EFFECT OF CHEMICAL IMPURITIES ON THE GALVANOMAGNETIC PROPERTIES OF CARBONS

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It has been understood that boronation of carbons results in a change of the Hall coefficient(R_H) equivalent to a decrease in HTT. However, experiments show that R_H remains positive even for the highest doses and the maximum reached is much lower than the maximum attained in direct heattreatment of carbons or in neutron irradiation of graphite. As to chemical donors, it is shown that introduction of sodium or potassium changes R_H in a way inverse to that of boron-doping; R_H reaches a negative minimum and converges to a negative constant.

The magnitudes of maximum and minimum of R_H appearing in carbons doped with chemical impurities have been often discussed in connection with those of maximum attained in heattreatment of samples. However, what is the physical basis for that?

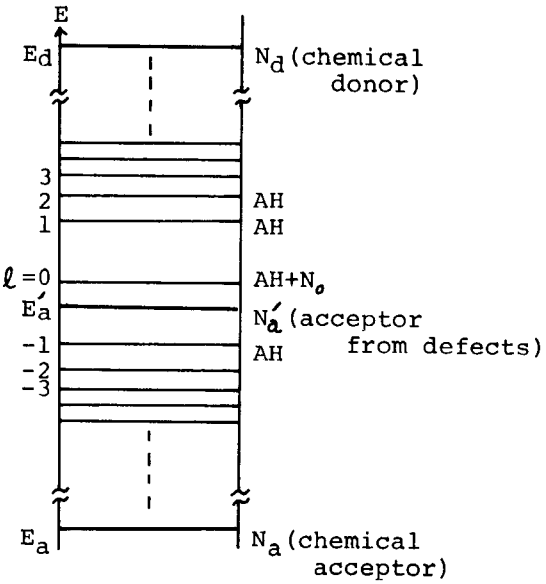
It is understood that the maximum in R_H appearing with heattreatment is due to variation of the carbon structure from turbostratic to graphitic one. However, it is shown by our analysis that the maximum appearing with doping can be explained in terms of our band model[1] by locating impurity levels deep below(for acceptor) or far above(for donor) the band edge.

Fig.1 shows our schematic energy diagram of a graphitic carbon in the presence of a magnetic field. Each Landau level has a state density proportional to a magnetic field(=AH,A:constant). At the band edge, a state density N_o is included as a simple expedient for the band overlap. An acceptor level(E_a') originating from structural defects is considered to be located at about 4meV below the band edge; their density denoted by N_a'. Whereas, we assume that the impurity levels are located deep from the band edge; for example, boron level is evaluated to be about 320meV below the band edge and potassium level to be 340meV above the band edge.

Using this band model, we have calculated the Hall coefficients of carbons doped with chemical impurities. The results are shown in Fig.2. At low temperatures($kT \ll E_a'$), an acceptor-doped carbon has a maximum in R_H ($=2/e(AH+N_o)$), and with increasing acceptor concentration R_H converges to a positive constant determined mainly by the acceptor level. With introducing chemical donors, R_H reaches a negative minimum($=-2/e(AH+N_o)$) and then converges to a negative constant determined by the donor level. At high temperatures($kT \gtrsim E_a'$), a maximum or a minimum is also obtained, but its magnitude decreases with increasing temperature. Therefore, theoretical magnitudes of maximum and minimum of R_H are smaller than those of maximum predicted in HTT dependence of undoped carbons and decrease with increasing HTT. The limiting value of R_H with high doses is independent of temperature(calculation is up to 300K).

Experiments made on the soft carbons by J.Bulawa et al.[2] and by S.Toyoda et al.[3] show that the theory is in semiquantitative agreement in both boron- and potassium-doped carbons heattreated above 2200C(Fig.3). The discrepancy in magnitude may be due to improper evaluation of the band parameters(E_a', N_a',N_o) for lack of precise data of R_H on the soft carbons. In terms of this band model, the effect of chemical impurities on the magnetoresistance of carbons can also be analyzed.

