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c-Si solar cells formed from spin-on phosphoric acid and boric acid

Akash Yadav [a], Gajendra Singh [a], Reza Nekovei [b], R. Jeyakumar [a, b, *]

[a] Physics of Energy Harvesting Division, National Physical Laboratory, Dr. K. S. Krishnan Road, Pusa Campus, New Delhi 110 012, India
[b] Department of Electrical Engineering, Texas A&M University–Kingsville, 700 University Blvd, Kingsville, TX 78363, USA

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ABSTRACT

This paper reports the fabrication of c-Si based solar cells using spin-on dopants. Solar cells were developed by texturing both surfaces of the c-Si, and forming the p–n junction by spin-coating the n-type dopant followed by rapid thermal processing (RTP). For back surface field formation on the rear side, a similar spin-coating step was undertaken for one cell and e-beam Al deposition for the other. In the case of double-sided spin-coated cell, simultaneous p–n junction and back surface field were formed in one RTP cycle. Without using high performance features in the device, double-sided spin-on doped cell showed V_{oc} of 600 ± 0.01 mV, J_{sc} of 33.1 ± 0.03 mA/cm^2, FF of 74.26 ± 0.06% and efficiency of 14.74%. As compared to single-sided spin-on doped cell, an improvement in efficiency of about 1.3% has been obtained which can be attributed to boron back surface field. Double-sided spin-on process significantly reduces thermal budget and improves throughput. Besides texturization, high efficiency features have not been used in the device. The results clearly demonstrate that c-Si based solar cells are potentially cost effective to manufacture.

1. Introduction

The emitter diffusion in c-Si wafers using phosphorus oxychloride ($POCl_3$)/diffusion furnace is a well established traditional method in the photovoltaic industry. The $POCl_3$ manufacturing process requires a high thermal budget for an extended period of time which degrades bulk lifetime. The cost versus efficiency ratio of traditional bulk crystalline silicon (c-Si) based solar cells are very high due to manufacturing costs associated with the thermal budget and various processing steps. To lower the cost versus efficiency ratio, manufacturing process requires low thermal budget and high throughput. In the spin-on method, spin-coating, low temperature curing, and emitter formation ~975 °C takes a total of 6 min, whereas in the existing (conventional) method, $POCl_3$ diffusion process around 975 °C takes up to 60 min. Therefore, a high throughput can be achieved using spin-on method. Another advantage is that spin-on method requires very low thermal budget. Cost reduction is mainly depends on the improvement in cell efficiency and fabrication methods.

In the traditional p–n junction c-Si solar cell fabrication, emitter is formed in two steps at a high temperature diffusion of n-type dopant (phosphorous) into the surface of boron doped p-type c-Si wafer. That is, for emitter formation, pre-diffusion process involves a high temperature of ~950 °C for 20–30 min followed by a drive-in dopant process that determines the junction depth requires the same temperature for about 20 min. These two processes in themselves entail a high cost/watt of solar power generated due to high thermal budget for emitter formation. By contrast, other technologies, such as hydrogenated amorphous Si (or a-Si:H) [1] and polymer based solar cells have lower fabrication costs, but concomitantly lower performance parameters too.

As mentioned above, using spin-on dopant process, high throughput can be achieved, since as compared to the traditional diffusion furnace method, spin-coating and simultaneous p–n junction and back surface filed formation by RTP requires much less time for cell fabrication. Simultaneous emitter/BSF formation in one RTP cycle has been reported with 12.8% efficiency [2]. The simultaneous RTP process significantly reduces thermal budget, cost/efficiency ratio of the solar cell and suitable for industrial mass production. By identifying a simple processing condition, reasonable efficiency has been obtained, which does not require high performance features such as anti-reflection coating, rear side patterned dielectric/reflector, local back surface filed, photolithography etc. that are normally required to achieve a comparable performance [2].

* Corresponding author. Physics of Energy Harvesting Division, National Physical Laboratory, Dr. K. S. Krishnan Road, Pusa Campus, New Delhi 110 012, India.
E-mail address: ramanuj@nplindia.org (R. Jeyakumar).

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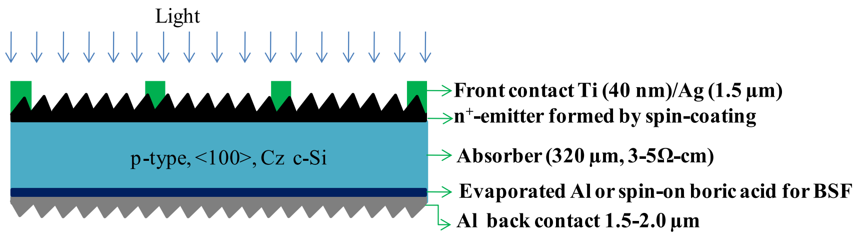

Fig. 1. Schematic diagram of completed p^+–p–n^+ type c-Si solar cell. Shadow mask was used for Ti/Ag top contact. At the rear side, for back contact, blanket Al was deposited by electron beam evaporation.

