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Schottky-type edge passivation of silicon solar cells

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ABSTRACT

We investigated Schottky-type edge passivation of Si solar cells using Ag nanodots and the enhancement of cell conversion efficiency by improving the fill factor. The threshold voltage for the termination of photocurrent is increased by about 0.13 V compared to the reference sample without edge passivation. The cross-section of the pn junction depletion region forms an Ag/Si Schottky contact in the depletion layer of the space and the image charges with a width of about 28 nm. However, the p- and n-electrodes form Ohmic contacts with a contact depletion width of less than 5 nm for the carrier tunneling process. The edge Schottky contact reduces the carrier recombination and saturation current at the surrounding edge region and enhances the fill factor and the pn junction property with increased shunt resistance, indicating that metallic edge passivation is an important process for large-scale Si solar cell fabrication.

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1. Introduction

Silicon solar cells have been extensively investigated to improve their conversion efficiency by introducing various surface passivation methods. Surface passivation is involved for the front surface, rear surface, and edge pn junction layers. For the front surface, the light anti-reflection coating (ARC) layer of SiO_x or SiN_x thin films also plays a role in surface passivation. Further, cell passivation has been carried out for thin films such as Al_2O_x and indium tin oxide, hydrogenated a-Si, and low-energy hydrogen ion implantation [1–5]. For the rear contact, a direct contact of Al metal is common for back surface field (BSF) structural formation, along with a local Al contact on the SiO_x layer for the mirror phase structure. For edge passivation, the laser isolation technique is common for pn junction separation. Several authors have reported edge passivation by hydrogen plasma implantation and anodic alumina passivation [6,7]. It remains an important matter for cell edge passivation to prevent carrier leakage.

During the furnace diffusion process, the wafer edge is doped by phosphorus dopant, which can be n-type on the surrounding wafer surface. After cell fabrication, the front and back electrodes can be directly channeled through the pn junction by the edge-isolation process of a laser cut. The edge pn junction cutting process can disconnect the n-type channel on the surrounding front and back surfaces. For more advanced cell fabrication, an additional etching process can remove the n-type layer on the back side, which also removes the n-type layer at the edge side. Then, a SiN_x layer, such as the ARC layer, can form on the front cell area and the edge side by plasma deposition. The pn junction contact with the SiN_x layers provides interfacial defect centers where electron-hole charge recombination happens.

In this work, we investigated the Schottky-type edge passivation effect on Si solar cells by coating the edges of Si solar cells with Ag nanodots. Metal contact on the cell edge did not show a short state or shunt effect, and it increased the conversion efficiency. Photoluminescence and electroluminescence showed reduced spectral emissions at the cell edges. This implies that the metal-semiconductor Schottky contact forms an interfacial barrier to deplete the carriers at the interface.

2. Experimental methods

We used 6in. p-Si(100) wafers with a resistivity of 0.3 Ω-cm for the solar cell fabrication process, as shown in Fig. 1. First, we carried out the saw damage removal and wafer cleaning processes. Then we performed a microtexturing process to form micro-pyramidal structures on the wafer surfaces by etching in a KOH-IPA (isopropyl alcohol) solution at 84.5 °C for 25 min. To form the n-type emitter layer, we performed the phosphorus diffusion process in a tube furnace using $POCl_3$ with a sheet resistance (R_{sh}) of 75 Ω/sq and a surface depth of 100 nm above the doping concentration of 5×10^{19} atoms/cm^3. As advanced cell fabrication, we completely removed the n-type doped layers on the back surface and the surrounding edge sides through an etching process with a 0.5% HF solution. We deposited an 80-nm thick SiNx layer by plasma enhanced chemical vapor deposition (PECVD) at 400 °C for 45 s. The busbars and fingerlines as front contacts were formed by

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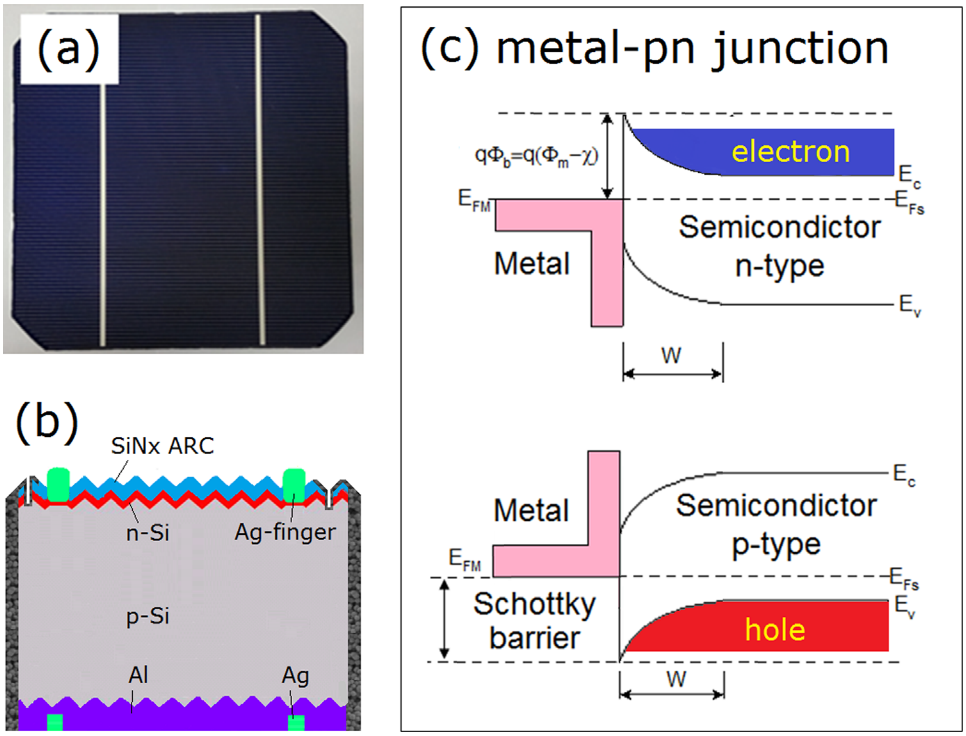

