Optik 149 (2017) 246–251

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Modeling and optimization of core/shell p-i-n Si/$Si_{0.2}Ge_{0.8}$ nanowire for photovoltaic

F. Benyettou [a], A. Aissat [a,b,*], I. Berbezier [c], J.P. Vilcot [b]

[a] Laboratory LATSI Faculty of Technology University of Blida.1, 09000 Blida, Algeria
[b] Institut d'Electronique, de Microeílectronique et de Nanotechnologie (IEMN), UMR CNRS 8520, Universiteí des Sciences et Technologies de Lille 1, Avenue Poincareí, BP 60069, 59652 Villeneuve d'Ascq, France
[c] IM2NP, Faculté des Sciences et Techniques, Campus de Saint Jérôme - Case 142, Avenue Escadrille Normandie Niemen, 13397 Marseille Cedex 20, France

ARTICLE INFO

Article history:
Received 30 May 2017
Accepted 15 September 2017

Keywords:
Material
Nanowire
Core/shell
Photovoltaic
Optoelectronic

ABSTRACT

In this work we propose a modeling and simulation of core/shell p-i-n Si/$Si_{0.2}Ge_{0.8}$ nanowire for photovoltaic. In the first step of this work, we have compared the core/shell p-i-n homojunction Si and heterojunction Si/$Si_{0.2}Ge_{0.8}$ Nanowire (NW) solar cell having a length of 3 μm and a radius of 0.19 μm, by studying their current-voltage and external quantum efficiency (EQE). Our results have shown that blending Silicon with 80% of Germanium enhances relatively the short circuit current and efficiency by 3.04% and 8.48% respectively. In other hand, the absorption edge of Silicon NW has extended from 1100 nm to 1200 nm, with a gain of EQE of 15% obtained in this range. In the second part, we have tried to optimize the Si/$Si_{0.2}Ge_{0.8}$ structure, by varying their radius and length. The corresponding results have indicated that a radius of 0.28 μm and a length of 10 μm are the optimal geometric parameters for any optimization of such structure.

1. Introduction

Solar energy is abundant, clean, and renewable. Solar cells are the devices that convert this energy into electricity. The most inconvenient of photovoltaic energy is their low yield and high cost using conventional solar cell. Nowadays, nanostructure materials are the subject of many researches in goal to overcome the limits of conventional solar cell and to exceed Shockley-Quisser conversion efficiency [1]. Quantum Dot Solar Cell (QDSC) [2–4], Dye-Sensitized solar cell [5] and organic bulk heterojunction devices [6] are one of the examples of such configurations. Despite these promising efforts, no technology has been able to achieve good efficiency and low cost of conventional Silicon p-n junction. This later is formed by planar p-type/n-type homo or heterojunction. Recently, nanowire have been appeared as alternative devices to improve optical absorption and collection efficiency in a planar solar cell [7,8]. Their large surface/volume ratio is useful to enhance the performances of electronic devices. Moreover, they decreasing the density of states in surface which leads to decrease the recombination of photogenerated carriers and reduce distance to collecting junction. Usually, two techniques are used for fabrication of NW: top-down and bottom-up techniques. Top-down technique uses lithography to define the fabricated structure and then transfer it to the substrate by etching or similar way. In bottom-up approach, the material is added to substrate in self-organized way. Bottom-up uses vapor liquid solid (VLS) method to synthesis the nanowire, in this method

* Corresponding author at: Laboratory LATSI Faculty of Technology University of Blida.1, 09000 Blida, Algeria.
E-mail address: sakre23@yahoo.fr (A. Aissat).

