Boric acid solution concentration influencing p-type emitter formation in n-type crystalline Si solar cells

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Abstract. Boric acid (BA) is a spin on dopant (BSoD) source which is used to form p⁺ emitters in n-type c-Si solar cells. High purity boric acid powder (99.99% pure) when mixed with deionized (DI) water can result in high quality p-type emitter with less amount of surface defects. In this work, we have used different concentrations of boric acid solution concentrations to fabricate p-type emitters with sheet resistance values ≤ 90 Ω/□. The corresponding junction depths for the same are less than 500 nm as measured by SIMS analysis. Boron rich layer (BRL), which is considered as detrimental in emitter performance is found to be minimal for BA solution concentration less than 2% and hence useful for p-type emitter formation.

1. Introduction
Boron (B) diffusion during p-type emitter formation results misfit dislocations due to atomic radii mismatch of B and Si [1-3] and forms the Boron rich layer (BRL) [4-6] when the B dopants on the emitter surface shows more rate of diffusion of B into the Si. BRL deteriorates the emitter properties and should be avoided [7].

Different B dopant sources are used for p-type emitter formation with an objective to lower the formation of BRL [8]. Boric acid (BA) spin on dopant source is one of them which does not require any safety precautions nor extra masking steps unlike mostly used BBr3 liquid dopant source [9,10]. In this work, we have studied the influence of different BA solution concentrations on different parameters of the emitter including BRL formation and study of bulk lifetimes. The emitters are fabricated with high purity (99.999%) boric acid solutions with concentrations ≤ 5% [11] and are optimized for different sheet resistance values with varying BRL thicknesses on the emitter surface.

2. Experimental approach and characterizations
Czochralski (CZ) n-type c-Si wafers with 1-5 Ω-cm resistivity and <100> orientation are used for the experiments. The Si surface is made hydrophilic after treating the surface with piranha solution. Then the BA dopant source is deposited by spinning at 3000 rpm for 20 seconds and just after that followed a baking step to avoid moisture trapping. The diffusion is carried out at temperature range 850°C to 950°C and accordingly different doping concentrations along with different junction depths are obtained. Secondary ion mass spectroscopy (SIMS) analysis is used to see the B doping profiles and corresponding junction depths.
For bulk lifetime measurements, \( n \)-type <100> Float zone (FZ) wafers with 1-5 \( \Omega \)-cm resistivity are used for the same diffusion conditions. Quasi steady state photoconductive (QSSPC) lifetime decay is used for lifetime measurements.

3. Results and discussion
SIMS analysis of the samples optimized for sheet resistances \( \leq 90 \Omega/\square \) is shown in Figure 1. The profile shows higher boron concentration, of the order of \( 10^{22} \) atoms/cm\(^3\) for the samples having BRL on the emitter surface. After removal of BRL by different oxidation techniques, the B concentration gets lowered to \( 10^{20} \) atoms/cm\(^3\). The junction depth is less than 500 nm for all the samples having BRL on the emitter surface. Complete removal of BRL lowers the junction depth to less than 400 nm. Formation of BRL on the emitter surface is \( \leq 20 \) nm for BA solution concentration \( \leq 2\% \). This BRL thickness gets removed completely with in-situ oxidation carried out during ramp down of the diffusion process at 700°C for 20 minutes. However, only in-situ oxidation is not sufficient enough to remove all the BRL thicknesses higher than that and so post diffusion oxidation processes are used.

![Figure 1. SIMS analysis showing different B concentrations for different junction depths corresponding to the diffusions of different boric acid solution concentrations.](image)

An improvement in effective minority carrier lifetimes by more than 2.5 times is seen due to diffusion of different concentrations of BA solutions, an example of the same is shown for 2% BA solution in Figure 2. Presence of borosilicate glass layer (BSG) on the emitter surface improves the effective carrier lifetime and presence of the BRL lowers the lifetimes. An improvement in the carrier lifetime is seen when BRL is removed from the emitter surface.

The bulk carrier lifetime of the starting FZ wafer is 1600±100\( \mu \)s, but degrades to less than half of the initial values due to BA diffusion. With the increase in BA concentration from 1% to 3%, there is an improvement in the bulk lifetime values, but beyond that the value decreases as shown in Figure 3.
4. Conclusion

Different concentrations of boric acid solution results in different thicknesses of boron rich layers on the emitter surfaces with varying junction depths. The effective and bulk carrier lifetimes vary for different boric acid solution concentrations. Boric acid dopant source introduces less diffusion induced defects and has high quality product yield. With suitable process steps, it appears to be a promising technology for emitter formation in n-type c-Si solar cells in near future.

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