BORON SPOTS INDUCED SHUNTS

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ABSTRACT

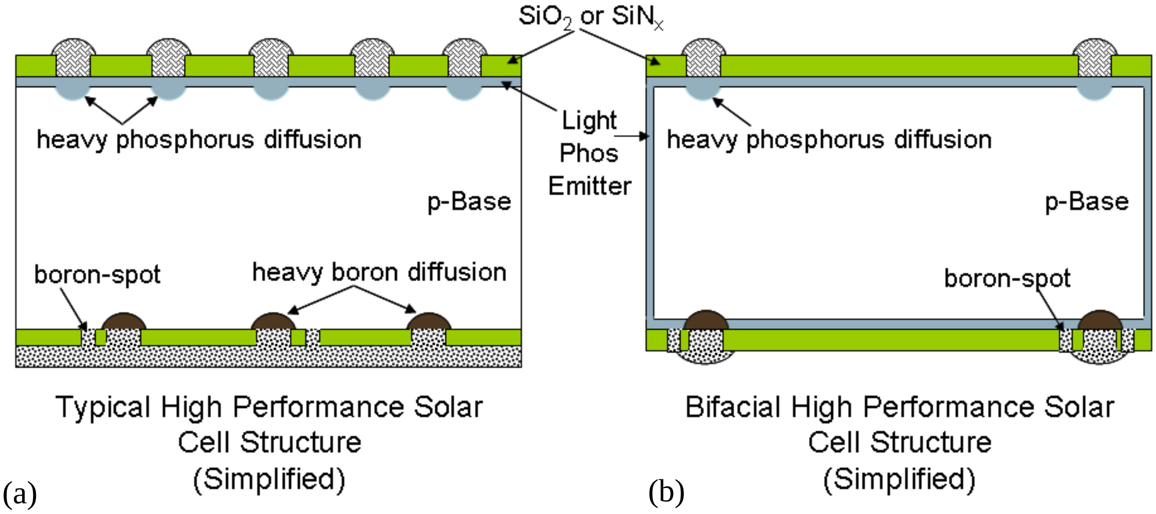
Various types of shunt can occur in solar cells, including process errors, defects, tunnel shunts between adjacent opposing diffusions and pinholes in insulating dielectric layers used to separate opposite-polarity regions. We have found that boron diffusions into small windows in dielectric layers generate pinholes in the dielectric layers following the removal of borosilicate glass (BSG). These "boron-spots" lie close to the edge of the diffusion windows. If a phosphorus diffused region underlies the dielectric then subsequent metallisation can short circuit the two regions.

INTRODUCTION

The presence of low shunt resistance in a solar cell reduces fill-factor and output power. In severe cases, reduced open-circuit voltage also occurs. Low shunt resistance not only degrades the solar cell performance, but also makes the development and the optimization of solar cells difficult since it masks much of the information in the IV curves that can be used for further characterisation. Shunts have been observed in many types of solar cells and for many reasons, including laser scribing damage [1-3], tunnelling effects [4] due to juxtaposition of opposing diffusion regions (n^+ and p+) , in devices passivated with a floating junction at the rear of the cell [5-6], and in devices with an inversion layer induced by a dielectric layer (e.g. SiN_x), with high fixed positive charges, connecting the front metal grid (e.g. n+) and rear metal (e.g. p+) [1, 7-8].

BORON SPOTS

Boron spots are the name we give to small pinholes formed in masking dielectric layers such as SiO_2 or SiN_x following boron diffusion from boron tribromide into small dielectric windows. These boron spots lie adjacent to the edges of the boron diffusion windows as shown in Figure 1. In high performance solar cells (Figure 1a) the presence of boron spots can cause a high recombination rate to occur where the rear metal contacts undiffused silicon. In bifacial solar cells (Figure 2b) the presence of boron spots close to the edge of boron contact windows can cause shunts following subsequent metallisations if a phosphorus diffusion underlies the boron spots.



