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Enhancement in photovoltaic properties of silicon solar cells by surface plasmon effect of palladium nanoparticles

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ABSTRACT

This work presents the surface Plasmon effect of Palladium nanoparticles (Pd NPs) on the photovoltaic properties of silicon solar cells. Pd NPs were deposited on the p-type silicon base of the n^+/p junction using a chemical deposition method in an aqueous solution containing Palladium (II) Nitrate (PdNO₃)₂ and Ammonium Hydroxide (NH₄OH) followed by a thermal treatment at 500 °C under nitrogen atmosphere. Chemical composition and surface morphology of the treated silicon base were examined by energy dispersive X-ray (EDX) spectroscopy, scanning electronic microscopy (SEM) and Atomic Force Microscopy (AFM). The effect of the deposited Pd NPs on the electrical properties was evaluated by the internal quantum efficiency (IQE) and current–voltage (I–V) measurements. The results indicate that the formation of the Pd NPs is accompanied by an enhanced light absorption and improved photovoltaic parameters.

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1. Introduction

The photovoltaic technology offers the possibility of environmentally friendly production of electricity based on an almost infinite source of energy, the sun. Silicon solar cells technology is the most widely used in the photovoltaic industry because of the low manufacturing cost [1]. However, the inefficient absorption of light which limits the conversion efficiency remains a key issue for the industrial production. Therefore and in order to overcome this problem, many researchers have reported that light trapping can be achieved by using (i) porous silicon layer on the top surface of the silicon solar cells as an anti-reflection coating (ARC), due to their rough surface and low effective refractive index compared to silicon [2-4], (ii) doped porous silicon layer with the rare earth (Cerium, Lanthanum) as an anti-reflection coating, which decreased the reflective loss of solar radiation and consequently improved the photovoltaic properties [5-7], (iii) an annealing step at about 500 °C after emitter diffusion [8] and (iv) by the insertion of a thin transparent conducting oxides (TCO) layer in the silicon solar cells, due to their high optical transmittance in the visible wavelength range, chemical stability and lower cost of production [9-11].

Finding new structures or optical devices as alternative approaches for light trapping in solar cells is a real challenge for researches. Recently, the plasmonic properties of noble metal nanoparticles have attracted the attention of researches community, due to their particular optical properties [12–17]. The specific optical properties of metal nanoparticles are a

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consequence of the appearance of a resonance in their absorption of light in interaction with an incoming electromagnetic wave. Therefore, in this work, we discuss new approach based on Palladium nanoparticles for light trapping and increasing the conversion efficiency of silicon solar cells.

Nowadays, metals nanoparticles can be purchased off the shelf, whose size distribution are very clearly known and can be deposited by means of various techniques such as thermal evaporation [18], sputtering [19], pulsed laser deposition [20], sol-gel method [21] and so on. However, many authors [22,23] have reported that placing nanoparticles is sensitively dependent on the details of the substrate nature and geometry and of the position of the nanoparticles. Moreover, it have been reported that morphology, size shape and distribution of nanoparticles strongly affect the scattering or the absorption of the incident light [24,25]. For this reason, we proposed to use spontaneous chemical deposition of Pd NPs followed by thermal treatment. This method is more particle than others [26] due to its simplicity, safety and low cost and it is easy to finding the optimal size and distribution of Pd NPs for improving light trapping by controlling the time deposition and the temperature of thermal treatment.

2. Experimental method

A schematic representation of the investigated silicon solar cells with and without the integrated Pd NPs is presented in Fig. 1. The cells have an area of 1 cm². The silicon wafers used in this study as a base of solar cells were born-doped p-type crystalline silicon (100) having a resistivity of 3Ω . Before starting the process, the wafers were dipped for a few seconds in a mixture acid solution containing 16% of HF, 64% of HNO₃ and 20% of CH₃COOH to remove the native oxide layer. The formation of Palladium nanoparticles on the base was effectuated by using spontaneous chemical method in an aqueous solution containing 0.05 M of (PdNO₃)₂ and 2 M of NH₄OH for 10 s followed by a thermal treatment at 500 °C during 45 min under N₂ atmosphere. Then, to form a tick n⁺ region and to achieve the investigated junctions, a phosphorous diffusion at 950 °C for 30 min was realized by homogenously spreading POCl₃: acetone solution on the treated p-type Si base with Pd NPs using the spinning method. The metallic contacts were made by screen printing of a silver paste for the front contact and aluminum/ silver paste for the rear contact followed by a thermal annealing at 630 °C and 830 °C, respectively.

The morphology and the chemical compositional investigations on the surface of the p-type Si base were studied using Scanning Electronic Microscopy (SEM) equipped with energy dispersive X-ray (EDX) spectroscopy and by using Atomic Force Microscopy (AFM) in tapping mode configuration by a Topometrix TMX 2000 Explorer AFM. The reflectivity spectra were realized using LAMBDA 950 UV–Vis–NIR spectrometer equipped with an integrating sphere. The internal quantum efficiency (IQE) was measured on a quantum efficiency measurement system. The current–voltage (I-V) measurements were performed by the use of a Keiphley 2400 source meter. All spectral measurements were taken at room temperature and under illumination of 100 mW cm⁻².

3. Results and discussion

3.1. Scanning electronic microscopy

In order to obtain information about morphology and chemical composition of the deposited Palladium onto p-type silicon base, we performed surface imaging analysis (Fig. 2(a)-(b)) using scanning electronic microscopy (SEM).

As revealed in Fig. 2(a), it is obvious that the formed palladium nanoparticles exhibiting a spherical shape with particles size around 10 nm are randomly distributed over the entire surface of silicon base. The inset in Fig. 2(b) shows the corresponding EDX spectrum, indicating the presence of silicon (Si) and oxygen (O) and confirming the synthesis of palladium (Pd) which is justified by the tow slight peaks centered at 3 and 2.8 KeV. The distribution of Pd NPs on the silicon base seems to be a promising new way of providing light trapping centers and consequently could enhance the photo conversion of silicon solar cells by exciting surface plasmon on palladium nanoparticles, which will be discussed later.



Fig. 1. A schematic representation of the investigated silicon solar cells with and without the incorporated Pd NPs.

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