There is a significant difference between our previous reported work [3] and the current work. In the previous work, results on two types of c-Si solar cells were presented. For both cells, P_2O_5/diffusion furnace was used in emitter formation and no spin-on dopant was used for emitter formation. Both these cells were identical except the BSF region. In one type, BSF was formed by blanket Al deposition followed by RTP, whereas in another type, BSF was formed by spin-coating of boric acid, followed by RTP.

In the current work, for cell 1, phosphoric acid was spin-coated on the front side, followed by low temperature curing and RTP to form the p–n junction and a phosphosilicate glass (PSG) layer removal process. This was followed by e-beam evaporation of Al on the back surface followed by RTP to form BSF. For cell 2, phosphoric acid and boric acid were spin-coated on the front and back surfaces, respectively, to form a p–n junction and BSF. Therefore cell 2 was a double-sided spin-on solar cell, while cell 1 was single-sided (i.e., top side) spin-on solar cell. For device fabrication, diffusion furnace was not used in the current work.

Single-sided spin-on doped/spray doped cells [4–16] with Al-BSF and double-sided spin-on doped cells with boron-BSF has also been reported [2,17,18]. Boron BSF has some advantages over Al-BSF [3,11]. In general, BSF introduces p^+-p (high-low) junction and acts as a potential barrier to minority carriers. High-low junction reduces surface recombination, and hence enhances V_{bi} and V_{oc}.

In Section 2, device fabrication details for single-sided spin-on cell having Al-BSF and double-sided spin-on cell having boron-BSF are described. Results and discussions are presented in Section 3.

2. Experimental

c-Si based p–n junction solar cells were fabricated with the structure Al (bottom)/p^+–Si/p–Si/n^+–Si/Ti/Ag on as-cut (both side unpolished), both side textured, <100> oriented, p-type c-Si wafer with 3–5 Ω-cm resistivity. Cross-sectional schematic diagram of fabricated cell is shown in Fig. 1. About ~320 µm thick, 2″ c-Si wafer was used in this work.

After saw damage removal and surface texturization [3,19–22], fabrication was performed as follows: For cell 1, phosphorous dopant source was spun onto the front side at 6000 rpm for 1 min and cured at various temperatures between 100 and 350 °C for 3 min in a furnace under nitrogen ambient. Then emitter was formed by RTP annealing at 975 °C. PSG formed during emitter formation was removed by 10% HF dip. Al deposition on the rear side followed by RTP at 900 °C forms Al-BSF at the rear side.

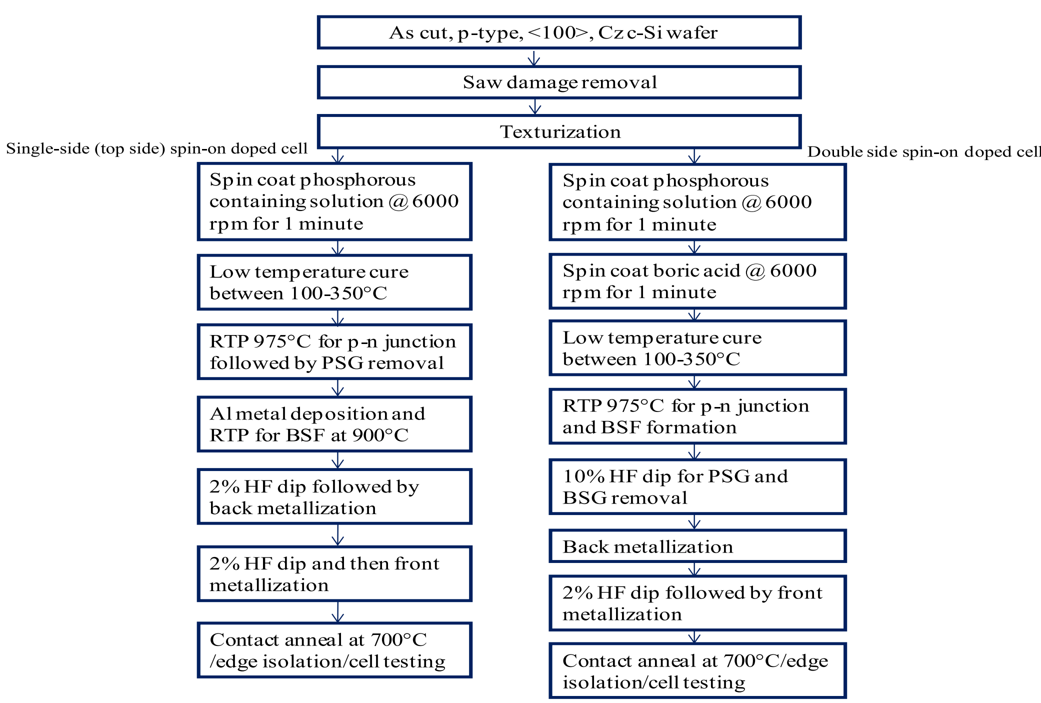

Fig. 2. Flow chart shows the fabrication processes for single-sided spin-on solar cell and double-sided spin-on solar cell.