Anomalous Hall effect of $CeFe_{1.95}Al_{0.05}$ in the vicinity of the metamagnetic transition

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The essence of the anomalous Hall effect (AHE) is not fully understood and it still attracts considerable attention. Magnetic and magnetotransport properties of $CeFe_{1.95}Al_{0.05}$ compound in diverse magnetic state are studied which is helpful to know the essence of AHE. The semiempirical relation $\rho_{xy}=R_0B+4\pi R_sM$, widely accepted, is valid in describing the behaviors of AHE in ferromagnetic and paramagnetic state, but invalid in antiferromagnetic state in $CeFe_{1.95}Al_{0.05}$ compound. © *2008 American Institute of Physics*. [DOI: 10.1063/1.2828515]

I. INTRODUCTION

It is well known that the Lorentz force causes the normal Hall effect when the electrons moves in crossed electric and magnetic fields. However, materials with large localized magnetic moments show anomalous characteristic. The Hall resistivity is composed of two contributions: the one is approximately proportional to the applied magnetic field known as "normal," and the other is approximately proportional to the magnetization known as "anomalous."[1] Anomalous Hall effect (AHE) attracts considerable attentions, and both intrinsic and extrinsic mechanisms of AHE are developed.[2–5] Conventionally, the AHE has been ascribed to spin-orbit interaction and polarized conduction electrons, which result in asymmetry scattering of conduction electrons. However, the real origin of AHE is still in dispute that whether the AHE is derived purely from extrinsic scattering or has an intrinsic mechanism. Recently, the research in AHE shows that the Berry phase curvature may play an important role in the intrinsic origin.[6,7] The researchers have not arrived at an agreement on this problem yet. Therefore, further research is necessary to reveal the essence of AHE.

Lavas C15 cubic structure $CeFe_2$ compound is well known for its relatively low Curie temperature (≈230 K) (Ref. 8) and magnetic moment ($\approx 2.16\mu_B$/f.u.) (Ref. 9) compared with others rare earth congener compounds. With elements doping in $CeFe_2$ compound, the antiferromagnetic (AFM) state get stabilized in low temperature.[10–15] With the increasing temperature, $CeFe_{2-x}Al_x (x<0.16)$ compounds undergo AFM, ferromagnetic (FM), and paramagnetic (PM) states.[10] It is a good candidate to study the diverse behavior of AHE in various magnetic states subtly. We report a study about the magnetic and AHE properties on $CeFe_{1.95}Al_{0.05}$ compound.

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II. EXPERMENT

Stoichiometric $CeF_{1.95}Al_{0.05}$ sample was prepared by arc melting in an ultrapure argon gas atmosphere. The purity of the raw materials is 99.9% for cerium and iron and 99.99% for aluminium. The product was sealed in a quartz tube of high vacuum, and a postannealing at 973 K for 1 week was taken for homogenization. The single phase specimen with Lavas phase C15 cubic structure is confirmed by the x-ray powder diffraction study. The magnetization and Hall effect measurement have been taken in a commercial physical properties measurement system from Quantum Design Inc. Electrical contacts were done by wire-bonding thin Au wires to silver epoxy pads on a rectangular sample of dimensions of $5\times2\times0.34$ mm^3. The sample was patterned by conventional lithographic methods into four-terminal Hall geometry.

III. RESULTS AND DISCUSSION

Figure 1 shows the temperature dependence of magnetization from 20 to 270 K under 0.1 T applied field. With the increasing temperature, the $CeFe_{1.95}Al_{0.05}$ compound undergoes AFM state (T_N=80 K), FM state (T_C=196 K), and PM state. Applied magnetic field and temperature promote to

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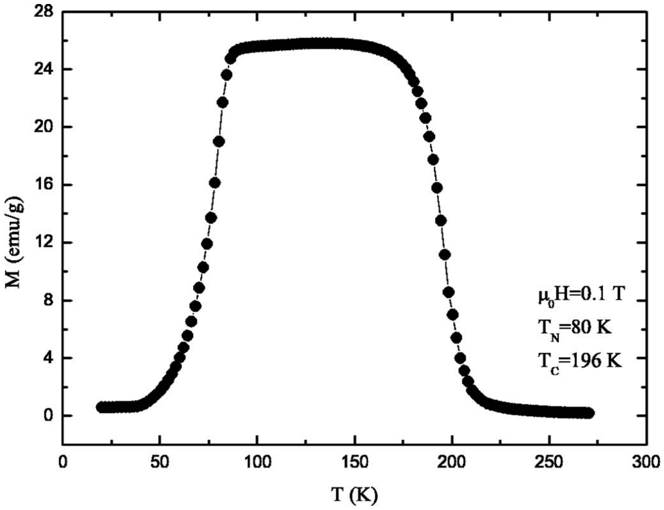

FIG. 1. Temperature dependent magnetization for $CeFe_{1.95}Al_{0.05}$ from 20 to 270 K in a field of 0.1 T. Néel temperature T_N and Curie temperature T_C are 80 and 196 K, respectively. Solid lines are guides for the eye.

destroy the AFM state. Multistate characteristic of $CeFe_{1.95}Al_{0.05}$ compound does provide an opportunity to study AHE in detail.

