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Novel approach for fabrication of buried contact silicon nanowire solar cells with improved performance

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ABSTRACT

Generally, a selective SiNW-type structure is used to avoid resistive loss in SiNW-based solar cells. However, the performance of these selective SiNW-based solar cells is lower than that of conventional Si solar cells, due to their low collection efficiency and high series resistance. Herein, a novel process is developed to enhance the collection efficiency of photogenerated charge carriers, and hence the performance of SiNW solar cells. Self-aligned single-step lithography is used to fabricate buried contact SiNW (SiNWBC) solar cells. The effectiveness of the SiNWBCs is manifested in the conversion efficiency ($\eta \approx 15.02\%$) of the solar cell, which is improved by ~7.82% compared to that of the control selective SiNW cell ($\eta \approx 13.93\%$). The performance and PV cell parameters of the SiNWBCs are analyzed and compared with those of this control cell. Losses due to the PV cell parameters of the SiNWBC solar cell are lower than those of the control cell. The reduced number of front surface recombinations lowers the n and J_0 values, resulting in enhanced SiNWBC cell performance.

1. Introduction

The cost per watt of solar energy can be reduced by either reducing the manufacturing cost or enhancing the efficiency of the solar cell. In recent years, Si nanowires (SiNWs) have been used as ARCs in several instances because of their very high absorption (Jung et al., 2013). Several reports discuss the synthesis of SiNWs using different techniques (Teo and Sun, 2007; Khan et al., 2014a). Some groups have optimized growth conditions to obtain minimal reflection losses by the geometrical engineering of the SiNWs (Khan et al., 2014a). The conversion efficiency (η) of the resulting solar cells is lower than that of conventional Si solar cells because both the recombination and resistive losses are increased after SiNW formation. The diode ideality factor and the reverse saturation current both increase as the surface recombination increases, decreasing the fill factor (FF) and hence the η of the cell (Khan et al., 2010). Recombination loss can be reduced by tailoring the structural properties of the nanowire to achieve a lower reflection value per length.

The resistive loss in SiNW-based solar cells is normally due to a high series resistance (R_s), which depends strongly on the structure of the SiNWs. This value can be decreased by increasing the thickness of the front metallic contact or by decreasing the contact resistance between the front surface and the front metallic contact using a selective SiNW (control) or buried contact SiNW (SiNWBC) structure. The SiNWBC structure has several advantages over the control structure. It has a high front contact (metal) aspect ratio, low metallic resistance, low contact resistance between the front surface and metallic contact, and low shadowing (reflection/optical) loss (Wenham, 1993). In a typical buried contact solar cell (BCSC), the current collection grid is recessed in grooves on the front surface. This provides more active area for illumination and photon absorption by minimizing the surface area covered by the front grid metallic contacts (Gee and Hacke, 2004). However, despite this increased area, the contact resistance between the front gridded metallic contact and the front surface in the BCSC is nearly equal to that in a conventional cell, because of the increase in contact area relative to the depth of the buried contact. The BCSC geometry has a larger illuminated area for devices than conventional cells have.

In this study, we investigated a new approach to fabricate SiNWBC solar cells using self-aligned, single-step photolithography. To the best of our knowledge, SiNWBCs are reported here for the first time. The values of FF and η of the SiNWBCs are improved by reducing the electrical losses. The PV cell parameters of the solar cells were also studied for loss analysis. We also discuss the advantages of SiNWBC cells over selective SiNW control cells (without buried contacts).

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2. Experimental

2.1. Samples preparation for control and SiNWBC solar cells

B-doped, p-type, 220-μm-thick, Czochralski-processed polished Si (100) wafers measuring 1.2 × 1.2 cm with 1.5 Ω cm resistivity were used as starting materials for solar cell fabrication. A two-step metal-assisted wet etching process comprising metal deposition and subsequent etching was used for SiNW formation (Khan et al., 2014a). In this study, both control (SiNWs selectively grown without buried contacts) and SiNWBC (with buried contacts) structures were prepared. Process schematics for the fabrication of both control and SiNWBC structures are shown in Fig. 1(a) and (b), respectively. In both the structures, one-time photolithography was used. A positive photoresist (PR^+, AZ1512, supplied by AZ Electronic Materials) was first coated on the back surface to avoid the growth of SiNWs here. The photoresist was then applied on the front surface to conduct photolithography.

