Short Communication

High-temperature superconductor, $YBa_2Cu_3O_{7-x}$ as all-solid-state lithium cell

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Abstract

The utility of the high-temperature superconductor, $YBa_2Cu_3O_{7-x}$, as the cathode material for an all-solid-state lithium cell has been examined. The capacity of $YBa_2Cu_3O_{7-x}$ is 223 mA h g^{-1} and the discharge efficiency is >92%. Measurements of a.c. impedance show that the charge-transfer resistance at the interface of the electrolyte/cathode is very low and increases with the depth-of-discharge of the battery. Studies using X-ray photoelectron spectroscopy (XPS) reveal that the cathode becomes doped with Li^+ ions as the cell discharges.

Introduction

Several electrochemical studies of high-temperature superconductors have been conducted in recent years [1–2]. Whitney *et al.* [3] have described the discharge process of cell that used $YBa_2Cu_3O_{7-x}$ as a cathode active material in a liquid lithium system. In this paper, we report the performance of a lithium cell employing $YBa_2Cu_3O_{7-x}$ as the cathode active material, and polymer poly(ethylene oxide) (PEO) + $LiClO_4$ as the solid-state electrolyte.

Experimental

$YBa_2Cu_3O_{7-x}$ was prepared by the method described in ref. 4. The cathode consisted of 30 mg $YBa_2Cu_3O_{7-x}$, 10 mg carbon and 10 mg poly(ethylene oxide)(PEO). The latter was pressed into a disc to fit inside a button cell (commercially designated as a R2032 type, as shown in Fig. 1. The anode was made of lithium foil. The PEO electrolyte film consisted of cross-linked PEO dissolved in a propylene carbonate (PC) solution of $LiClO_4$. The film was dried under vacuum at 50 °C for 20 h. The thickness of the film was ~150 μm. The discharge unit was a model HJ--201B, made in Japan. Impedance measurements were obtained with a 5208 lock-in analyser in combination with a 273 potentiostat (PAR) controlled by a IBM-PC XT computer. A three-electrode system was used. The working electrode was $YBa_2Cu_3O_{7-x}$ and the counter and reference electrodes were constructed from lithium. After a complete discharge,

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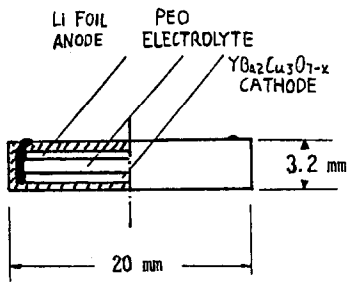

Fig. 1. Configuration of button cell.

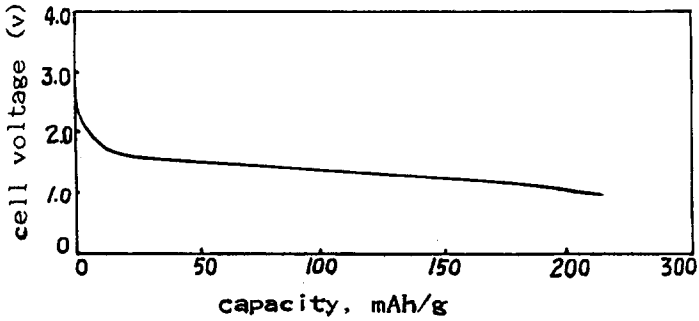

Fig. 2. Discharge curve for Li/PEO/$YBa_2Cu_3O_{7-x}$ cell as function of capacity.

the cathode active material was characterized by X-ray photoelectron spectroscopy (XPS) using a VG ESCALOG MK-11 instrument made in the UK.

Results and discussion

The cell was discharged at a current of 0.2 mA. The discharge curve is shown in Fig. 2. It can be seen that the voltage decreases slowly after a discharge of 20 mA h g^{-1}. The working voltage is between 1.6 and 1.3 V. The delivered capacity is ~223 mA h per g of $YBa_2Cu_3O_{7-x}$ to a cutoff voltage of 1.0 V. The discharge efficiency was >92%. These results indicate that $YBa_2Cu_3O_{7-x}$ is promising cathode active material for solid-state cells.

Part of the XPS spectrum for the cathode material after a complete discharge is displayed in Fig. 3. This shows that lithium ions are present on the surface of the cathode. It appears that copper ions are reduced and lithium ions are simultaneously transferred into cathode during discharging of the cell.

The a.c. impedence data are given in Fig. 4 for the assembled cell and after a complete discharge. On the basis of the equivalent circuit (also shown in Fig. 4), the high-frequency intercept with the real axis yields the bulk resistance of the PEO electrolyte, while the diameter of the semicircle represents the cathodic interfacial charge-transfer resistance. It can be seen that the charge-transfer resistance at the cathodic interface is very low. This benefits the transport of charge. In the arc of low frequencies, there is a straight line. This suggests that the discharge process is controlled by ion diffusion. After a complete discharge, the charge-transfer resistance

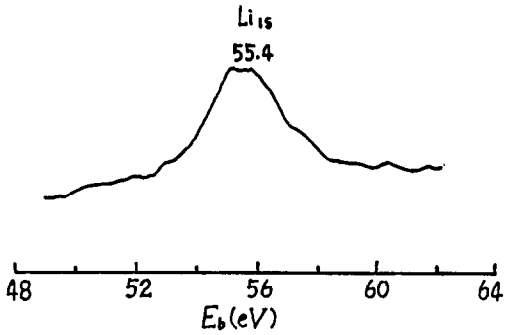

Fig. 3. XPS spectrum of Li on the surface of $YBa_2Cu_3O_{7-x}$ cathode.

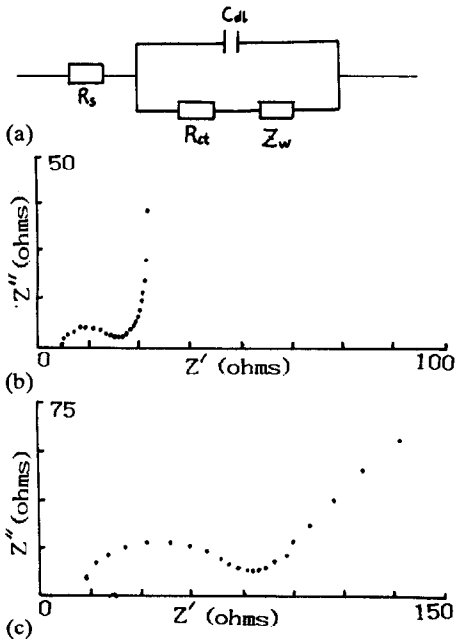

Fig. 4. (a) Equivalent circuit, (b) impedance spectra of $Li/PEO/YBa_2Cu_3O_{7-x}$ for the assembled cell, and (c) after a complete discharge, at 20 °C.

increases (from ~13 to ~60 Ω). Thus, interfacial charge transfer becomes more difficult.

References

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