LIGHTWEIGHT, STABLE, AND RECHARGEABLE BATTERY AND CAPACITOR WITH ACTIVATED CARBON FIBER ELECTRODE

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Résumé - Nous avons réalisé une batterie et une capacité électrique à double couche en utilisant des fibres de carbone activé comme matériau d'électrode.

Abstract - We made a rechargeable battery and an electric double layer capacitor by use of an activated carbon fiber as the electrode material.

Recently, polyacetylene /1,2,3/ and poly-(p-phenylene) /4/ have been reported to be useful as the electrode material in rechargeable batteries. In the charge and discharge processes of these batteries, electrochemical "doping" and "undoping" of the material are involved. The large energy density of this kind of battery is due to the large specific surface area of polymer film. In a search for other electrode materials, we noticed that a special kind of activated carbon fiber (ACF) /5/ made from cellulose or phenolic resin has the following attractive properties as the electrode material: (1) it has a much larger specific surface area (1500 - 2500 m^2/g) than polyacetylene; (2) it has a high electrical conductivity of about 10 - 70 S cm^{-1}; (3) various types of ACF, such as felt, fiber, cloth, and paper sheet can be obtained commercially with low cost /6/; (4) it is quite a stable material in the air; (5) it has a small bulk density of 0.05 g/cm^3 for a felt.
We have made a rechargeable battery by use of a p-doped ACF as a cathode and lithium metal as an anode. We have also made an organic electrolyte capacitor by use of a p-doped ACF as a cathode and a n-doped ACF as an anode /7/.

I - RECHARGEABLE BATTERY

A felt of ACF (33 mg, 2.5 cm^2), type KF-1600 available from Toyobo Co. Ltd., and a strip of lithium were separated by a glass fiber filter of 0.25 mm thickness. They were then placed in a glass vessel containing a 1 mol dm^{-3} solution of $LiClO_4$ in a mixed solvent of propylene carbonate (PC) and 1,2-dimethoxyethane (DME) in an argon atmosphere. Platinum wires attached to the ACF and lithium were connected to the positive and negative terminals of a D.C. power source, respectively. After passing 8.16 C, the battery, Li | $LiClO_4$ in PC-DME | (ACF^{a+})-$(ClO_4^-)_a$, was made. The molar ratio of dopant to carbon atom was estimated to be a = 0.036 /8/. The open circuit voltage (V_{oc}) of 3.9 V and short-circuit current (I_{sc}) of 203 mA were obtained, which correspond to a maximum power density of 20 kW/kg, based on the weight of the $(ACF^{a+})(ClO_4^-)_a$ and that of lithium consumed. Figure 1 shows the charge-discharge characteristics of the ACF battery under a

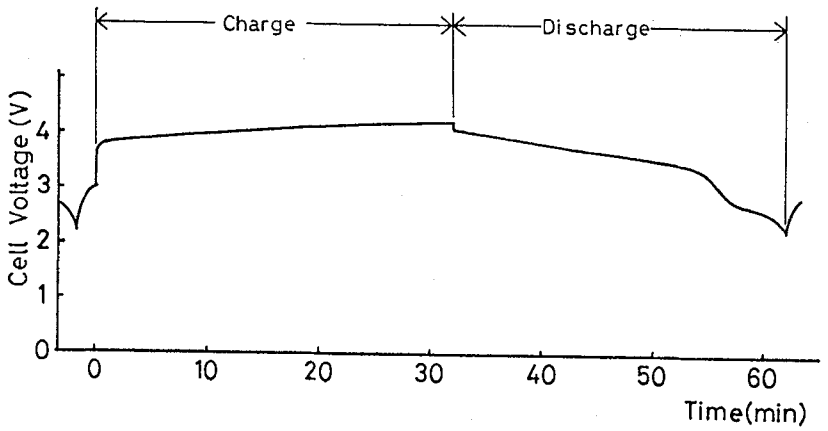

Fig. 1 - Charge-discharge characteristics of the battery, Li | $LiClO_4$ in PC-DME | $(ACF^{a+})(ClO_4^-)_a$, under a constant current of 0.8 mA/cm^2.

constant current of 0.8 mA/cm^2. The plateau of the voltage in this figure indicates the battery operation in this system. In view of the high electrical conductivity of ACF, graphite structure is assumed to be contained in ACF. Thus, the relatively flat voltage in Fig. 1 arises from the intercalation of perchlorate ion into ACF lattice. The charge efficiency in the cycle was calculated to be 93.7 %. The energy density was 110 WH/kg, based on the weight of $(ACF^{a+})(ClO_4^-)_a$ and that of lithium consumed. A partial charge-discharge (4.2 - 3.5 V, 66 % of the stored charge) cycle was reproducible for more than 10 times.

