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Sodium Diffusion in Hard Carbon Studied by Small-Angle Neutron Scattering and Muon Spin Relaxation

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The recent surge of Li-ion batteries has triggered an increased interest to investigate Na-ion battery materials [1,2], because Na is more abundant than Li, resulting in lower material costs. Although many Na transition metal oxides are available as a cathode material for the Na-ion battery, there is, at present, no suitable anode material [1]. The most common anode materials for the Li-ion battery are not compatible for the Na-ion battery, because graphite is electrochemically inactive in an intercalation and deintercalation reaction of Na^+ ions.

Since non-graphitizable carbon (hard carbon) is electrochemically active as a Na insertion host, hard carbon is heavily investigated as an anode material for the Na-ion battery. However, the relationship between the structure of hard carbon and dynamics of Na insertion is still not fully clarified despite huge efforts in the past decade [2]. We have therefore attempted to study the microscopic structural nature of sodium intercalated hard carbon (NaC_x) with small-angle neutron scattering (SANS) and the dynamics of Na diffusion in NaC_x with muon spin rotation and relaxation (μ^+ SR).

The transverse field μ^+ SR measurements on NaC_x clearly showed a motional narrowing behavior above around 150 K, which indicates that Na^+ starts to diffuse above 150 K. The zero field and longitudinal field measurements clarified the presence of the two muon sites ($\mu 1$ and $\mu 2$). Since the Na concentration around the $\mu 1$ site is higher than that around the $\mu 2$ site, the $\mu 1$ site locates in the graphene layer and the $\mu 2$ site in the amorphous region [3]. At the presentation, we will also discuss the results of SANS on NaC_x .

[1] N. Yabuuchi *et al.*, Chem. Rev. **114**, 11636-11682 (2014).

[2] K. Kubota *et al.*, Chem. Mater. **32**, 2961-2977 (2020).

[3] K. Ohishi *et al.*, ACS Phys. Chem. Au **2**, 98-107 (2022).

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