INVESTIGATION OF RESISTANCE DISTRIBUTION IN ELECTROCHEMICAL CAPACITORS

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The maximum current density and power density of electrochemical (EC) capacitors are limited by the internal resistance, which are contributed by the electrical and ionic resistances. The ionic resistance depends on the ionic conductivity of the electrolyte, the porosity and thickness of the electrode and separator paper. The electrical resistance is mainly contributed to the electrode material including the bulk resistance and contact resistance between porous particles/fibers, the contact between the current collector and the electrode, the contact between the current collector to the neighboring current collector for a multi-cell capacitor, and resistance of current collector itself. Both electrical and ionic resistance may depend on the mechanical pressure applied to the cell.

I. A Capacitor with Bipolar Structure

The distribution of internal resistance in a 5-cell EC capacitor comprised electrode material of 80 wt.% $RuO_2.xH_2O$ and 20 wt.% activated carbon and electrolyte 38 wt.% H_2SO_4 acid solution was analyzed. The size of the current collector was 5.0 cm in diameter. The size of the electrode was 3.9 cm in diameter. The thickness of each electrode, current collector, and separator paper were about 50, 50, and 25 μm, respectively. Fig. 1 shows the resistance as a function of the applied pressure. It can be seen that at applied pressure less than 4 kg/cm^2, the resistance decreased with increasing applied pressure; however, at applied pressure greater than 4 kg/cm^2, the resistance was insensitive to the applied pressure, and the resistance decreased with increasing applied pressure at a much slower rate. An internal resistance of about 0.24 Ω (0.573 Ω-cm^2/cell) was obtained at applied pressure of 4 kg/cm^2. The electrical resistances of the electrode material and current collector were measured using four-probe method. At 4 kg/cm^2, the resistivity of the electrode was about 0.75 Ω-cm, which corresponds to a resistance of 0.0038 Ω-cm^2 for a 50 μm-thick electrode. Therefore, in the 5-cell capacitor, the electrical resistance contributed by electrodes should be about 0.0031 Ω. the resistivity of the current collector was about 1.0 Ω-cm. The resistance contributed to current collectors is about 0.004 Ω. The resistance and resistivity of separator/electrolyte are about 0.019 Ω-cm^2 (25 μm-thick) and 7.6 Ω-cm at frequency of 20 kHz, respectively. The resistance contributed from separator/electrolyte is less than 0.008 Ω. The current collector related contact resistances were measured at different applied pressures. At 4 kg/cm^2, the contact resistance for current collector and metal end plate, current collector and neighboring current collector, and current collector and electrode material were 0.05 Ω-cm^2, 0.04 Ω-cm^2, and 0.125 Ω-cm^2, respectively. Summarizing above observation, it was found that the contact resistance between the current collector and the electrode is a predominant resistance source. We have demonstrated that a low contact resistance could be achieved with a composite current collector, which is made with conducting plastic sheet coated with metallic films on both surfaces, and with low mechanical pressures. These experiments also opens the possibility that low resistance and high performance EC capacitors can be made with light packaging structure such as prismatic and button cell structure.

II. A Capacitor with Spiral-Wound Structure

The activated carbon powder was used as the electrode material and was coated on both surfaces of an aluminum foil (17 μm-thick) used as the current collector. The thickness of the carbon electrode was about 76 μm. The electrode size was 2.4 x 40 cm^2. Porous paper with a thickness of 50 μm was used as the separator. The electrolyte used in this study was tetraethylammonium tetrafluoroborate (Et_4NBF_4) in propylene carbonate. The capacitor was made with a spiral-wound structure with diameter of wound body 1.69 cm. In the direction along the current collector, the resistance of the cell was mainly determined by the current collector and was 1.7×10^{-3} Ω/cm. In the direction perpendicular to the current collector, the resistance as a function of applied pressure was measured from a cell with size of 1.29 cm^2, and was shown in Fig. 2. It was found that a minimum resistance of 13.66 Ω-cm^2 was obtained at applied pressure of about 1 kg/cm^2. The resistance distribution at such applied pressure was 0.86 Ω-cm^2, 1.91 Ω-cm^2, and 8.11 Ω-cm^2 contributing to the electrode material, contact between the current collector and electrode, and separator/electrolyte, respectively. A transmission line model was used to describe the cell resistance dependence of the cell configuration such as the electrode size and thickness, which determined the total capacitance of the cell, the thickness of the current collector, and the location of the leads. The potential distribution along the current collector direction during charge and discharge process could also be determined using transmission line model.

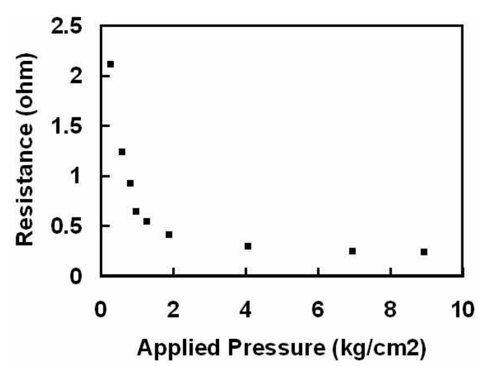

Fig. 1 The resistance as a function of applied pressure from a 5-cell capacitor.

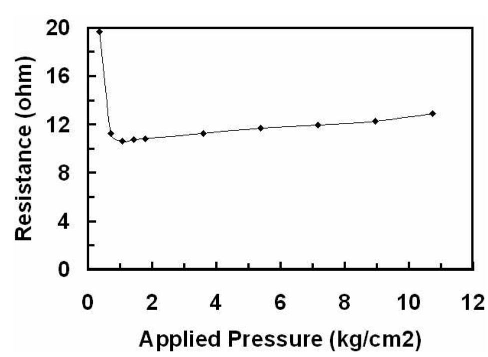

Fig. 2 The resistance as a function of applied pressure from an 1.29 cm^2 cell.