Enhanced light absorption in porous silicon with nanocrystalline TiO_2 deposited by metal-organic chemical vapor deposition (MOCVD)

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Abstract

In this paper, nanocrystalline TiO_2 thin films were successfully deposited on porous silicon (PSi) by metal organic chemical vapor deposition (MOCVD) technique for different periods of times: 5, 10 and 15 min. The objective was to improve the optical absorption properties of the porous layers dedicated for photovoltaic application. The structural, morphological and optical properties of the elaborated TiO_2/PSi samples were analyzed by means of X-ray diffraction (XRD), scanning electron microscopy (SEM), atomic force microscopy (AFM), photoluminescence (PL) and UV-Visible absorption spectroscopy methods. The effect of deposition time on the microstructural properties which influence the optical characteristics of the obtained samples was also examined. The XRD analysis confirms the nanocrystalline structure of the deposited TiO_2 composed only by anatase. The SEM characterization evidenced an increase in the TiO_2 film thickness showing more uniform surfaces as the deposition time rises. Correspondingly, the surface roughness increases with the particle size and film thickness as indicated by AFM studies. The UV-Vis measurements showed a considerable enhancement in optical absorption of porous silicon after the deposition of nanocrystalline TiO_2 films. Indeed, the TiO_2 coatings deposited on PSi for 15 min with thickness of 200 nm have the best structure quality and exhibit, consequently, the highest absorption. From these interesting results, we demonstrate the viability of the use of the MOCVD as reproducible process for the elaboration of highly efficient antireflective layers.

Keywords: Porous silicon, MOCVD, TiO_2, optical properties, structural properties, microstructure, photoluminescence.

1. Introduction

Porous silicon and TiO_2 are important materials which are extensively employed in many applications especially solar cells [1], [2]. In fact, porous silicon is characterized notably by large specific surface area, good absorbance, direct and large band gap (2.2 eV) which favors its utilization as an antireflection coating (ARC) in solar cells [2-4]. The application of TiO_2 as antireflection coating permits to reduce the reflection losses and thus to increase the conversion efficiency of solar cells [5].

This work aims to improve the light absorption in porous silicon with the deposition of nanocrystalline TiO_2 films by MOCVD technique. We have made a comparative study of the morphological and optical properties between TiO_2 films deposited at 5, 10 and 15 min in order to investigate the effect of the deposition time on the performances of these films.

For this study, a various characterization techniques were used to analyze the physicochemical and optical properties of the produced TiO_2/PSi films dedicated for photovoltaic application.

2. Experimental procedure

A range of TiO_2 films were deposited on PSi substrates at 550°C using a low pressure MOCVD system for different periods of times. The MOCVD installation scheme is previously presented with detailed description by A. Crisbasan in [6].

Titanium tetraisopropoxide (TTIP) with chemical formula of $Ti(OC_3H_7)_4$ (99.999% - Sigma Aldrich) and Ferrocene ($Fe(C_5H_5)_2$) (98% - Sigma Aldrich) are used as TiO_2 precursor and metal catalyst, respectively.

The organometallic precursor, placed in a water bath, was vaporized. The thermal decomposition of the TTIP leads to the formation of TiO_2 onto the PSi surface following the main reaction:

$$Ti(OC_3H_7)_4 \rightarrow TiO_2 + 4C_3H_6 + 2H_2O$$

More details about the TiO_2 growth could be found in [7].

3. Results and discussion

3.1 Structural characterization

The XRD analysis (Fig.1) confirm the nanocrystalline structure of the deposited TiO_2 composed only by anatase phase (diffraction peak at 2θ=25.3°) which is known as the most efficient crystalline form for application as ARC in solar cells.

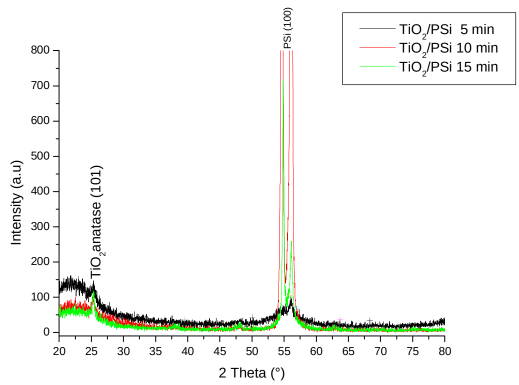
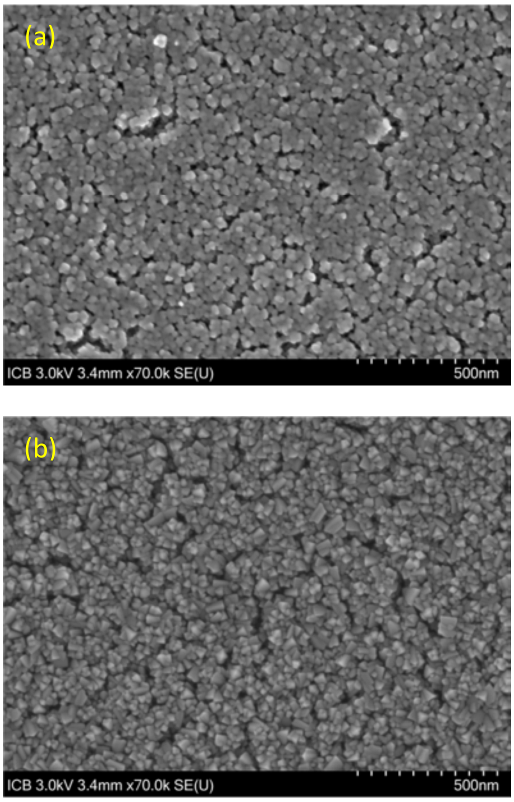


