

# Fabrication of transparent TiO<sub>2</sub> nanotubes-film on FTO glass by an electrophoretic deposition process

Yulong Liao, Wenxiu Que\*, Jin Zhang, Peng Zhong

Electronic Materials Research Laboratory, School of Electronic and Information Engineering, Xi'an Jiaotong University, Xi'an 710049, Shaanxi, People's Republic of China

\*[wxque@mail.xjtu.edu.cn](mailto:wxque@mail.xjtu.edu.cn)

## Introduction

Titanium dioxide (TiO<sub>2</sub>) nanotubes have attracted considerable interests in the scientific and technological community, due to their unique functional properties such as good chemical stability and high photoconversion efficiency [1]. Therefore, TiO<sub>2</sub> nanotubes-film electrodes have been widely utilized in various applications including water splitting, catalysts in fuel cells, photocatalytic degradation of organic pollutants, and dye sensitized solar cells (DSSCs). Usually, TiO<sub>2</sub> nanotube-films can be synthesized by a wide variety of techniques such as sol-gel method, chemical vapor deposition, and electrophoretic deposition (EPD) [2, 3]. However, the EPD method allows for the simple fabrication of large scale and complex shape thin film, with control of coating thickness, simple equipment required and low cost. In this paper, we report our study on the fabrication, characterization, structural and optical properties of transparent TiO<sub>2</sub> nanotubes-film on FTO glass by the EPD process.

## Experimental

### Materials

Individual TiO<sub>2</sub> nanotube-powders were firstly prepared by a two-step process, which includes that TiO<sub>2</sub> nanotubes-powders were synthesized by a rapid anodization process and then they were disaggregated into individual TiO<sub>2</sub> nanotubes under assistance of ultrasonic oscillation, as our earlier report [4]. Subsequently, the as-obtained TiO<sub>2</sub> nanotubes were deposited on FTO (F-SnO<sub>2</sub> coated glass) substrates by using the EPD method. The electrolyte was prepared by adding the TiO<sub>2</sub>

nanotubes into 100 mL absolute anhydrous ethanol with a small addition of water and acetylacetone. The electrophoretic cell contained two electrodes of FTO glass; one electrode was a cathodic substrate and the other electrode served as a counter-electrode, and the two electrodes were kept at a distance of 20 mm. The EPD process was thus performed using an optimized constant voltage (40 V) at room temperature for 20 min. After the EPD, the FTO substrate was oven dried at 100 °C for 30 min.

### Characterization

Morphological and structural properties of the anodized TiO<sub>2</sub> nanotubes-powder and the EPD film were characterized by field emission scanning electron microscopy (FESEM, JSM-7000F, JEOL Inc., Japan) and transmission electron microscope (TEM, JEM2100, JEOL Inc., Japan). The transmittance spectrum of the as-deposited TiO<sub>2</sub> nanotubes-film was measured by a JASCO V-570 UV/VIS/NIR spectrometer.

## Results and Discussion

Figure 1(a) shows a TEM image of the as-prepared anodized TiO<sub>2</sub> nanotubes-powder. It can be seen that hundreds of TiO<sub>2</sub> nanotubes are aggregated together, which means they are not appropriate for the EPD. After ultrasonic oscillation, the bundled TiO<sub>2</sub> nanotubes are well disaggregated into individual TiO<sub>2</sub> nanotubes, as shown in Fig. 1(b). These nanotubes are about 20 nm in outer diameter, while their tube-lengths are of multi-distribution. The nanoparticles in Fig. 1(b) can be ascribed to the collapse of the partial TiO<sub>2</sub> nanotubes. These results are good in line with our earlier study in Ref. [4].

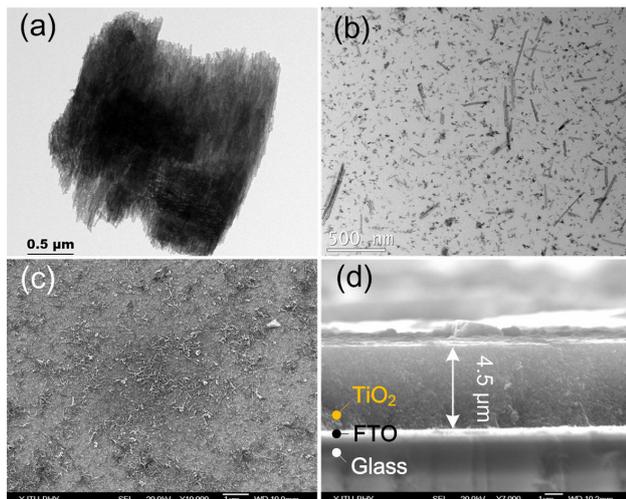


Fig. 1 Morphological and structural properties of the anodized  $\text{TiO}_2$  nanotubes-powder (a), (b) and the EPD  $\text{TiO}_2$  nanotubes-film on FTO glass(c), (d).

Figure 1(c) and (d) shows the SEM images of the top view and cross-section view of the as-deposited  $\text{TiO}_2$  nanotubes-film on FTO substrate, respectively. It can be seen that the individual  $\text{TiO}_2$  nanotubes were unselectively deposited on the FTO glass surface, forming a  $\text{TiO}_2$  film with a thickness up to 4.5  $\mu\text{m}$ . Also, reasonably dense and uniform packing of the nanotubes in the EPD film can be clearly observed too. That is to say, high quality of  $\text{TiO}_2$  nanotubes-film can be obtained with electrophoretic deposition time of 20 min. If we keep increase the deposition time, the  $\text{TiO}_2$  film will crack or detach from the FTO substrate, which implies that the optimized deposition time is 20 min at present work.

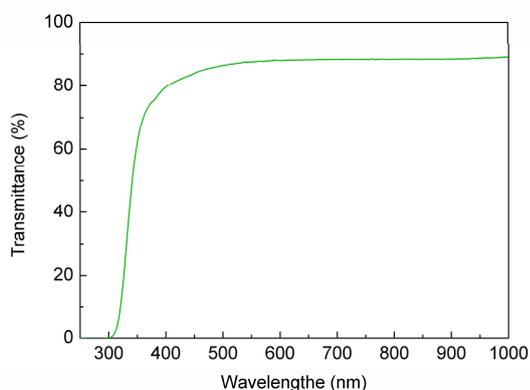


Fig. 2 Transmittance spectrum of the EPD  $\text{TiO}_2$  nanotubes-film on FTO glass substrate.

Figure 2 shows the transmittance spectrum of the EPD  $\text{TiO}_2$  nanotubes-film. The film is transparent and has a high value of transmittance ( $> 80\%$ ) from 380 nm to 1000 nm. The sharp decrease in transmittance at  $\sim 350$  nm is due to the FTO glass absorption. Actually, such kind of transparent  $\text{TiO}_2$  nanotubes-films can be utilized in many potential applications such as photoelectronic devices.

## Conclusions

Transparent  $\text{TiO}_2$  nanotubes-films on FTO substrate have been successfully fabricated by the EPD method. The precursor  $\text{TiO}_2$  for EPD is individual  $\text{TiO}_2$  nanotubes derived from rapid anodization process and subsequent ultrasonic disaggregation. Results indicate the individual  $\text{TiO}_2$  nanotubes can be unselectively deposited on the FTO glass surface, forming a dense  $\text{TiO}_2$  nanotubes-film on FTO with a thickness up to 4.5  $\mu\text{m}$ . The deposited  $\text{TiO}_2$  film is transparent from 380 nm to 1000 nm.

## References

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