(a) Typical High Performance Solar Cell Structure (Simplified)

(b) Bifacial High Performance Solar Cell Structure (Simplified)

Figure 1: Boron spots in typical high performance solar cell (a) and bifacial solar cell (b).

Boron spot formation is illustrated in Figure 2. Following the formation of a diffusion mask comprising SiO_2 (20 nm) and SiN_x (90 nm) on a silicon wafer, small windows (0.2 x 5.5 mm) were opened in the SiO_2/SiN_x stack by photolithography (silicon dioxide masks produce similar results). Boron diffusion (20 Ω/□) into the windows from a boron tribromide source was performed at 1000°C for 30 min. Boron glass deposited on the dielectric layer during the boron diffusion was removed by etching in 10% HF for 4 min. Following the boron glass etch, a high density of pinholes ("boron-spots") was observed in the dielectric layer immediately adjacent to the window. If a phosphorus diffusion underlies the dielectric layer, then subsequent metallisation by either electroplating or evaporation can join the two opposing diffusions, causing a shunt as shown in the Figure 2 (iv).

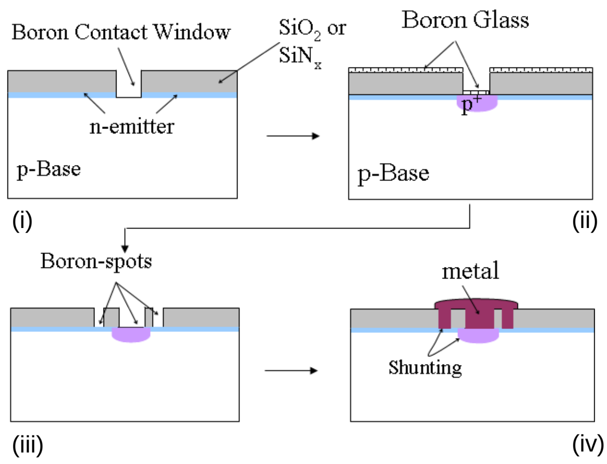


Figure 2: Generation of boron-spots after the boron diffusion (not to scale). (i) boron contact windows opened after SiO2 or SiNx deposition, (ii) boron diffusion into contact windows, (iii) boron-spots generation following BSG removal, and (iv) subsequent metallisation contacting the phosphorus diffusion through the boron spot.

Investigation of Boron Spots

Immediately after the boron diffusion, boron spots are not seen in the dielectric layer. However when the samples are deglazed in 10% HF to remove borosilicate glass (BSG), the spots become visible (Figure 3). Their ability to cause increased recombination (as illustrated in Figure 1(a)) implies that the spots are not boron-diffused, and hence form after the boron diffusion – presumably during cooling of the wafer from the diffusion temperature.

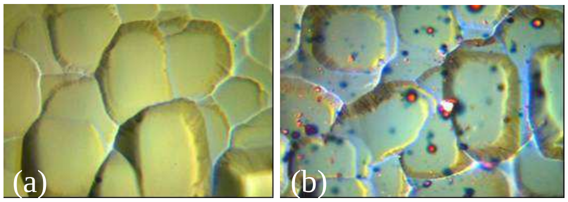


Figure 3: Dielectric layers inspected after the boron diffusion (a) and after the BSG deglaze (b).

The boron spots are generally clustered close to the boron diffusion windows - the density of boron spots declines rapidly with distance from the windows as shown in Figure 4.

To further confirm that the boron spots are indeed pinholes in the dielectric layer, which are formed following the boron diffusion, (100) oriented silicon wafers with boron spots were deglazed and then subjected to etching in an alkaline solution of tetramethylammonium hydroxide (TMAH or $(CH_3)_4NOH$) at 90 °C for 3 min. This etch condition would remove 3 microns of silicon from a (100) oriented wafer. This selective etch attacks silicon dioxide, silicon nitride and (111) oriented silicon surfaces slowly, causing square-based inverted pyramids to form below pinholes in a dielectric. As shown in Figure 5, boron spots formed highly visible inverted pyramids on the sample when etched in TMAH. The slow speed with which TMAH etches silicon dioxide shows that the boron spots constitute pinholes through the entire thickness of the dielectric mask following boron diffusion and deglaze. Etching of samples in TMAH for longer period also made additional small blemishes in the dielectric layer, demonstrating partial formation of defects in the dielectric.

