ELECTRONIC PROCESSES IN BORON-DOPED TURBOSTRATIC CARBONS

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§1. Introduction

Turbostratic carbon has been known to exhibit distinguished negative magnetoresistance at liquid nitrogen temperature(1) but its electronic structure as well as origin of the negative magnetoresistance has not been fully understood yet. In the present work, the effect of boronation on the galvanomagnetic properties and diamagnetic susceptibility of turbostratic carbon is investigated with a particular emphasis on the variation in magnitude of the negative magnetoresistance with boronation.

§2. Experimentals and results

A Texas coke heat treated at 2100°C for 10 min. was used as a turbostratic carbon specimen in the present work. Boronation was carried out at 1650 - 1800°C by using boric acid powder(2). Galvanomagnetic properties were measured at 77 K by a usual DC amplification technique and diamagnetic susceptibility was determined by Farady method using a Cahn electrobalance as a function of temperature between 77 K and 300 K.

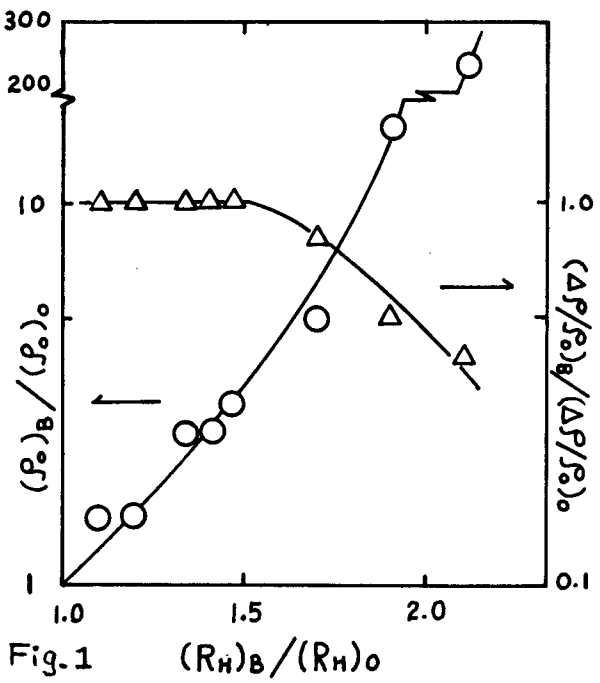

Fig. 1

Fig. 1 summarizes effects of boronation on the galvanomagnetic properties. The abscissa indicates ratio of the Hall coefficient after boronation $[(R_H)_B]$ to that before boronation $[(R_H)_O]$, showing a measure of effective concentration of substitutionally ionized boron. Each ordinate shows a similar ratio of the zero-field electrical resistivity and the magnetoresistance measured at 7 kOe respectively. The result reveals that the Hall coefficient ratio increases up to 2.2 and the resistivity ratio amounts even to 230. On the other hand, the magnitude of negative magnetoresistance is quite insensitive to boronation and, in particular, it does not vary at all when the Hall coefficient ratio is smaller than 1.5, suggesting that the negative magnetoresistance is a phenomenon insensitive to the position of Fermi level.

