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# Study and investigation of phosphorus doping time on emitter region for contact resistance optimization of monocrystalline silicon solar cell

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## ABSTRACT

In this paper, contact resistance of monocrystalline silicon solar cells was optimized by the variation of phosphorus doping time on emitter region. Wet-chemical texturization was performed to form pyramidal structure on silicon wafer surface. The surface morphology of the textured wafers was studied by field emission scanning electron microscope (FESEM) and surface reflection measurement (SRM). The textured wafers were doped by varying phosphorus doping time using constant flow rate of phosphorus oxychloride ($POCl_3$) in a high-temperature diffusion furnace. The phosphorus doped silicon wafers were metalized by screen printer using silver and aluminum paste in the front and back surface of the wafers respectively. To form ohmic contacts between silver/aluminum layer and the silicon wafer, rapid thermal annealing (RTA) was performed on the screen-printed solar cells. The contact resistance of screen-printed solar cells was measured using transmission line method (TLM). 25 minutes doped sample showed minimum front and back contact resistances, which could potentially be useful for efficient monocrystalline silicon solar cells fabrication.

## Introduction

Harvesting of solar energy by solar cells has been increasing rapidly from last two decades as a substitute of fossil fuel-based energy sources [1–7]. The crystalline silicon solar cell is one of the dominant solar energy harvesting technology, where metallization of silicon wafer plays a crucial role in efficient collection of solar energy. For metallization, screen-printing is one the most suitable method in the photovoltaic industry because of its low fabrication cost, easy process, and quick metal deposition process with minimum environmental hazards [8,9]. Most of the larger scale solar cell production is based on metallization of doped emitter layer of silicon wafer [10]. The quality of the emitter, identified by measuring sheet resistance, plays a dominant role to enhance the photovoltaic performance [11,12]. Therefore, the emitter doping concentration ($N_s$) must be kept enough high (i.e., $N_s > 10^{19}$ atoms/cm$^3$) [13] to reduce the contact resistance ($R_c$) [14,15], which is the interface resistance between metallization materials and underneath semiconductor layer [9].

It is previously reported [10,16] that the quality of contacts between conductor and semiconductor materials plays a significant role for high-efficient solar cell. However, it is a challenging job to form an intimate contact between silver/aluminum and silicon without debasing the emitter region [10]. The formation of contact and its characteristics are influenced by the emitter doping level which may electrically active or inactive and a dead layer might be formed due to over doping [5]. Therefore, contact resistance becomes a matter of concern when emitter layer suffers from under or over doping. For this reason, optimization of doping time i.e. doping concentration is mandatory to get effective contact resistance [16]. But, the effect of contact resistance between conductor and semiconductor materials is rarely addressed in silicon solar cell research. Because of this, for the first time, we have investigated the effect of different phosphorus doping time on front and back contact resistances of the monocrystalline silicon solar cells.

In this research, monocrystalline silicon solar cells were fabricated by the variation of phosphorus doping time on emitter region, and then sheet resistance measurement was performed by four-point probe method to identify the changes of P-doping concentration with diffusion time. Also, contact resistance between the silver/aluminum layer

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and silicon wafer was determined by using transmission line method (TLM) [17–19]. Finally, the optimized contact resistance is proposed for the fabrication of efficient silicon solar cells.

## Materials and methods

In this work, six (6) p-type (1 0 0) oriented Czochralski monocrystalline silicon wafers were used. The thickness, area, and resistivity of the wafers were 200 µm, 127 × 127 mm$^2$, and 1–3 Ω.cm respectively. The wafers were cleaned and textured using the chemical solution of NaOH (1 g) + de-ionized $H_2O$ (10 ml) and KOH (1 g) + IPA (5 ml) + de-ionized $H_2O$ (125 ml) respectively for 10 min at 70 °C temperature. The purpose of cleaning and texturing the samples was to eliminate the surface contaminants and form the pyramidal structure on the wafer surface that could trap the incident light efficiently. Then the surface morphology and the optical surface reflection of the textured wafers were measured by FESEM (JSM-7600F) and SRM system. After that, phosphorous atoms were diffused into the p-type silicon wafers using phosphorous oxychloride by a high-temperature diffusion furnace (MRL PHOENIX, USA) to form the p-n junction. In this experiment, six (6) silicon wafer samples were doped with six different diffusion time such as 5, 10, 15, 20, 25, and 30 min respectively. The change of doping concentration with doping time was identified by measuring sheet resistance using four-point probe method. The sheet resistance of the wafer was measured from the five different positions of the doped wafer surface which have been already discussed elsewhere [11,12]. The P-type Si wafers before and after phosphorous diffusion are shown in Fig. 1 (a) and (b).