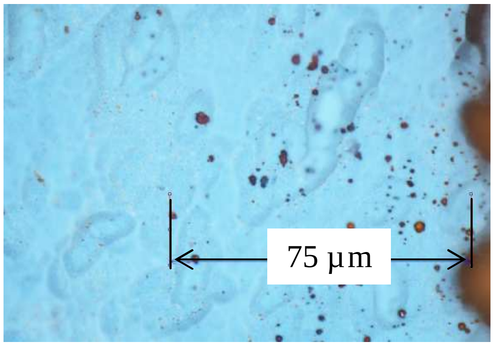


Figure 4: Boron spots within 100 μm from the boron diffused window decorated with silver following silver electroplating.

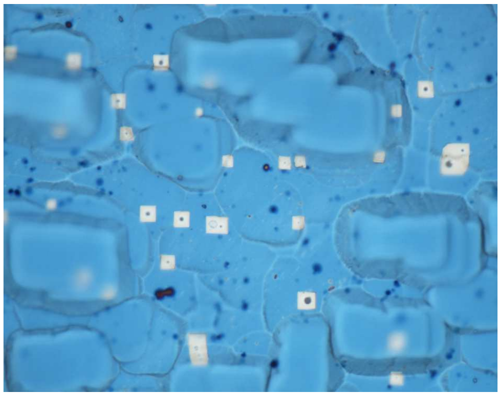


Figure 5: Samples with boron spots after the TMAH etch.

The generation of boron spots is hypothesised to be caused by local stress in the silicon, since boron-doped silicon has a lattice constant that is slightly smaller than that of silicon. This could cause tensile stress in the vicinity of the boron diffusion window and cause pinholes to appear in the dielectric. The generation of boron-spots could also be linked to misfit-dislocations induced by boron diffusion induced defects [9-11]. Neither phosphorus diffusions nor thermal oxidation are observed to cause pinholes in masking dielectrics, which rules out most alternative explanations.

It was also observed that smaller boron windows are more susceptible to producing boron spots than large boron windows, the cause of which is to be investigated further.

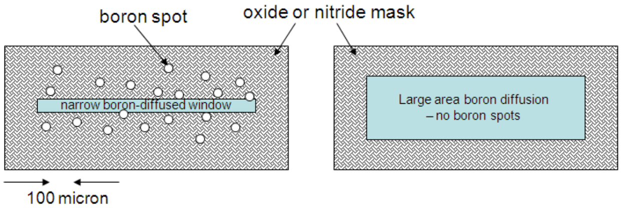


Figure 6: Boron spots in smaller windows as compared to large windows.

AVOIDING PROBLEMS RELATED TO BORON SPOTS

Problems related to boron spots can be ameliorated by the following methods (amongst others):

- Removal of the dielectric layers and regrowth of a passivating dielectric layer, followed by an aligned photolithographic step to re-open the boron contact windows. However, this negates the ability to self-align the metal contact with the boron diffusion, which makes the process more lengthy and complicated.
- Creation of a non-diffused buffer region between boron and phosphorus diffused regions. However, this adds to process complexity.
- Use of large-area boron diffusion windows (hundreds of microns diameter) to minimize boron spot formation rates.
- Reduced boron dose ($>50\ \Omega/\square$), or avoidance of a boron diffusion altogether - but at the cost of increased recombination rates at the p-contacts.
- Laser Isolation shunt recovery [12-13]. However, laser isolation causes crystal damages in the cells leading to high carrier recombination affecting the cell conversion efficiency [14-15] – particularly if left unpassivated as it is the end of the fabrication process.
- Confinement of metal contacts to well-within the boron-diffused region.