II - ORGANIC ELECTROLYTE CAPACITOR

Two ACF felt electrodes (3.3 cm^2) /9/ separated with a glass fiber filter were immersed in a PC solution of Bu_4NClO_4 (1.06 mol dm^{-3}). After passing 7.8 C, the cell configuration was $(ACF^{a-})(Bu_4N^+)_a$ | Bu_4NClO_4 in PC | $(ACF^{a+})(ClO_4^-)_a$. The molar ratio of the dopant to carbon atom was estimated to be a = 0.024 at this stage /8/. The V_{oc} and I_{sc} were 3.6 V and 275 mA, respectively. The plot of the quantity of electricity passed against the cell voltage is shown in Fig. 2. This figure gives a linear relation below 2.5 V both in the charge and discharge processes. Thus, the above configuration gave a capacitor. Since the size of Bu_4N^+ is too big to intercalate into the lattice of ACF, the cation is assumed to form an electric double layer with ACF, giving rise to a real capacitor at the anode. The specific capacity in the above configuration was estimated to be 27 F/(1 g of ACF). The large specific capacity arises from the electric double layer /10/ formed over quite large surface area of ACF.
Figure 3 shows the charge-discharge characteristics of the capacitor under a constant current of 0.6 mA/cm^2. Even after more than 200 cycles, charge-discharge characteristics were still reproducible. The charge efficiency of each cycle was not less than 95 %. Although the above configuration is a capacitor in principle, it may be used as a rechargeable battery owing to its extremely large specific capacity.

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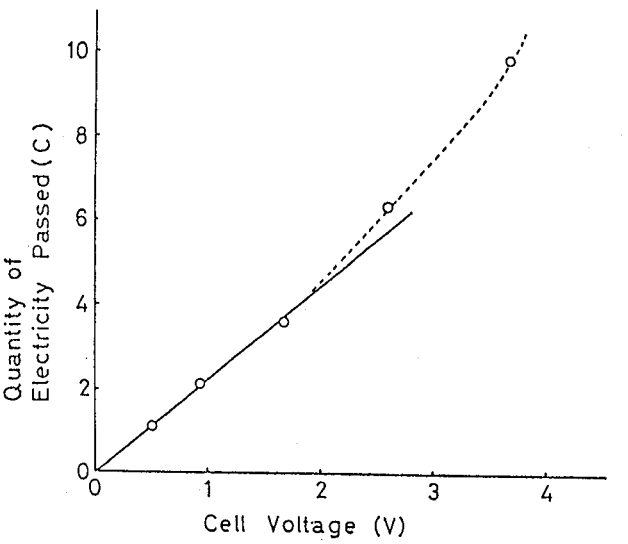

Fig. 2 - Relation between the quantity of electricity passed and the cell voltage.

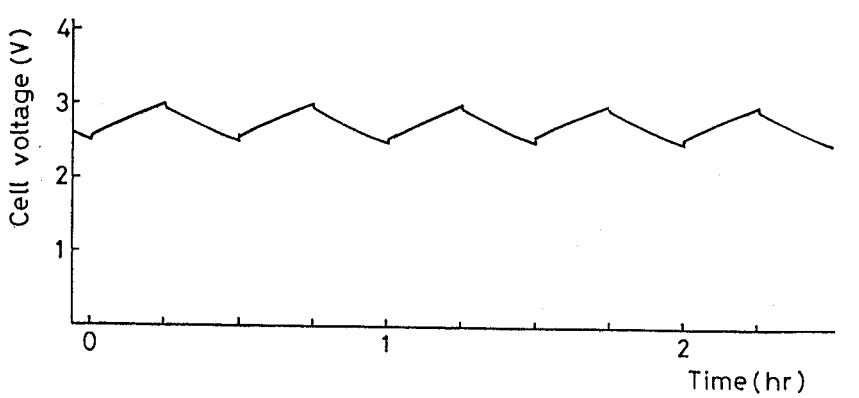

Fig. 3 - Charge-discharge characteristics of the capacitor, (ACF^{a-})-$(Bu_4N^{+})_a$ | Bu_4NClO_4 in PC | $(ACF^{a+})(ClO_4^{-})_a$, under a constant current of 0.6 mA/cm^2.

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[8] Estimated from the elemental analysis of ACF: C, 88.03; N, 0.97; O, 10.15 %.
[9] Forty six mg of ACF was used as both electrodes.
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