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Influence of fabrication parameter on the nanostructure and photoluminescence of highly doped p-porous silicon

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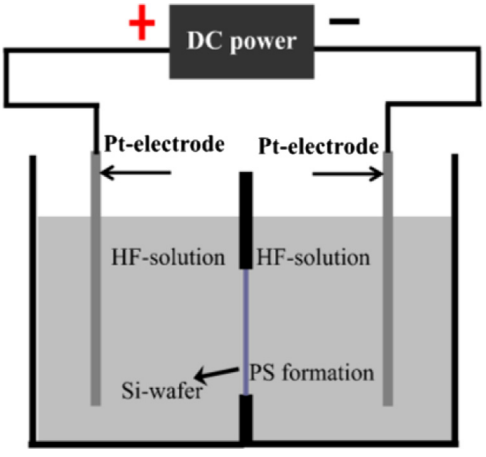
ABSTRACT

Porous silicon (PS) was prepared by anodizing highly doped p-type silicon in the solution of H_2O/ethanol/HF. The effects of key fabrication parameters (HF concentration, etching time and current density) on the nanostructure of PS were carefully investigated by AFM, SEM and TEM characterization. According to the experimental results, a more full-fledged model was developed to explain the crack behaviors on PS surface. The photoluminescence (PL) of resulting PS was studied by a fluorescence spectrophotometer and the results show that PL peak positions shift to shorter wavelength with the increasing current density, anodisation time and dilution of electrolyte. The PL spectra blue shift of the sample with higher porosity is confirmed by HRTEM results that the higher porosity results in smaller Si nanocrystals. A linear model ($\lambda_{PL/nm}=620.3-0.595P$, $R=0.905$) was established to describe the correlation between PL peak positions and porosity of PS.

1. Introduction

Since the intense visible photoluminescence and electroluminescence of porous silicon (PS) were discovered [1–3], an extremely large amount of efforts have been focused on this attractive material to integrate optical and electronic functions on-chip [4,5]. Meanwhile, due to its unique properties such as huge specific area, good compatibility with silicon-based IC technology and adjustable physical–chemical structure, the applications of PS in many other areas have also been largely reported. It mainly included chemical sensors and biosensors [6–8], solar cell [9,10], thermal isolation material [11] and biomedical field [12,13], etc.

PS has been primarily produced by the electrochemical etching method, which yields a reproducible pore structure if the key parameters can be accurately controlled. The controllable preparation is significant to the application of PS in optical or other fields. It is well known that the photoluminescence (PL) performance of PS is affected by its nanostructure, such as porosity, pores and Si branches sizes and distributions. Although numerous literatures [14–16] have already been reported concerning fabrication and optical properties of PS, the relationship between fabrica tion parameters and optical properties of PS is not yet well established [17]. The recent reports on this topic show that the researchers are still attempting to optimize the PS for special optical applications [18,19].



Scheme 1. Schematic of the electrochemical cell with two Pt electrodes.

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The p^+ single crystalline Si wafers are mostly reported as the substrates for fabricating Bragg gratings sensor [20], waveguides [21] and optical biosensor [22]. For this reason, the highly boron doped silicon wafer was selected as the substrate material in present work. The effects of key fabrication parameters (HF concentration, etching time and current density) on the porous structures and PL behaviors were carefully investigated. Finally, a linear model for describing the relationship between porosity of PS and the PL peak position was established.

Table 1
The etching conditions and the analysis results of PS sample.

Sample no.	Current density (J, mA/cm^2)	Etching time (t, min)	HF concentration (C, %)	Porosity (P, %)	Roughness (R, nm)
1-a	20	25	10	31.2	5.99
1-b	20	25	8	45.6	10.3
1-c	20	25	6.67	61.2	11.8
1-d	20	25	5.71	69.6	15.6

2. Experimental

2.1. PS preparation

A serial of PS samples were fabricated through electrochemical etching in alcoholic HF electrolyte. The double-polished single crystalline p^+-Si (100) wafers with thickness of 480 ± 20 μm and resistivity of 0.01–0.09 Ω cm were used as the original material.

