the limited region around the [0001] direction. With deviating from this principal axis, the signal became weak and disappeared finally away from the [0001] direction by 25^o. The α branch is nearly independent of the field direction. It may be suggested that it originates from the orbit on a nearly spherical Fermi surface, of which the radius is 0.47 Å^{-1} and the cross-section corresponds to about 20% of the Brillouin zone hexagonal base area. The cyclotron effective mass at the direction [0001] was 0.72 m_0, where m_0 is the free electron mass, for the α branch. In the region around [0001]-axis, the β branch with the lowest frequency was also observed; however, the amplitude was very weak. On the other hand, many kinds of dHvA branches were detected around the [11$\overline{2}$0]-direction, but no oscillation was observable in the field angle over 40^o from the [11$\overline{2}$0] direction. The characteristics of the observed branches indicate that the Fermi surface is a multiple connected open sheet. In order to clarify well the Fermi surface, one should make a detail investigation at other directions and a band structure calculation.

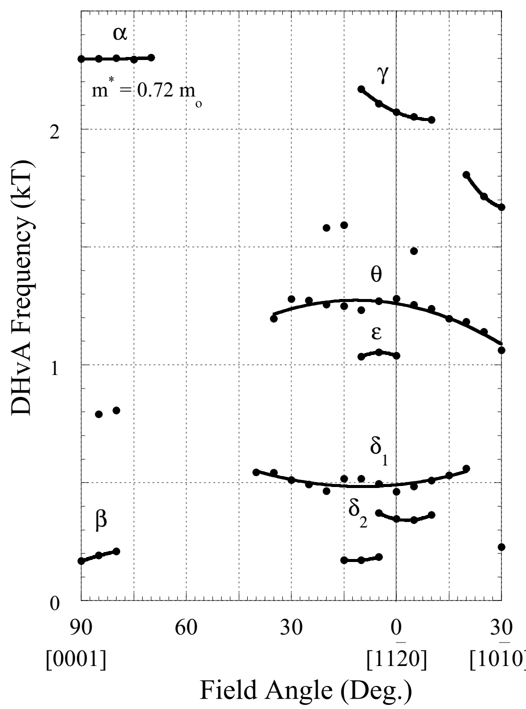

Fig. 3. The angular dependence of dHvA frequencies in $GdAl_3$.

In summary, we have grown a high quality of single crystal $GdAl_3$ and observed the dHvA oscillations. The $GdAl_3$ compound has a multiple connected open surface.

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