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Synthesis of $CuO@Fe_2O_3$ Nanotubes Featuring an Electron-Hole Separation Layer for Improved Semiconductor-Sensitized Thermal Cell Efficiency

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[Introduction]

Vast amounts of low-grade heat are wasted in our environment due to the lack of efficient, low-cost energy conversion solutions. To address this issue, this research focuses on Semiconductor-Sensitized Thermal Cells (STCs), a novel technology that directly converts low-grade heat into electricity. And we introduced a *pn* junction of *p*-type CuO and *n*-type Fe_2O_3 to promote electron–hole separation. Additionally, CuO was structured into hollow nanotubes to increase the electrode–electrolyte interface and heat-excited current density. The unique characteristics of STCs—such as their rechargeability—open new possibilities for effectively utilizing abundant low-temperature thermal energy.

[Experimental]

In this study, $CuO@Fe_2O_3$ nanotubes designed as a hole-charge-separation layer were synthesized via a hydrothermal method. First, primary CuO nanotubes were grown on a Cu substrate, then Fe_2O_3 was deposited onto that structure. The Cu substrate bearing the $CuO@Fe_2O_3$ nanotubes served as a half-cell. Electrochemical measurements, such as cyclic voltammetry and carrier density analysis, were conducted in a $CuCl/CuCl_2$ electrolyte dissolved in PEG600. To further elucidate the electronic properties, the Fermi levels obtained with a Kelvin probe measurement (FAC-2, Riken Keiki) were integrated with Mott–Schottky analysis to reveal the band structure. Finally, after assembling a full cell using an FTO counter electrode, its thermal energy conversion performance was evaluated.

[Results and Discussion]

Transmission electron microscopy (TEM) observations, as shown in Fig. 1, confirmed the successful synthesis of Fe_2O_3 nanoparticles on CuO nanotubes. Compared to electrodes with 5, 15, or 20 minutes of CuO nanotubes growth, the 10-minute sample achieved the best electrochemical performance, characterized by superior discharge and remarkable recovery properties. At a temperature of 40 °C and with an active surface area of 0.126 cm², the electrode produced an open-circuit voltage of 0.58 V and a short-circuit current of 4.24 µA. Under a constant discharge current of 20 nA, followed by four hours of open-circuit voltage monitoring, stable recovery performance was maintained over 120 cycles. Furthermore, band structure analysis revealed that the energy band positions of the constituent materials are closely aligned. This alignment facilitates an efficient transport mechanism for thermally excited charge carriers, which is crucial for optimizing the performance of thermal cells.

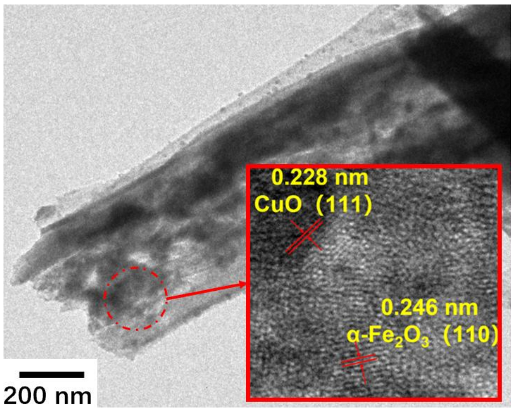

Fig. 1 TEM images of $CuO@Fe_2O_3$ nanotubes.

Keywords: *STCs, Nanotubes, Electron-Hole Separation Layer*

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