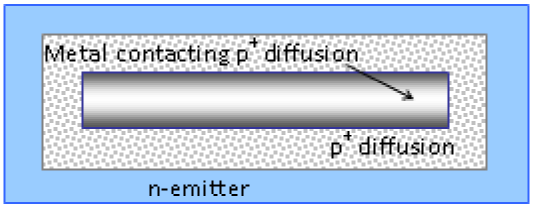


Figure 7: A large area boron window, in which the metal is confined well away from phosphorus emitter.

CELLS FABRICATION

The impact of boron spots on cell performance is illustrated using miniature silicon solar (MSS) cells having a dimension of 2.5 x 8 mm, which are being fabricated to be used in conjunction with a tandem cell stack [16]. The role of the MSS, as one of the cells in the tandem stacks, is to absorb photons in the energy range 1.42 – 1.1 eV.

The MSS cell (Figure 1(b)) has an active emitter wrapped around the entire cell except for the p-contacts at the rear of the cell, to increase the current collection in the absence of texturing due to the need to propagate the light, not absorbed by the MSS cell, to the underlying cell in the tandem stack. The cells were surrounded by a thin oxide (20 nm) for passivation purpose and a nitride layer (90 nm) for anti-reflection. The cell has negative contacts at the sunward side and positive contacts at the rear of the cell. Heavy diffusions are incorporated directly beneath the contacts to minimise contact recombination and contact resistance. The fabrication of MSS cells is described elsewhere [17].

Shunt formation paths for MSS cells include:

- Shunts induced by metallisation straddling the opposing n and p^+ diffusions
- Tunnel shunts between the rear p^+ diffusions and the adjacent n-emitter diffusions
- Boron-spot.

As shown in Figure 1(b), the presence of boron spots adjacent to boron windows, coupled with the existence of phosphorus diffusion under the boron spots, could lead to low shunt resistance following the subsequent metallisation. Excluding the boron diffusion from the cell fabrication process could circumvent the problems, at the cost of increased recombination rates at the p-contacts.

MSS cells were processed with and without boron diffusions. Samples were then metallised including electrolytic silver plating, sintered, diced and I-V tested. 1-sun current-voltage curves for cells fabricated with or without the boron diffusion are shown in Figure 8. Cells fabricated with boron diffusions exhibited shunting and reduced performance, while cells without boron diffusion were free of shunting. The cause of the shunt is connection of the p-type metallisation with the adjacent phosphorus diffusion via boron spots.

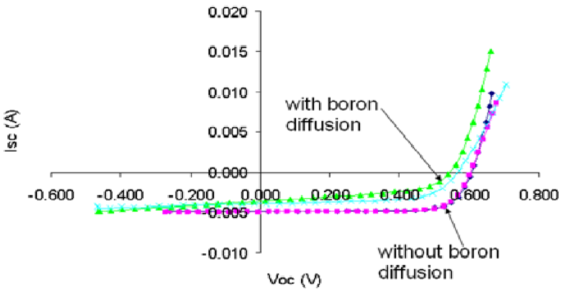


Figure 8: Cells fabricated with or without boron diffusion.

CONCLUSION

Boron diffusion into small dielectric windows followed by the removal of the diffusion glass creates boron spots, which are pinholes adjacent to the windows right through the dielectric layers (SiO_2 or SiN_x). Boron spots are not diffused with boron. They cluster near (<100 µm) to the boron contact windows, and the density of boron spots declines quickly with distance from the window edges. No pinholes are observed in dielectric layers following phosphorus diffusions. If a phosphorus diffusion underlies the boron spots then subsequent metallisation could short two opposite diffusions together. Generation of boron-spots is hypothesised to be linked to the reduced lattice constant of boron doped silicon.

ACKNOWLEDGEMENTS

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