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High density core-shell silicon nanowire array for the realization of third generation solar cell

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Abstract

The future use of nanostructures such as silicon nanowires in solar cells will only occur if their growth is self-organized, with high density, controlled dimensions and spacing.
In this work we develop and study the first elaboration steps of high quality arrays of nanowires functionalized as solar cells using a radial junction. The core of the structure is made of a P-doped nanowire grown by Chemical Vapor Deposition (CVD) using the Vapor-Liquid-Solid (VLS) method, and the shell is fabricated by a 2D conformal deposition of N-doped silicon layer by CVD. The resulting device is then a dense array of vertically aligned and functionalized silicon nanowires that presents interesting enhanced light absorption.

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1. Introduction

The research for new energy sources is now of great stake and the weight of photovoltaics is increasing, however its cost remains high and prevents a good industrial development. Research is therefore carried out to find more cost effective ways of producing photovoltaic solar cells, among which the use of nanostructures such as silicon nanowires is investigated. Currently most of the studies and

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characterizations are performed on single nanowire devices and resulting in promising photovoltaic capabilities [1,2]. But the use of these structures in large scale solar cells will only be possible if the control of their size and organization is achieved with high efficiency.

A solution can be found with the use of a nanoporous Anodic Aluminium Oxide (AAO) layer which allows a good control in the localization and size of the nanowires: the alumina cylindrical channels act as a guide for the bottom-up growth of the nanowires, resulting in high density arrays of vertically aligned nanowires. This technique only requires basic electrochemical steps to create the AAO membrane before growth and is then very cost effective compared to techniques using electron-beam-lithography to localize the wires.

We previously demonstrated the possible growth of high density silicon nanowire arrays using AAO template on silicon wafer [3]. In this paper we report on the fabrication of high quality nanowire arrays and show that they are well suited for solar application. Indeed the large specific area developed and the optical properties of such arrays increase their absorption of light. Moreover, we propose a core-shell structure for the P-N junction, which enables a decoupling between light energy absorption and charge carrier collection [4].

2. Experimental

2.1 Silicon nanowire array

An aluminium film was evaporated onto a silicon substrate using an e-beam evaporator at a vacuum of approximately 10^{-7} mBar. The AAO layer was then formed using a double anodization process described elsewhere [5] in a standard electrochemical cell with a platinum counter electrode. A 3% by weight oxalic acid ($C_2H_2O_4$) was used as alectrolyte and the alumina was formed under a constant voltage of 40V using a Parstat 2273 potentiostat. The pores of the alumina layer were then enlarged by dipping the sample in a 7% by weight orthophosphoric acid (H_3PO_4) solution at 30°C for about ten minutes. The final diameter of the pores depends on the enlargement duration and can be controlled from 50 to 90 nm. This last step also removes the remaining oxide barrier at the bottom of the pores.

The silicon nanowires are grown using gold as catalyst. A solution of gold chloride containing Au^{3+} ions is then used to deposit the catalyst at the bottom of the pores of the AAO layer by an electrochemical technique: a current is imposed by a Keithley 2612A between the silicon substrate and the gold solution causing the gold ions to be reduced at the interface with the substrate, creating a gold deposit at the bottom of the pores of the AAO layer. The samples are then placed in a Chemical-Vapor-Deposition (CVD) reactor for a Vapor-Liquid-Solid (VLS) mode growth, which is carried out at 580°C under a total pressure of 3Torr with a flow of 25 standard cubic centimetre per minute (sccm) of silane SiH_4, 100 sccm of hydrogene chloride HCl, and diborane B_2H_6 at a ratio determined as a function of the doping level wanted. Once the nanowire growth is achieved, the AAO layer is etched in a commercial aluminium etch solution at 60°C in order to expose the silicon nanowire array.

The last step is to deposit the 2D conformal layer of N-doped silicon to form the radial electronic junction. After removal of the gold catalyst from the nanowire array, the sample is placed in the CVD reactor where silicon is deposited at the temperature of 600°C under a pressure of 3Torr and a 40 sccm flow of silane. Phosphine (PH_3) is added at a flow rate calculated as a function of the desired doping level.

2.2 Characterization

Morphological characterizations are made using a Zeiss Ultra 55 Scanning Electron Microscope (SEM) equipped with a field effect electron gun allowing less than 10nm resolution.

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