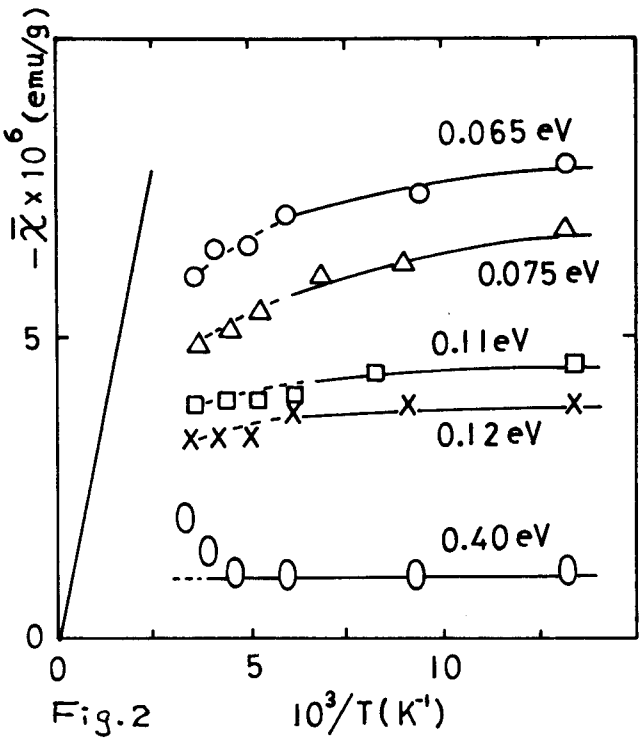

Fig. 2

Fig. 2 shows the average diamagnetic susceptibility as a function of the reciprocal of temperature. The solid lines are theoretical ones developed by Haering and Wallace(3) on the basis of a band model of two-dimensional graphite. The parameter indicates the Fermi level depression at OK (Δ) which is estimated to be from 0.065 eV up to 0.40 eV for the present specimens.

The above-mentioned Fermi level depression is sufficiently large for one to regard electronic structure of the specimens as a one-carrier system at liquid nitrogen temperature.

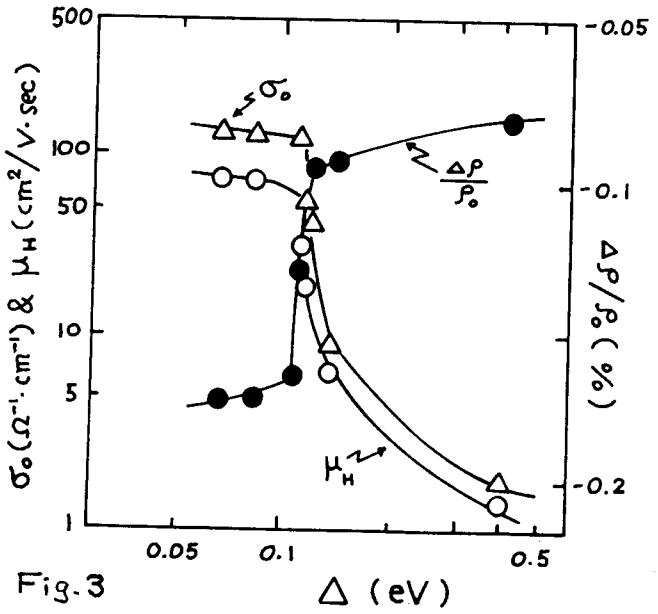

Fig. 3

Fig. 3 reveals variations as a function of Δ in the zero-field electrical conductivity (σ_0), the magnetoresistance ($\Delta\rho/\rho_0$) at 7 kOe and the Hall mobility (μ_H) calculated by conventional formulae for one-carrier system. These quantities are found to change in a drastic way at Δ of about 0.1 eV but they are quite insensitive to the change of Δ above and below 0.1 eV.

§3. Discussion

The mobility (μ_H) is expressed by

$$\mu_H = (e/m^*)\tau$$

where m* denotes the effective mass and τ the relaxation time respectively. According to the uncertainty principle, the energy uncertainty (ΔE) is estimated by

$$\Delta E \sim \hbar/\tau = e\hbar/(m^*\cdot\mu_H).$$

To the first approximation, the effective mass can be related to the Fermi level depression as follows;

$$\Delta \simeq \hbar^2 k_F^2/2m^*$$

where k_F represents the Fermi wave number. Moreover, the Fermi wave length (λ_F) may roughly be correlated to crystallite size (L_a) of the present specimen as follows;

$$\lambda_F = 2\pi/k_F \lesssim \frac{1}{2} L_a \sim 50\,\text{Å}.$$

The estimation in conjunction with the numerical values for μ_H shown in Fig. 3 leads to the following results:

$\Delta E \lesssim \Delta$ for $\Delta \lesssim 0.1$ eV

$\Delta E > \Delta$ for $\Delta > 0.1$ eV

This indicates that the band model cannot be applied to the specimens having Δ larger than 0.1 eV and that Δ is merely a phenomenological parameter having no proper physical significance for these specimens. On the other hand, application of the band model seems fairly reasonable when Δ is smaller than 0.1 eV but the physical significance of Δ is still not so clear as is originally indicated by the model. Therefore, the electronic structure of turbostratic carbon before as well as after doping is not fully explained in terms of the rigid band model of two-dimensional graphite. The negative magnetoresistance peculiar to turbostratic carbon is considered closely related to disturbance of the band structure and should be interpreted by taking disturbed structure into account.

References

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