For the control sample, Ag nanoparticles (NPs) were deposited onto the substrate, followed by photolithography using PR^+ spin-coating at 1000 rpm for 30 s, soft baking at 90 °C, exposure to UV light using the patterned mask, developing, and hard baking at 120 °C (PR^+ remained in places where contacts were to be made). The Ag NPs were uniformly deposited onto the Si substrate using a mixed solution of $AgNO_3$ (0.03 M), HF (4.6 M) and deionized water (DIW) for 30 s. These samples were dipped in a mixed solution of HF (4.6 M), H_2O_2 (0.5 M) and DIW for 2 min at room temperature to form vertically aligned SiNW arrays on the Si surface, except in the areas covered by PR^+. After the etching process, the samples were rinsed in DIW and dried in air, and the PR^+ was removed using acetone. Finally, the selectively etched SiNW samples were dipped in concentrated HNO_3 for 10 min to completely remove the remaining Ag NPs.

For the SiNWBC structure formation, selective SiNWs were grown, followed by a photolithography process similar to that used for the control samples. The microscopic images (100× magnification, 0° tilting angle) of various processing steps for buried contact formation are shown in Fig. 2(a)–(d). After the SiNW etching process (Fig. 2(a)), additional Ag NPs were deposited on the etched SiNW surface. In the second Ag NP deposition process, a thicker Ag layer was obtained and the outer surfaces of the SiNWs were oxidized. After Ag NP deposition, the samples were dried and the PR^+ was removed using acetone (Fig. 2(b)). An aqueous solution of tetramethylammonium hydroxide (TMAH, 3% by volume) was used to etch grooves in the Si at 65 °C. Finally, the samples were rinsed in DIW and the Ag NPs were completely removed using

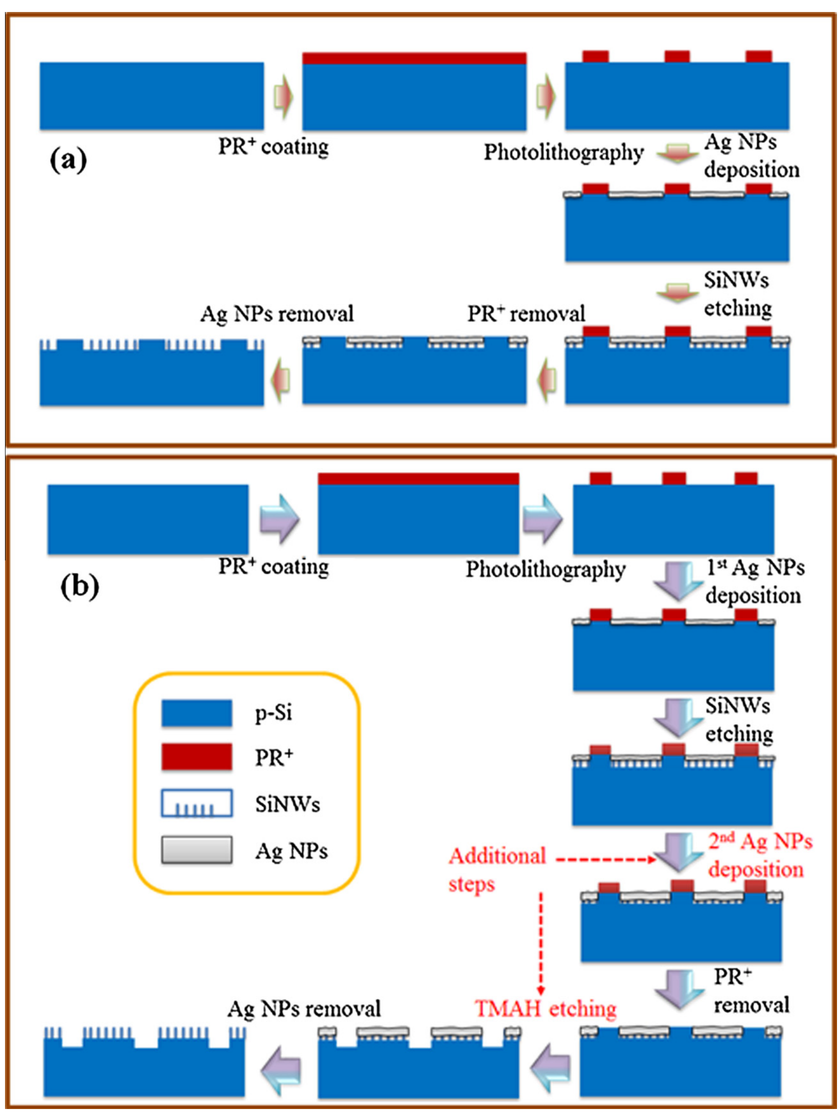

Fig. 1. Sample preparation schematics for the (a) control and (b) SiNWBC solar cells.