c-AXIS MAGNETORESISTANCE OF GRAPHITE

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INTRODUCTION

Highly oriented pyrolytic graphite(HOPG) and kish graphite(KG) exhibit the large positive magnetoresistance in strongly contrast with the pyrocarbon samples which show the weak negative magnetoresistance[1].

Figures 1 and 2 represent our experimental results of $\Delta\rho_c/\rho_c$ for KG and HOPG samples at H=6.8 kG over 4.2 K $\sim$ 300 K. In an ideal graphite sample with a parallel layer stacking $\Delta\rho_c/\rho_c$ should be zero since $\mathbf{v}_c \times \mathbf{H} = 0$, where $\mathbf{v}_c$ denotes the electron velocity along the c-axis. In the next section we propose a qualitative explanation for the two main results: (i) Why does $\Delta\rho_c/\rho_c$ become finite? and (ii) the big difference in $\Delta\rho_c/\rho_c$ for KG and HOPG.

MECHANISM OF THE c-AXIS MAGNETORESISTANCE

Observed magnetoresistance takes the following values for H=6.8 kG:

$$\frac{\Delta\rho_c}{\rho_c} = \begin{cases} 400 & \text{for KG} \\ 8 & \text{for HOPG} \end{cases} \quad \text{at 4.2 K} \tag{1}$$

and

$$\frac{\Delta\rho_c}{\rho_c} = \begin{cases} 0.274 & \text{for KG} \\ 0.114 & \text{for HOPG} \end{cases} \quad \text{at 300 K} \tag{2}$$

These results imply that the c-axis magnetoresistance stems from a slight mixing of the a-axis conduction caused by a small deviation from the parallel layer alignment.

Consider a crystallite with a small angle θ between $\mathbf{H}$ (parallel to z-axis) and its c-axis. Simplified series resistance model leads to the following expression for the conductivity σ_z as

$$\sigma_z = \left\langle \left(\frac{\alpha}{\sigma_c \cos^2\theta} + \frac{\beta}{\sigma_a \sin^2\theta} \right)^{-1} \right\rangle_\theta \tag{3}$$

where $\langle \ldots \rangle_\theta$ indicates an average over θ, and α and β are the parameters with order of unity (z-axis should not be confused with the c-axis).

(i) $H = 0$ case:

Figure 3 illustrates the typical ρ_c versus T-curves for HOPG and KG samples without magnetic field[2]. HOPG satisfies the condition

$$\frac{\alpha}{\sigma_c \cos^2\theta} \gg \frac{\beta}{\sigma_a \sin^2\theta} \tag{4}$$

, while the opposite relation is realized in KG

$$\frac{\alpha}{\sigma_c \cos^2\theta} \ll \frac{\beta}{\sigma_a \sin^2\theta}. \tag{5}$$

According to Ono's theory[2,3] the c-axis conduction in HOPG is mainly controlled by a strong electron wave reflection on the stacking fault planes and we obtain eq.(4). On the other hand, the stacking faults play a minor role in KG and the observed metallic temperature dependence of ρ_c comes from the behavior of ρ_a.

(ii) $H \neq 0$ case:

In the presence of a magnetic field σ_a is a strong function of $H_{eff} = H\cos\theta$, while σ_c is assumed to be independent of H.

(a) HOPG

σ_a rapidly decreases with H and eq.(4) becomes

$$\frac{\alpha}{\sigma_c \cos^2\theta} \ll \frac{\beta}{\sigma_a \sin^2\theta}, \tag{6}$$

and a large magnetoresistance is observed as

$$\frac{\Delta\rho_z}{\rho_z} \approx \frac{\beta}{\alpha}\left(\frac{1}{\theta_0^2}\right)\frac{\sigma_c}{\sigma_a(H)} \approx 20\left(\frac{\beta}{\alpha}\right). \tag{7}$$

In deriving the above value we employed the following parameters:

$$\begin{aligned} \sigma_c &= 10 \quad (\Omega cm)^{-1} \quad [2] \\ \sigma_a(H\cos\theta) &\approx \sigma_a(H) = 0.5 \times 10^3 \quad (\Omega cm)^{-1} \quad [4] \\ \theta &\approx \theta_0 = 2^\circ (\text{mosaic spread}) \\ \sigma_a(H) &\ll \sigma_a(0) \end{aligned}$$

If we assume $\alpha/\beta \approx 1/2$, eq.(7) is close to the observed value.

