ELECTRICAL CONDUCTION IN C-DIRECTION OF GRAPHITE

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§1. Introduction

Electronic conduction along the c-axis of graphite has not been sufficiently understood. For instance, experimental results of the absolute value as well as temperature dependence of the c-axis resistivity have been widely scattered from author to author and also from sample to sample, intrinsic nature of the c-axis resistivity having been not established. The present work reveals both absolute value and temperature dependence of the c-axis electrical resistivity of highly crystalline graphite in relation to the structural perfection evaluated from temperature dependence of the basal plane resistivity.

§2. Experimentals and results

Graphite specimens used in the present work were kish graphite (KG) prepared by Toshiba Ceramic Company, Japan and compression annealed pyrolytic graphite (CAPG) manufactured by Union Carbide Corporation, America. The resistivity measurements were made by means of a phase sensitive detection technique, being confirmed to agree well with those of a usual DC amplification method for the specimens immersed directly in liquid nitrogen. The specimen thickness was calculated by making use of the results of mass measurements and the theoretical density (2.26 g/cm^3).

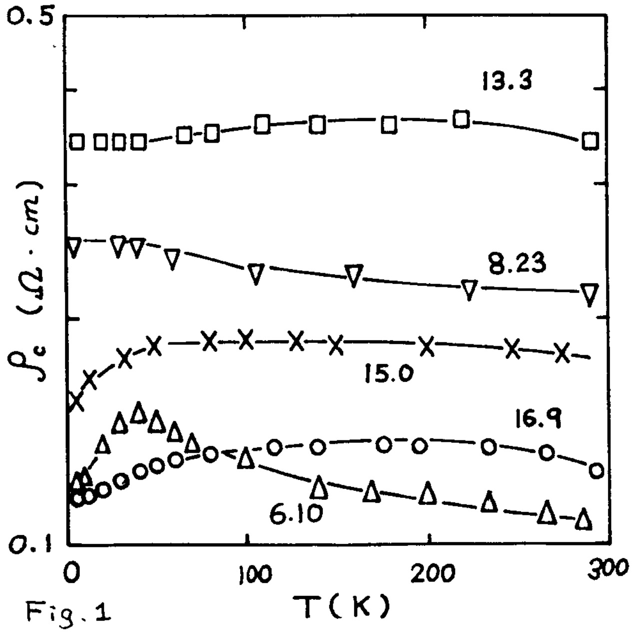

Fig. 1

Fig. 1 illustrates temperature dependence of the c-axis resistivity (ρ_c) of kish graphite specimens. The parameter indicated shows ratio of the basal plane resistivity at 300 K to that at 4.2 K [$\rho_a(300)/\rho_a(4.2) = R_T$]. In the specimens having R_T smaller than 10, ρ_c has a maximum around 50 K and shows a semi-conductor-like temperature dependence above it. With further increase of R_T, the maximum of ρ_c around 50 K disappears and its temperature dependence becomes gradually metallic-like, though a marked metallic-like behaviour similar to those obtained by Primak and Fuchs(1) in natural crystals, and by Tsang and Dresselhaus(2) in other kish graphite is not observed in the present specimens.

A maximum of ρ_c around 50 K is often observed in variour highly oriented pyrolytic graphites and may possibly related to the presence of such defects as microcracks. In the present work, therefore, the thickness of CAPG specimen is varied by slicing the original specimen, and the effect of specimen thickness on ρ_c is examined.

