THE EFFECTS OF FAST NEUTRON IRRADIATION ON THE GALVANOMAGNETIC PROPERTIES OF GRAPHITE

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1. Introduction

Highly oriented pyrolytic graphite was irradiated with fast neutrons at -90°C in the NBS reactor (Gaithersburg, M.D.) to doses 0.18-2.9x10¹⁷nvt (E>1MeV) or 0.29-4.6x10¹⁷nvt (E>2MeV). Galvanomagnetic effects (Hall resistivity, p₅₅, and magnetoresistance, pₓₓ) were measured between 1.2 and 4.2K in the water-cooled solenoids at NRL (Washington, D.C.) in fields up to 9Tesla (90Kg). Description of existing specimens used in the present work and detailed measurements of galvanomagnetic measurements are given elsewhere(1).

From the resistivity ratio (p₂₉₈/p₄.₂K = 14.2) the present specimens are of high quality.

2. Results for Oₓₓ

From these data the conductivity components Oₓₓ and Oᵧᵧ were obtained. Classical Theory (2) predicts that Oₓₓ = B² should saturate in high fields, where B is the field at which the resistivity is doubled. As seen in fig. 1 this condition is satisfied for all specimens at 9Tesla but it is Oᵧᵧ that saturates for all specimens. This behavior has been observed in pristine graphite by a number of workers in this temperature and field range (See ref. 1 for discussion).

3. Results for Oᵧᵧ

Classical theory also predicts that Oᵧᵧ should saturate and this behavior is observed (fig. 2). The limiting value of Oᵧᵧ allows the number of acceptors NA to be calculated from the formula:

\[ \text{Oᵧᵧ} = \text{NA} \times (P-N) \times (e)^{2} \]

where P, N are the densities of holes and electrons respectively.

It is noted that values of (P-N) should also be given from the limiting value of the Hall Parameter (RH²(OᵧᵧB²)² for B²>B⁄₂, according to theory). However, RH does not saturate at high fields because the limiting value of RH is predicted on the basis that Oₓₓ, Oᵧᵧ, Oᵧᵧ, Oᵧᵧ should saturate in high fields. Neither of these conditions is satisfied at high fields, and RH did not saturate. Earlier workers (3) had estimated (P-N) from Hall data at ambient temperature at relatively low fields (eg B=0.5T). Their estimates for the number of acceptors per unit dose level would be several times higher than that given here for the same data. For instance, using the value of RH at 9T, and comparing with data for Oᵧᵧ, we obtain:

No. of Oᵧᵧ per dose = (30³¹⁰)p/10¹⁷nvt (E>1MeV) = Oᵧᵧ data acceptors =

If Hall data were used at lower field the calculated value of NA would be even higher.

4. Shift of Shubnikov de Haas Oscillations in the Quantum Limit

In figs 1 and 2 an oscillatory component of the conductivity components can be seen. The Shubnikov de Haas oscillations can be seen by using the shift of the quantum limit oscillations which can be observed more readily without recourse to complicated curve-fitting procedures. The following conclusions follow from the present work:

(1) The shift of the coincidence fields for electron levels generally follows the predictions of the rigid band model, but the shift of the hole level is much smaller than predicted. Agreement cannot be obtained by employing a scaling factor for the acceptor levels calculated using (1) and (2). Thus a rigid band model does not appear to be appropriate.

(2) A calculation was made to assess the change of coincidence fields with band overlap parameters. The data could not be fitted with a reasonable set of parameter changes.

(3) The shifts of the coincidence levels are generally in agreement with a band model in which the parameter ν2 is negative. This is in agreement with Cooper et al's results(4) but in disagreement with Soule's results on boron-doped graphite(7).

(4) In the low dose region the abrupt shift of the n=1 electron level with dose is difficult to explain unless changes occur in phase-shift parameters. The absolute increase in the amplitude of the n=1,2 (electron) oscillation for sample #2 is difficult to explain. Since the introduction of acceptors should increase the scattering probabilities, an absolute decrease in the amplitude of the Shubnikov de Haas oscillations should be observed.

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Fig. 1. OxyB versus field plot. Hours in the reactor for these specimens are given in figure 3. Doses can be interpolated directly from exposure time and dose of specimen irradiated to 32 hours (7)
(2.9x10^17nvt(E>1MeV); -1.6x10^17nvt(E>1MeV)).

Fig. 2. OxyB versus field plot.

Fig. 3. Oscillatory components of Oxy after midline drift subtracted with a bucking signal. In these data, small magnet calibration errors, which differ from sample to sample, are not corrected for. Values in brackets refer to hours in the reactor.

Fig. 4. Summary plot of the shift in the coincidence fields 1E, 2E, 2H (E and H refer to electron and hole) with (P-N) obtained from OxyB data. Theoretical curves based on the rigid band model are shown. Double curves refer to spin-splitting which can only be resolved experimentally for the pristine sample.

References