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Review

Progresses in dye-sensitized solar cells

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ABSTRACT

Recent progresses on the modification of photoanodes and electrolytes related to the concept of oriented nano-channels, and the fabrication of flexible cells aiming at practical application in dye-sensitized solar cells are reported. Some mechanisms of material preparation are analyzed, and perspectives are proposed.

Contents

1. Introduction

Dye-sensitized solar cells (DSCs) have been widely investigated due to their low production cost and potentially high conversion efficiency ever since its invention almost two decades ago [1]. In such a cell, sunlight is harvested by a sensitizer (dye) that is attached to the surface of a wide band gap semiconductor, typically an oxide such as TiO_2 film. Photo-excitation of the dye results in the injection of electrons into the conduction band of the oxide. The dye is regenerated by hole injection from an organic hole conductor or an electrolyte, such as an ionic liquid containing most frequently the iodide/triiodide couple as a redox system. The redox system is regenerated in turn by the reaction with the electrons at the counter electrode which have passed through the external circuit. The voltage generated under illumination corresponds to the difference between the quasi-Fermi level of the electron in the oxide and the redox potential of the electrolyte or the work function of the hole conductor. Thus, the device is regenerative, producing electricity from light without any permanent chemical transformation [2].

The TiO_2 photoanode and electrolytes play a key role in charge separation and transfer in DSCs, and the advances of these materials may greatly promote the photovoltaic performances by optimizing structural and electrochemical properties. On one hand, oriented nano-structures might provide channels for charge transfer, shortening their diffusion courses and enhancing the conductivity of the cell. Such oriented nano-structures might not only exist in photoanodes as well-known nanowires [3] or nanotubes [4], but also potentially make sense in electrolytes, especially quasi-solid and solid-state ones, to help improve the comparatively lower conductivity. On the other hand, updating of fabrication techniques might contribute to cells with greater practicability, such as flexible cells.

Here, we report some of our recent work on (1) the modification of photoanodes and electrolytes related to the concept of oriented nano-channels and (2) the fabrication of cells aiming at practical application. Some mechanisms of material preparation are analyzed, and perspectives are proposed.

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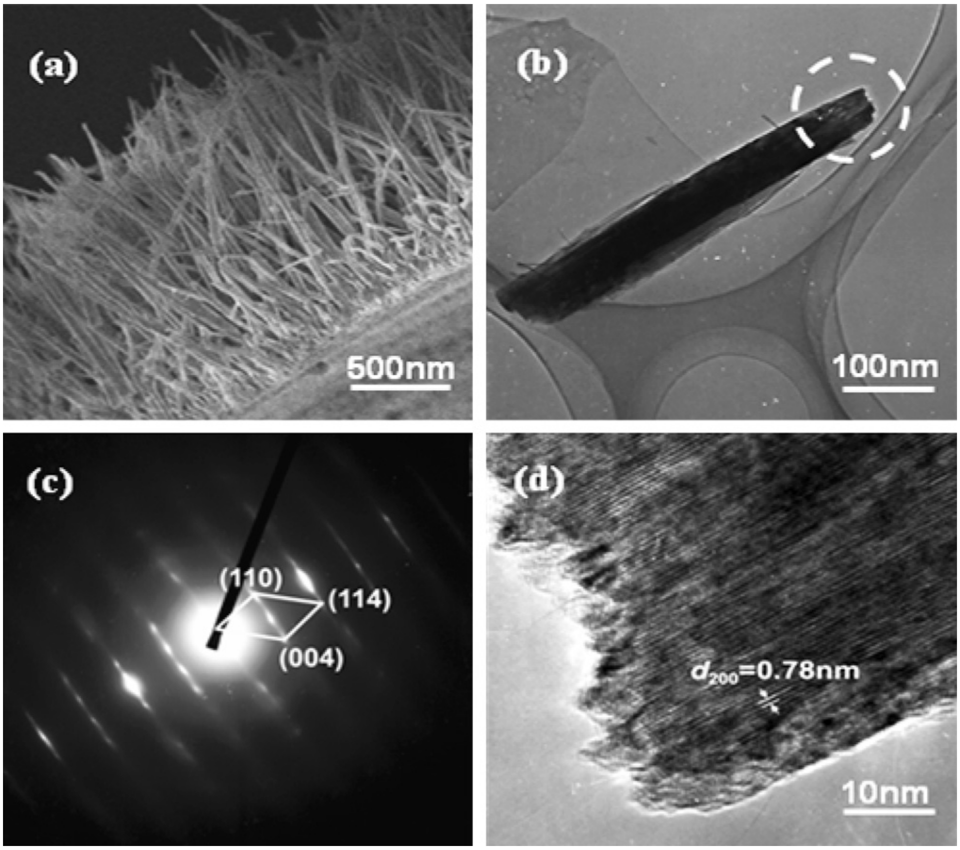