For contact resistance measurement, front and back side of the solar cells were metalized with silver and aluminum paste respectively using a TLM based printing screen [20,21]. The solar cell after screen printing is shown in Fig. 1(c). The screen-printed solar cells were placed in a preheated oven at 150 °C for 10 min so that the paste gets attached well to the wafer surface. Then the rapid thermal annealing (RTA) of screen-printed cells was performed at a maximum temperature of 820 °C which provided ohmic contact between the silver/aluminum and silicon wafers. Finally, the front and back contact resistances of the solar cells were determined using transmission line method (TLM).

## Results and discussion

### SEM analysis of textured wafer

To fabricate efficient silicon solar cell, surface texturization plays a vital role to reduce optical surface reflection by forming randomly distributed pyramid structure on the silicon wafer surface [22–24]. The textured wafer surface was analyzed by FESEM and the SEM images before and after texturization are shown in Fig. 2.

It is observed from Fig. 2(b) that, after texturing the wafer surface was fully covered with almost uniformly distributed pyramid structure. The formation of these pyramids was due to the anisotropy of the etch solution i.e. different crystal orientations are etched at different rates [25–28]. The pyramidal surface particularly plays a dominant role to reduce the optical surface reflection and favorable for efficient solar cell fabrication [23].

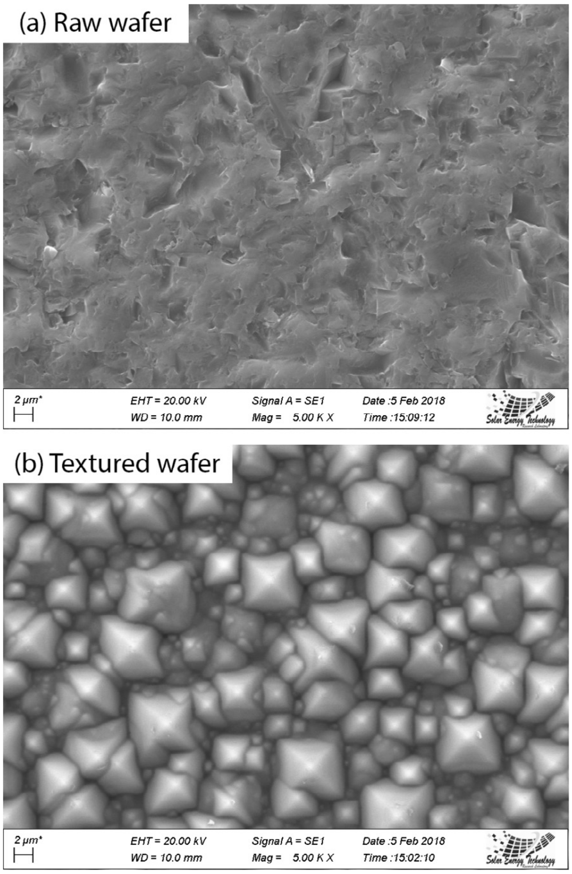

**Fig. 2.** SEM images for (a) raw wafer, and (b) textured wafer.

### Analysis of surface reflection

Surface reflectance of the textured wafer was measured by collecting reflected light from the wafer surface as a function of wavelength using the surface reflectance measurement system. The graphical representation of optical reflectance data for the raw and textured wafers is shown in Fig. 3(a).

Fig. 3(a) shows that the percentage of reflectance decreases with increasing wavelength up to 500 nm and becomes almost constant between 500 and 1000 nm. Further increases of wavelength, the percentage of reflectance increases. It is observed that in the visible wavelength range (450–1000 nm), the reflectance decreases and the

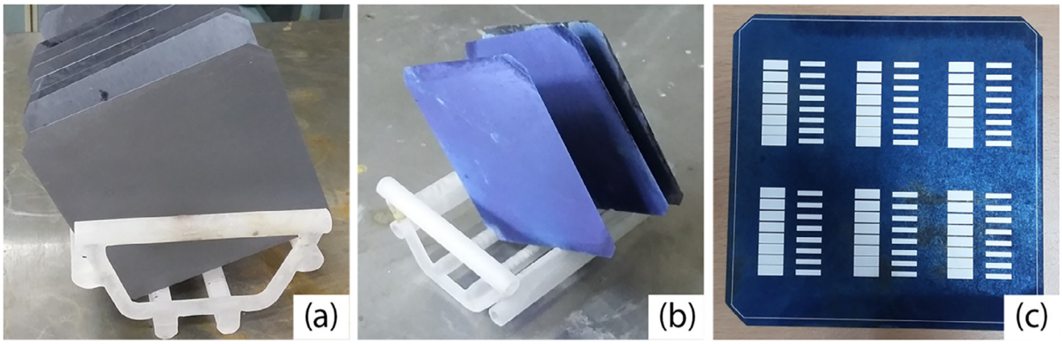

**Fig. 1.** (a) Raw (undoped) wafers, (b) phosphorous doped wafers, and (c) TLM based screen printed solar cell.