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Photoelectrochemical properties of iron (III)-doped TiO_2 nanorods

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Abstract

Fe (iron)-doped TiO_2 nanorods were grown on fluorine doped tin oxide (FTO) substrates with various Fe doping concentrations using modified chemical bath deposition (M-CBD). We investigated the effects of Fe doping concentration on the morphological, structural, optical, and photoelectrochemical (PEC) properties of the TiO_2 nanorods. From this study, it was found that the PEC properties were mainly dependent on the morphological and optical properties of the Fe-doped TiO_2 nanorods. At low Fe doping concentration, the PEC properties were highly affected by the optical properties. On the other hand, the PEC properties were significantly affected by the morphological properties at high doping concentration. We observed a maximum photocurrent density of 0.48 mA/cm^2 at a Fe doping concentration of 2 at% from this study. In addition, the donor density and flat-band potential of the Fe doping concentration from the Mott–Schottky plot were analyzed.

Keywords: TiO_2 nanorod; Fe doping; Photoelectrochemical (PEC); Modified-chemical bath deposition (M-CBD)

1. Introduction

Generally, TiO_2 is highly stable against chemical and photo corrosion, is non-toxic, present in abundant reserves, inexpensive and contains the redox level of water in its energy band gap [1,2]. Because of these characteristics, TiO_2 has been widely studied as a photoelectrochemical electrode for producing hydrogen and oxygen using water splitting [3]. However, one disadvantage of TiO_2 is its low photocurrent efficiency due to its wide band gap (3.0–3.2 eV), which limits the absorption of sunlight in the visible light region, and the short diffusion distance of the minority carrier (hole) [4,5]. Many studies have used one-dimensional (1-D) structures, such as nanorods, nanowires and nanotubes, to solve these problems. Large surface areas can improve the photocurrent densities of 1-D structures by extending the contact area with the electrolyte and by minimizing the diffusion distance [6,7]. The growth of 1-D TiO_2 nanostructures has been performed using various growth methods, including hydrothermal, chemical bath deposition (CBD), thermal oxidation and chemical vapor deposition methods [8–14]. Among these methods, the CBD and hydrothermal methods have been widely studied for growing nanorods and nanowire structures because they are easy to use and are inexpensive [8,9]. To improve the light efficiency by expanding the light absorption wavelength range, many doping studies using a transition metal (Fe, S, Sn and Co) have been performed [15–17]. Among the various doping materials, iron(III) has a high potential for use because it can easily replace Ti^{4+} due to their similar ionic radii [18]. However, very few PEC studies have been conducted regarding TiO_2 1-D nanorod structures [19,20].

In this experiment, we grew Fe-doped TiO_2 nanorods using the modified CBD (M-CBD) method. The M-CBD supply solution was added at a constant concentration to the FTO substrate to reduce unwanted homogeneous reactions [21,22]. The morphological, structural and optical properties of the Fe-doped TiO_2 nanorods with various Fe(III) ion doping concentrations were analyzed using field emission scanning electron microscopy (FE-SEM, Quanta 200 FEG), atomic force microscopy(AFM), X-ray diffraction (XRD) with Cu Kα radiation and UV–visible spectrophotometry (SCINCO, S-3100). The PEC performance of the

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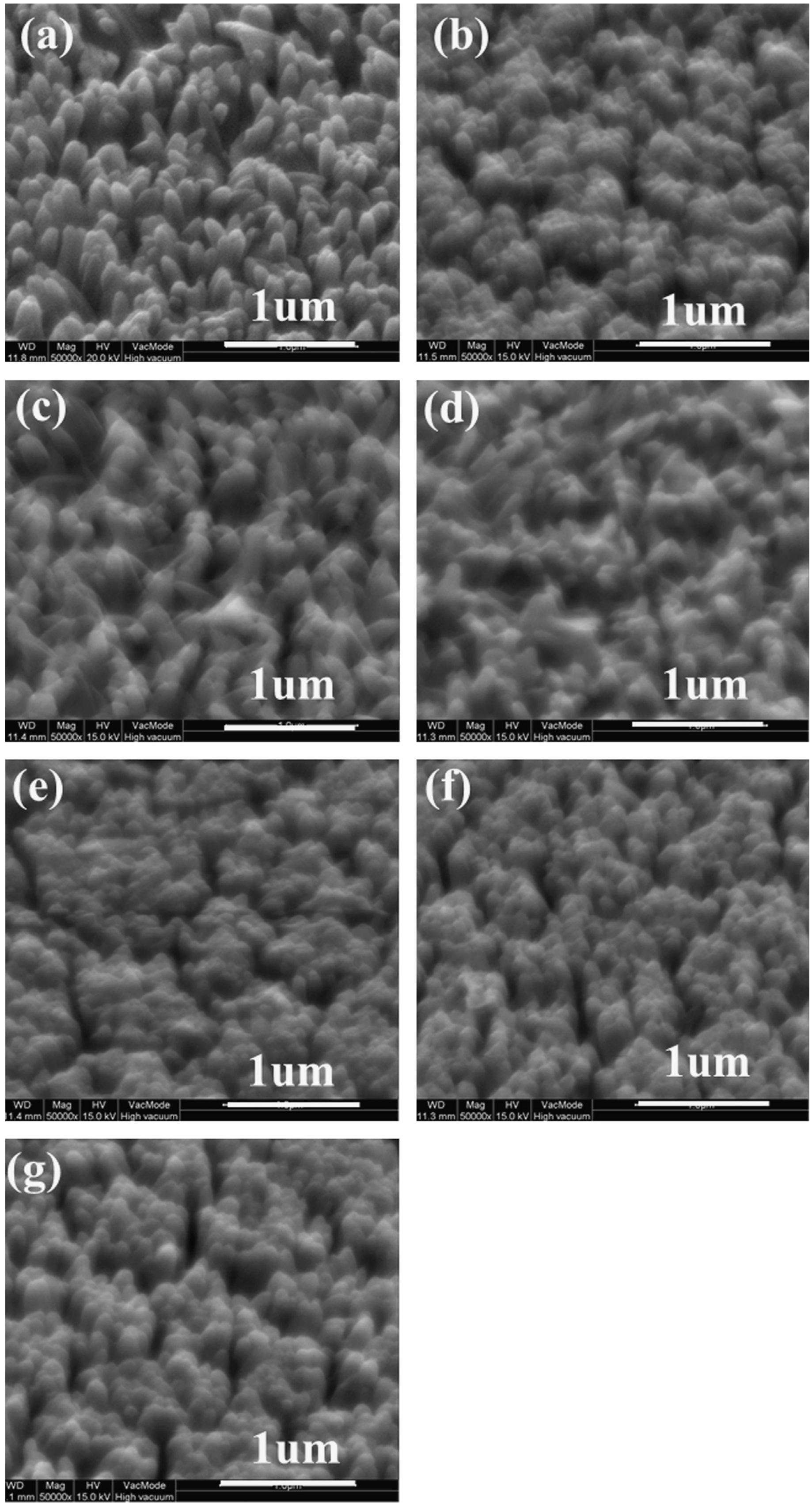

Fig. 1. 40° tilt view SEM images of the TiO_2 nanorods resulting from various Fe doping concentrations: (a) 0 at%, (b)1 at%, (c) 2 at%, (d) 3 at%, (e) 5 at%, (f) 10 at% and (g) 20 at%.