Fig. 1. (a) Scanning electron microscopy image of the hydrogen titanate ($H_2Ti_5O_{11}\cdot H_2O$) nanowire array synthesized by a hydrothermal reaction at 180 °C for 4 h; (b) transmission electron microscopy image of one nanowire; (c) SAED pattern for the nanowires of the array; (d) high-resolution transmission electron microscopy image of the end of one nanowire.

2. Titania nanoarrays in DSCs [5]

TiO_2 (anatase) nanoarrays were obtained by direct hydrothermal treatment of Ti substrates followed by ion exchange in HCl and post annealing. The as-prepared films were composed of monoclinic $H_2Ti_5O_{11}\cdot H_2O$, which has been demonstrated by SEM images, HRTEM images and SAED patterns (Fig. 1).

A postulated mechanism of the nanowire growth is illustrated in the model as shown in Fig. 2. At the beginning, the Ti substrate reacted with the NaOH aqueous solution and many $Na_2Ti_5O_{11}$ nanocrystallines were created and covered the plate. The nanocrystallines then transformed into a nucleus, from which the nanobelts begin to grow. The growth in the cross direction was inhibited because of the competitive growth from too many nuclei simultaneously, whereas the growth in the direction perpendicular to the substrate was free. As a result, the nanobelts began to grow vertically on the substrate through a dissolution–recrystallization process, during which the dislocations caused the defect strain in the cross direction and thus increased with the nanobelt growth. When the nanobelt was long enough, the strain was large enough to suppress the nanobelt into a multilayer structure and then the multilayer nanowire was formed. This mechanism was demonstrated in detail by SEM and HRTEM images of films prepared under different conditions [5]. The $Na_2Ti_5O_{11}$ nanowire array film was then immersed into an HCl aqueous solution to exchange Na^+ into H^+. The resulting $H_2Ti_5O_{11}\cdot H_2O$ nanowire array film was postannealed and transformed into a TiO_2 nanowire array film. XRD patterns (Fig. 3) showed that anatase began to form at 250 °C (curve c) and $H_2Ti_5O_{11}$ phase almost disappeared completely at 450 °C (curve e).

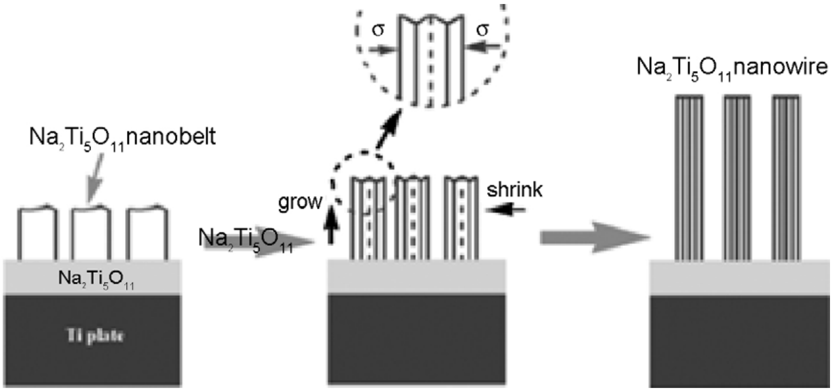

Fig. 2. Mechanism of the nanowire growth.