The magnetic and magnetotransport properties in AFM, FM, and PM states are investigated carefully in this paper. Figure 2 shows the applied field dependence of Hall resistivty ρ_{xy} and magnetizations in the vicinity of phase transition from AFM to FM state. With the increasing in applied field, magnetizations increase smoothly under low field, and then change rapidly till saturation under strong field, which is a key character of metamagnetic transition. However, with the increasing applied field, the Hall resistivity ρ_{xy} changes rapidly under low field and is saturated under strong field. The Hall resistivity ρ_{xy} to a weak applied magnetic field and the spontaneous magnetization M can usually be fitted by a semiempirical relation,[1]

$$\rho_{xy} = R_0 B + 4\pi R_s M, \tag{1}$$

where ρ_{xy} is the Hall resistivity, R_0 is the ordinary Hall coefficient, $B=\mu_0[H+(1-N)M]$ is the applied magnetic induction, μ_0 is vacuum permeability, N is the demagnetization factor, R_s is anomalous Hall coefficient, M will be the spontaneous magnetization M_s for temperatures below the Curie temperature, while above this temperature it will be the macroscopic intensity of magnetization. According to the geometrical shape of the sample, $(1-N)$ is so small that it can be negligible, and then $B \approx \mu_0 H$. Equation (1) can be rewritten as

$$\rho_{xy} \cong R_0 \mu_0 H + R_s \mu_0 M. \tag{2}$$

Note that the behavior of ρ_{xy} should be similar with M under applied field. However, it is obvious that the behaviors of M versus H are not consistent with ρ_{xy} versus H in the vicinity of metamagnetic transition (AFM to FM) (see Fig. 2). It is noted that M measured in AFM and FM states is macroscopic magnetization which is different from the spontaneous magnetization. However, the metamagnetic characteristic of spontaneous magnetization should be similar with that of macroscopic magnetization in the vicinity of phase transition. It is easily to draw a conclusion that the metamagnetic transition (AFM to FM) does not affect the behavior of AHE. It seems that the Eqs. (1) and (2) are invalid in the vicinity of