http://dx.doi.org/10.1016/j.ijleo.2017.09.056

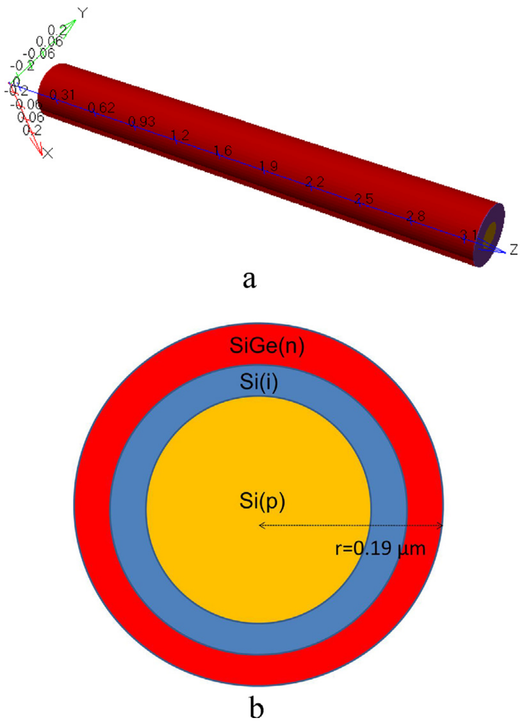

Fig. 1. (a) 3D structure of core/shell p-i-n Si/SiGe. (b) Top view of the structure.

a metallic nanoparticules are employed to growth the nanowire [9]. In addition, the capability to alter the directions of light propagation to the direction of charge separation is one of the most motivations for developing nanowire PV devices. Silicon nanowire is embedded into core/shell solar cell as shown in Fig. 1, creating also a p-i-n radial junction with diameter varying from nanometer to some micrometers. Cutline section of a core/shell nanowire gives a circular core/shell structure which also called Quantum Dot Quantum Well (QDQW) if the diameter is less than 10 nm. Experiments reveal that a single Silicon nanowire exhibits an open circuit voltage of 0.485 V, short circuit of 6.5 mA/cm^2, fill factor of 70% and an efficiency of 2.2% under 1 sun AM1.5G [10,11]. Because Si is an indirect bandgap semiconductor, a few microns are required to absorb the majority of the photons comprised in the solar spectrum. As a solution to this limitation, Si nanowire (NW) can be allied with others semiconductors to make alloy materials. Among the semiconductors that Silicon can be blended with it is Germanium to create Si_xGe_{1-x} shell II–V alloy. Thanks to the physicals properties and bandgap of Si_xGe_{1-x} which is tunable between 1.12 eV and 0.66 eV, this material earns an importance in the field of optoelectronics. In this latter, we are interested on modeling and optimization of core/shell p-i-n Si/$Si_{0.2}Ge_{0.8}$ NW with radial junction. Many effects are investigated and discussed like influence of radius and length of NW on the main characteristics parameters of a solar cell: current-voltage and external quantum efficiency (EQE). The variation of spatial total density of current in the radial junction is also presented. Fig. 1(a) shows the 3D structure of core/shell p-i-n Si/$Si_{0.2}Ge_{0.8}$ NW with a total length of about 3 µm and a radiusof 0.19 µm. Fig. 1(b) shows the top view of the structure where the red layer represents n-type SiGe shell layer, the bleu one is the intrinsic layer and the brown is the p-type Si core.

2. Theoretical model

The following sections describe the physical models that have been used for this simulation. A Low Field Mobility model is used for calculations of the mobility of carriers dependent temperature, and it is given by the following:

$$\mu_{n_0}(T_L) = MUN\left(\frac{T_L}{300}\right)^{TMUN} \tag{1}$$

$$\mu_{p_0}(T_L) = MUP\left(\frac{T_L}{300}\right)^{TMUN} \tag{2}$$

Concentration dependent model is used for calculations of the mobility of carriers dependent concentration, and it is given by the Masetti model [12].

$$\mu_n = \mu_{n\,\mathrm{min}} \exp\left(\frac{-P_{c.n}}{N_D}\right) + \frac{(\mu_{n\mathrm{max}} - \mu_{n\mathrm{min}})}{1 + \left\{\frac{N_D}{C_{r.n}}\right\}^{\alpha.n}} - \frac{\mu_{1.n}}{1 + \left(\frac{C_{s.n}}{N_D}\right)^{\beta.n}} \tag{3}$$