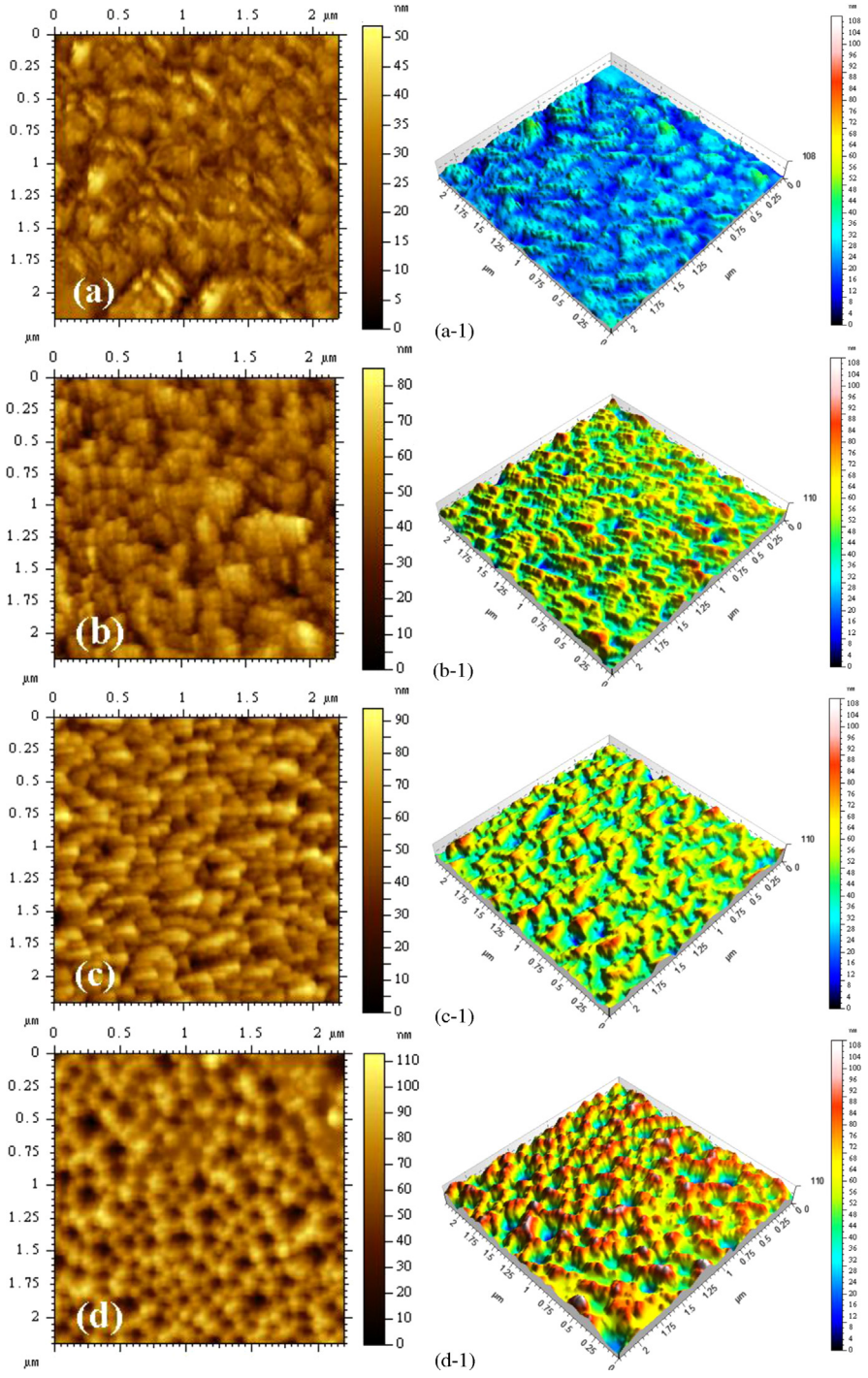

Fig. 1. 2D and 3D AFM photographs of the samples prepared under various HF concentrations.