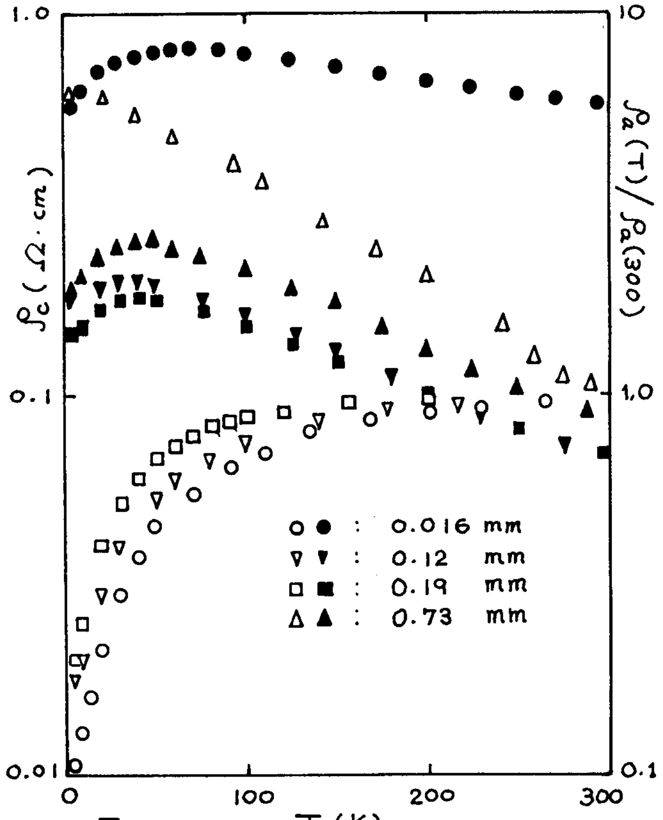

Fig. 2

Fig. 2 summarized the effect of specimen thickness on both ρ_a and ρ_c of CAPG. The thickness of the originally selected specimen is 0.73 mm and is stepwise reduced down to 0.016 mm. It should be noted that originally semiconductor-like temperature dependence of ρ_a becomes metallic-like after being sliced to 0.19 mm and, moreover, the metallic -like behaviour is enhanced with the decrease in thickness. Furthermore, the thinnest specimen has the highest value of ρ_c throughout the temperature range examined and its semiconductor-like temperature dependence becomes less marked than those of the thicker specimens.

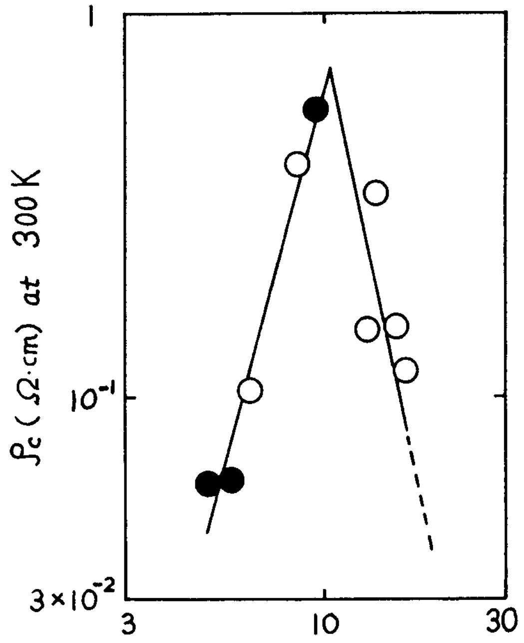

Fig.3

Fig. 3 reveals ρ_c of CAPG (solid circle) and KG (open circle) at 300 K as a function of R_T, indicating that ρ_c has a maximum at R_T of about 10. The result suggests the following items:

(i) If such a highly crystalline graphite specimen having R_T larger than 30 as EP-14 of Soule(3) is obtained, ρ_c could be as low as 10^{-3} $\Omega\cdot$cm at 300 K as is shown by the dotted line in Fig. 3.

(ii) The statement describing that ρ_c / ρ_a of an ideal graphite would be infinity is obviously a wrong one (4), which might be mislead if only such relatively poor specimens as those having R_T smaller than 10 are examined.

§3. Concluding remarks

ρ_c of an ideal graphite could be as low as 10^{-3} $\Omega\cdot$cm at room temperature and its temperature dependence should be metallic-like at least below room temperature. The value obtained by Primak and Fuchs(1), however, seems too low because R_T of their natural crystals does not exceed 20. A similar low value observed by Tsang and Dresselhaus(2) in other kish graphite is not easy to be discussed in detail since they have not examined temperature dependence of ρ_a of the same specimen.

Electronic conduction in c-direction of graphite should be interpreted not in terms of hopping conduction but on the basis of the band theory.

It should be emphasized that the thickness of PG specimen is a critical factor in determining the c-axis as well as basal plane transport phenomena in graphite.

References

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