

## Improvement in the Characteristics of Electric Double Layer Capacitor Using a Mixture of Arc Black and Carbon Nanoballoon

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Carbon nanomaterials with different structures were mixed for an electric double layer capacitor (EDLC) electrode. We used two kinds of carbon nanomaterial: arc black (AcB) and a carbon nanoballoon (CNB). Arc black was synthesized by arc discharge. CNB was produced by heating the prepared AcB at 2400 °C. AcB mostly consists of an amorphous component and has a large specific surface area. On the other hand, CNB has a graphitic surface and a high conductivity. To utilize their characteristics, AcB and CNB were used as the main materials of the EDLC electrode in weight ratios of 1 : 1, 2 : 1, and 1 : 2. The obtained EDLC electrode was filled with 1 M H<sub>2</sub>SO<sub>4</sub> as the electrolyte. As a result, by mixing AcB and CNB, both the power and energy densities became higher than those of AcB or CNB alone. The EDLC mixed in 1 : 1 weight ratio of AcB and CNB showed the highest performance, with a higher electric power density than activated carbon (AC). © 2013 The Japan Society of Applied Physics

### 1. Introduction

The reduction of CO<sub>2</sub> emissions from cars has recently become an important issue, and the development of rechargeable batteries and fuel cells for powering hybrid electric vehicles (HEVs) or electric vehicles (EVs) is now in progress.<sup>1,2)</sup> The Li-ion battery has a high energy density and therefore is widely used. However, it is beset with many problems, such as smoke emission which is a source of concern. In this paper, we describe the characteristics of electric double-layer capacitors (EDLCs).<sup>3,4)</sup> EDLCs are safer than the Li-ion battery. EDLCs perform charge and discharge by the electric double layer that arises from the interface of an electrode and the electrolysis solution.<sup>5)</sup> An oxidation-reduction reaction does not arise from a charge and discharge process. Therefore, EDLCs are safe and robust. However, compared with that of the existing Li-ion battery, the energy density of EDLCs is 1/10 or less.<sup>6)</sup> Because the discharge amount of EDLCs depends on the electron transport between electrodes, the conductivity of an electrode is strongly related to the charge and discharge capability of EDLCs. Furthermore, the amount of electric charge stored is proportional to the number of adsorbed ions. Simply, the specific surface area of electrode materials is large, so the specific capacitance of the EDLC is also large.<sup>7)</sup> We use two carbon nanomaterials for the electrode: arc black (AcB) and a carbon nanoballoon (CNB). AcB was synthesized by arc discharge. CNB was produced by heating the prepared AcB at 2400 °C.<sup>8–12)</sup> In our previous experiment, AcB showed a higher specific capacitance than CNB.<sup>13)</sup> However, when the charge-discharge speed was high, the specific capacitance of CNB became higher than that of AcB. For the application of EDLCs in HEVs and EVs, in this research, we aim at improving the characteristics of EDLC by mixing AcB and CNB.

### 2. Experimental Procedure

#### 2.1 Synthesis of carbon nanomaterials

AcB was prepared using a twin-torch arc discharge

apparatus.<sup>14–16)</sup> Two electrodes in the shape of an arc torch were placed at an acute angle in the chamber. The material of the electrode is graphite. G347S (Tokai Carbon,  $\phi 6 \times 150 \text{ mm}^3$ ) was used for the evaporation electrode, and G348 (Tokai Carbon,  $\phi 10 \times 150 \text{ mm}^3$ ) was used for the counter electrode. First, the evaporation electrode was placed in front of the counter electrode, about 1 mm away from it. The chamber was evacuated and filled with N<sub>2</sub> gas. By flowing N<sub>2</sub> gas, carbon deposition on the counter electrode by evaporation was inhibited. When the chamber internal pressure reached 80 kPa, electric discharge was started and AcB was synthesized. The voltage was AC 27 V, and the discharge current was 200 A. At this time, by continuing to release the evaporation electrode into the discharge region, arc discharge can be maintained for 5 min and AcB can be synthesized automatically and continuously. After arc discharge, the temperature of the chamber dropped to 100 °C. AcB deposited on the inner wall of a chamber was collected. AcB contains mainly cocoon-shaped carbon particles with many amorphous ingredients.

CNB was obtained by heating AcB in a Tammann oven in Ar gas at 2400 °C for 2 h. CNB has a high electrical conductivity and consists of hollow particles. The synthesized AcB and CNB were observed using scanning electron microscopy (SEM; Hitachi S-4500II) and transmission electron microscopy (TEM; JEOL JEM-2100F). Moreover, thermogravimetric/differential thermal analysis (TGA/DTA; Shimadzu DTG-60/60H) and laser Raman spectroscopy (JASCO NRS-1000, excitation wavelength: 532 nm) were used to evaluate the crystallization of the carbon nanomaterials.<sup>17–20)</sup>

#### 2.2 Preparation of EDLC electrodes

In this research, we used a two-electrode cell with two coin-type electrodes for the electrochemical measurement of the EDLC.<sup>21)</sup> First, 160 mg of AcB, 160 mg of CNB, and 40 mg of the conductive improvement agent (EC-600JD) were kneaded for 10 min by an automatic mortar (Nitto Kagaku ANM-1000), for use as the main material. Then, 45  $\mu\text{l}$  of