(b) KG

The inequality (5) still holds in KG and thus, we have

$$\frac{\Delta\rho_z}{\rho_z} \approx \sigma_a(0)\left\{\frac{1}{\sigma_a(H)} - \frac{1}{\sigma_a(0)}\right\} \approx \frac{\sigma_a(0)}{\sigma_a(H)}. \qquad (8)$$

By inserting the values obtained in ref.(4) into eq.(8), we have

$$\frac{\Delta\rho_z}{\rho_z} \approx 10^2 \sim 10^3 \text{ for } H = 6.1\text{kG and } T = 4.2 \text{ K}, \qquad (9)$$

which is consistent with the experimental result, where H=6.1 kG is the field intensity employed ref.(4).

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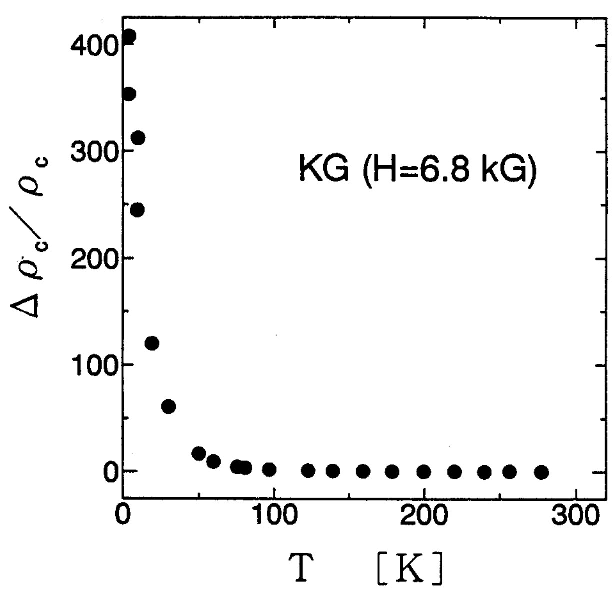

Fig.1 $\Delta\rho_c/\rho_c$ versus T curve for KG sample.

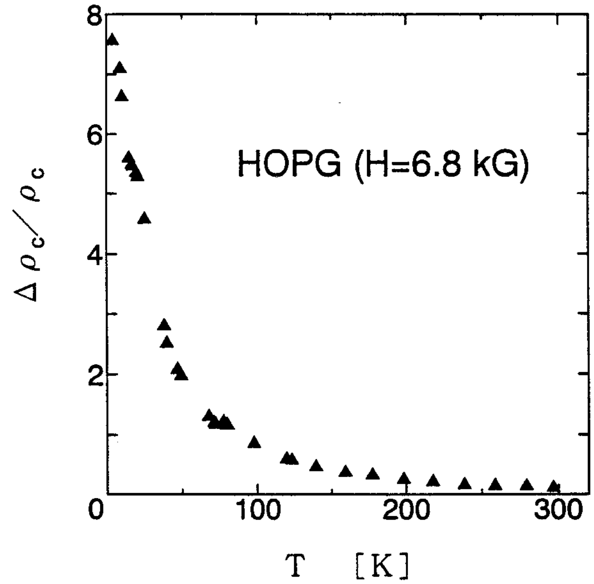

Fig.2 $\Delta\rho_c/\rho_c$ vs T curve for HOPG sample.

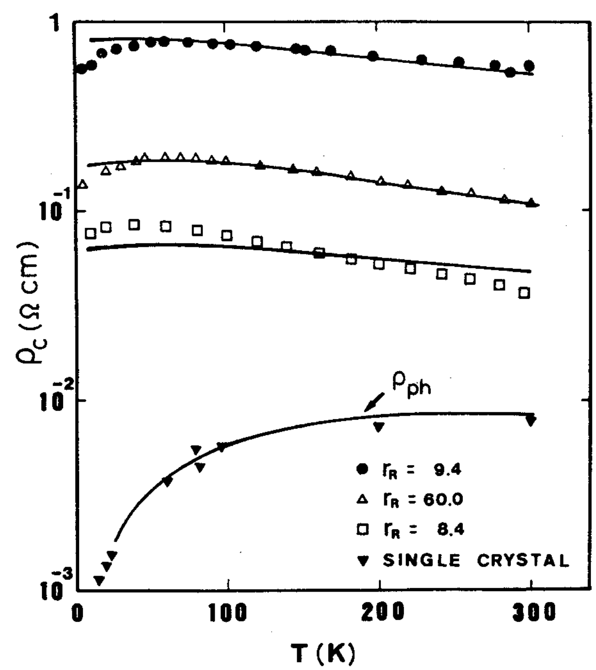

Fig.3 ρ_c curves for HOPG and KG sample(H=0).