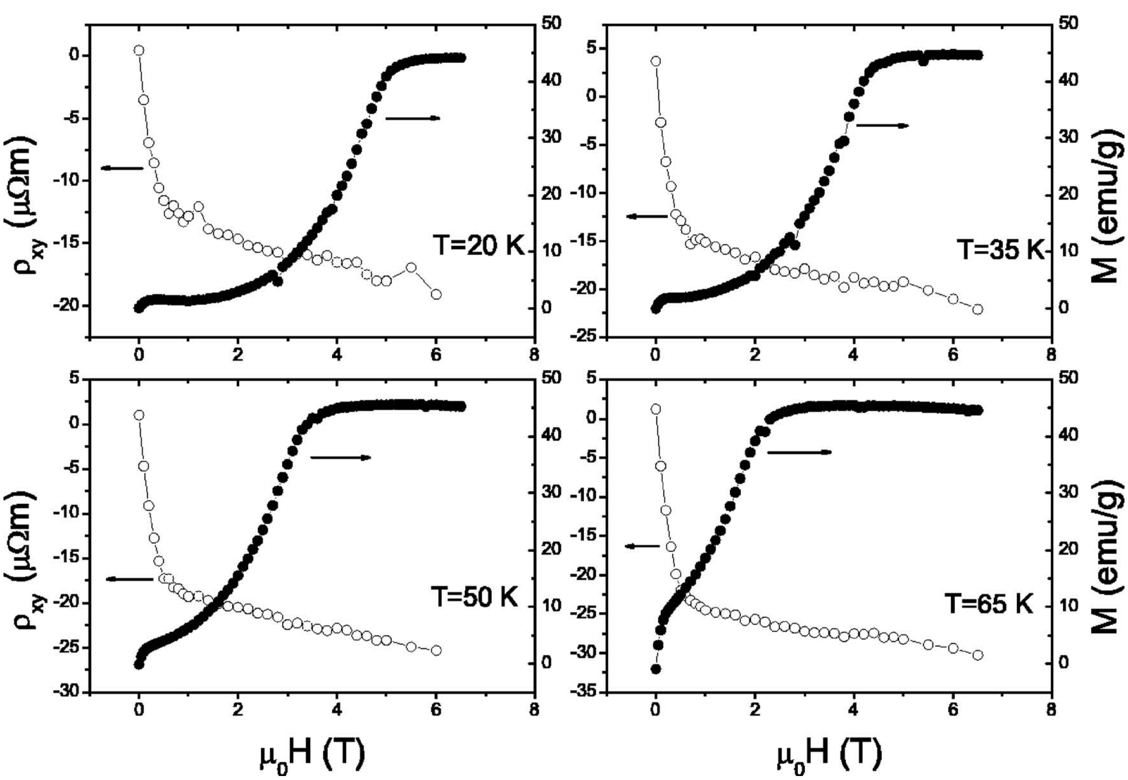

FIG. 2. Magnetic field dependent Hall resistivity (hollow dots) and magnetization (solid dots) of $CeFe_{1.95}Al_{0.05}$ at 20, 35, 50, and 65 K (metamagnetic transition from AFM to FM). Solid lines are guides for the eye.

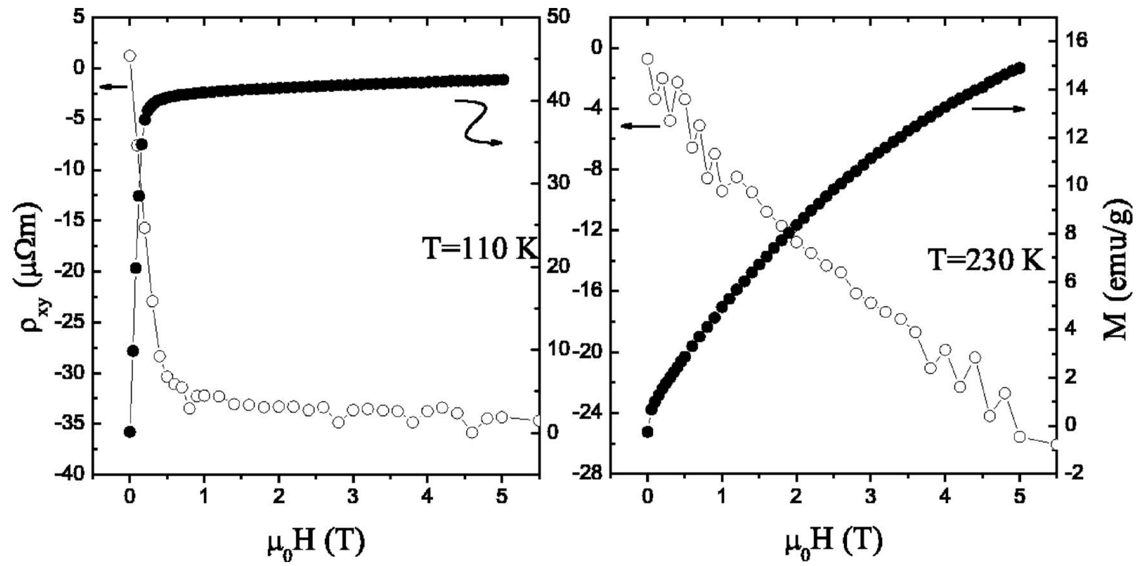

FIG. 3. Magnetic field dependent Hall resistivity (hollow dots) and magnetization (solid dots) of $CeFe_{1.95}Al_{0.05}$ at 110 K (FM) and 230 K (PM). Solid lines are guides for the eye.

metamagnetic transition (AFM to FM) for $CeFe_{1.95}Al_{0.05}$ compound.

Figure 3 shows the applied field dependence of Hall resistivty ρ_{xy} and magnetizations in FM and PM states. Different from the behaviors in the vicinity of AFM-FM phase transition, the action of magnetizations changed with the applied field is similar with that of Hall resistivity in FM and PM states. It indicates that the Eqs. (1) and (2) are valid in FM and PM states for $CeFe_{1.95}Al_{0.05}$. Obviously, interesting rules of AHE for $CeFe_{1.95}Al_{0.05}$ compound lurk in the vicinity of metamagnetic transitions which are not observed before.

IV. SUMMARY

With the temperature increasing, $CeFe_{1.95}Al_{0.05}$ compound undergoes AFM, FM, and PM states. Metamagnetic transitions occur from AFM to FM induced by applied field. AHE in three magnetic states are studied in details. The semiempirical relation $\rho_{xy}=R_0B+4\pi R_sM$ describes the AHE behaviors well in FM and PM states, but the relation describes the AHE behaviors poorly in the vicinity of metamagnetic transition from AFM to FM state in $CeFe_{1.95}Al_{0.05}$ compound. So advanced effort should be paid to clarify the unique characteristic of AHE in $CeFe_{1.95}Al_{0.05}$ compound.

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