Fig.1. The XRD patterns of TiO_2/PSi for different times of deposition.

3.2 Morphological characterization

The SEM characterization (Fig.2) evidenced an increase in the TiO_2 film thickness and grain size showing more uniform and regular shape leading to an improvement in the film crystallinity as the deposition time rise. Correspondingly, the surface roughness increase with the particle size and film thickness as confirmed by AFM studies (Table 1).



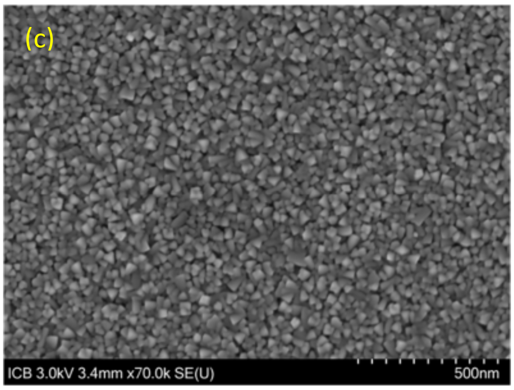


Fig.2. SEM images of TiO_2 deposited on PSi for different periods of times: (a) 5 min; (b) 10 min; and (c) 15 min.

Table 1: Microstructural parameters of the deposited nanocrystalline TiO_2 films.

parameters / Deposition time	Mean grain size (nm)	RMS Roughness (nm)	TiO_2 thickness (nm)
5 min	20	6.53	120
10 min	25	6.92	170
15 min	30	7.73	200

3.3. Optical characterization

The PL measurements indicate an intensive emission of porous silicon in the visible range of the solar spectrum with a peak at 685 nm corresponding to 1.8 eV which is the band gap energy of PSi [2] (Fig.3). Moreover, it was observed a decrease in the PL signal of TiO_2/PSi indicating a reduced carriers recombination rate.

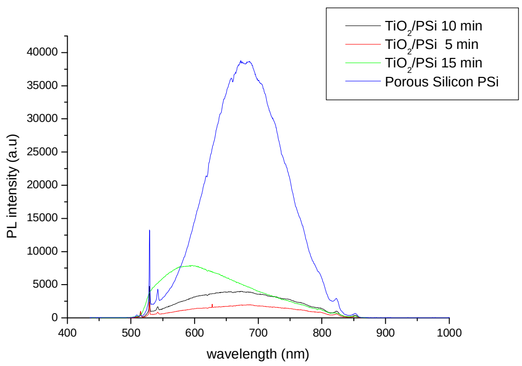


Fig.3. PL spectra of PSi and TiO_2/PSi deposited by MOCVD for different periods of times.

The UV-Vis measurements (Fig.4) showed a considerable enhancement in optical absorption of porous silicon after the deposition of TiO_2 films. Indeed, the TiO_2 coatings deposited on PSi for 15 min with thickness of 200 nm have the best structure quality and exhibit, consequently, the highest absorption.

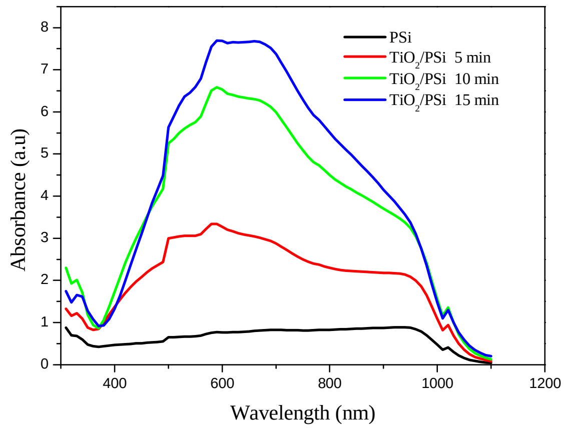


Fig.4. UV-Vis absorption spectra of c-Si, PSi and TiO_2 deposited on PSi for different periods of times.

4. Conclusion

From the characterization results, all the produced TiO_2 films are pure anatase and smooth. However, TiO_2 samples deposited at 15 min with thickness of 200 nm exhibit better microstructure resulting in higher optical absorption. From these interesting results, we demonstrate the viability of the use of the MOCVD as reproducible process for the elaboration of highly efficient antireflective layers.

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