References
1)T.Kimura and K.Yazawa,Carbon 11,139(1973)
2)J.Bulawa,S.Mrozowski and A.S.Vagh,Carbon 10,207(1972)
3)S.Toyoda and S.Mrozowski,Carbon 7,239(1969)



$$E_\ell = \pm\left(\frac{3}{2}\right)^{1/2}\gamma_0 a\left(\frac{eH}{\hbar c}|\ell|\right)^{1/2}$$

$$W = \frac{4}{\pi c_0}\cdot\frac{eH}{\hbar c} = AH$$

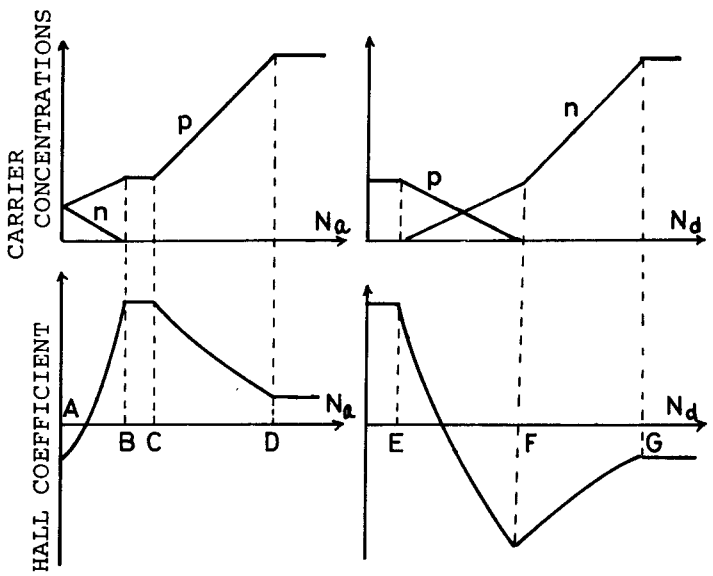
γ_0 =2.8eV, a =2.64A

e =1.6x10^{-19} C, c:light velocity

c_0: twice the interlayer spacing

$\hbar$: Planck constant

Fig.1 Schematic energy diagram of our band model for graphitic carbon



A:p=n=$(N_o+AH)/4$ E:p=$(N_o+AH)/2$,n=0

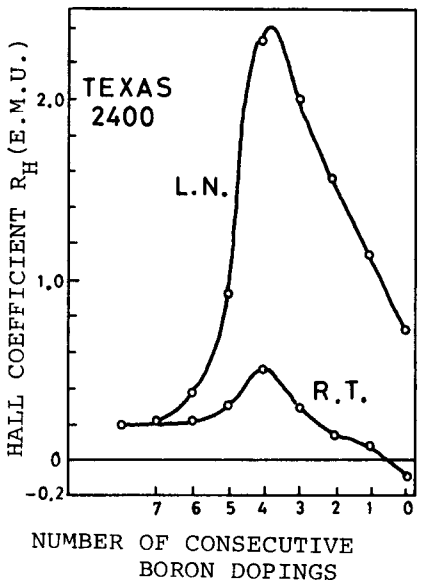
B:p=$(N_o+AH)/2$,n=0 F:n=$(N_o+AH)/2$,p=0

D:p=$N_o/2+W_{ao}$,n=0 G:n=$N_o/2+W_{do}$,p=0

W_{ao} :total state density between E=0 and E_a

W_{do} :total state density between E=0 and E_d

Fig.2 Schematic chemical acceptor (left) and donor(right)concentration dependences of carrier concentrations and Hall coefficients at low temperature.



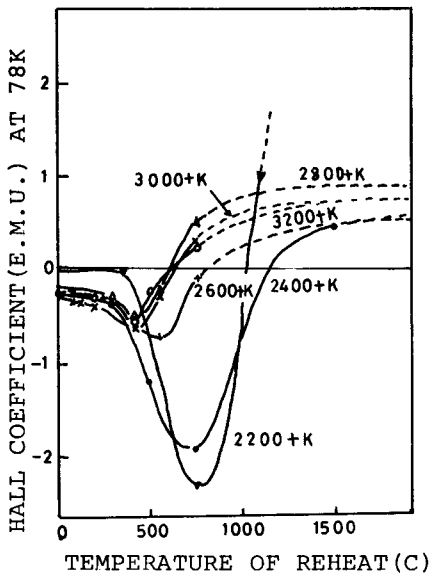


Fig.3(left) Changes in the Hall coefficient of a soft carbon heattreated to 2400C as boron is introduced in a number of consecutive operations.
After J.Bulawa et al.[2]

(right) Changes in the Hall coefficient for soft carbons as the degree of potassium doping decreases with increasing temperature of reheat. The numbers in the figure indicate HTT.
After S.Toyoda et al.[3]