Fig. 1. The fabricated Si solar cell (a) with a schematic diagram (b) of the cross-sectional view with edge passivation by Ag nano-ink and (c) a band diagram of the depletion interface of the Ag-Si Schottky contact with a larger Ag work function (Φ_m) than Si electron affinity (χ). The doped Si surface with stable space charges can contact the Ag metal, and the space charges induce image charges at the metal surface. The space-image charges form a dipole field at the Ag/Si contact, with the depletion width (w) depending on the doping concentration and interfacial potential barrier (Φ_b).

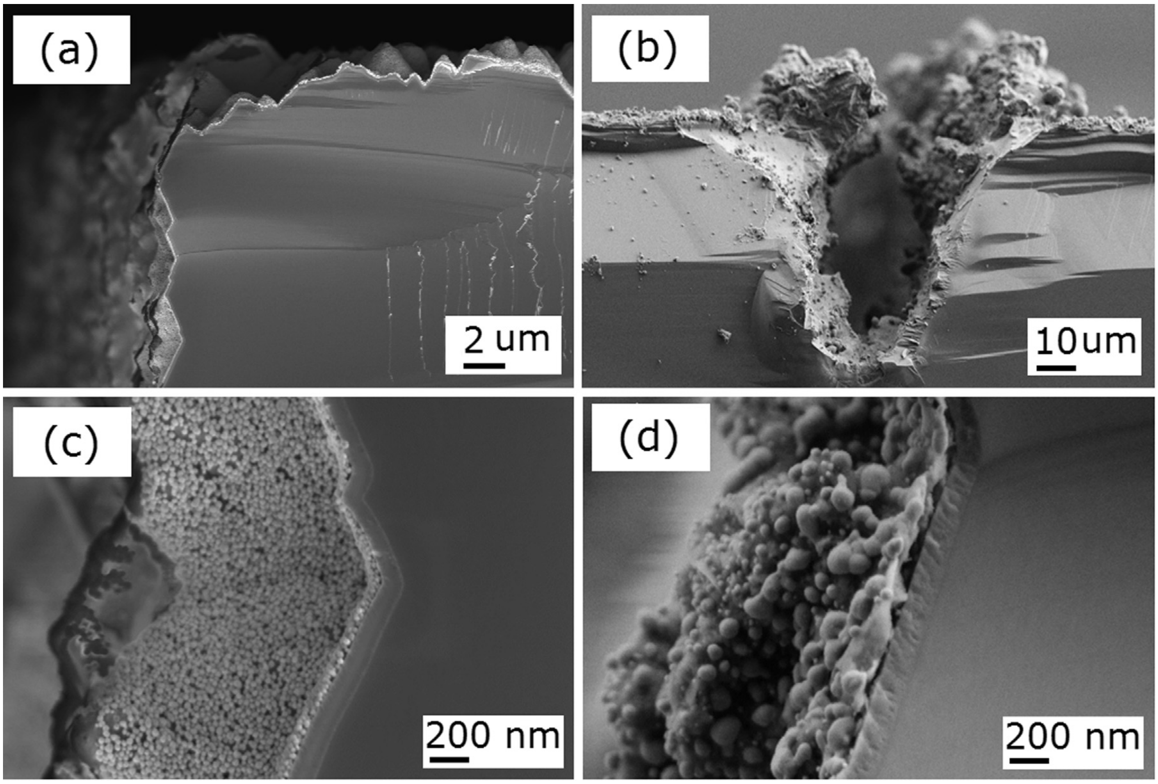

Fig. 2. Cross-sectional FE-SEM images of Si solar cells for edge passivation by Ag nano-ink. The wafer edge was covered by Ag nanodots (a), and the laser-cut region (b) of the edge isolation was also covered with Ag nanodots after the co-firing process. The Ag nanodots are shown in the side region image before (c) and after (d) co-firing, which increases the size of the Ag nanodots.

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