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Analysis of laser doping of silicon using different boron dopant sources

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ABSTRACT

Implementation of selective emitter that decouples the requirements for front doping and metallization leads to improve the efficiency of crystalline silicon solar cells. Formation of such an efficient selective emitter using a laser beam with a suitable wavelength is an attractive method.

The present work focuses on the analysis of laser doping of boron using different finite sources such as borosilicate glass (BSG) deposited by PECVD, spin-on solution and BCl_3 gas source. KrF excimer laser (248 nm) was used for the selective doping. The surface dopant concentration and depth, as measured using SIMS, were controlled by variation of the laser fluence, pulse number and dopant source thickness. Depending on the type of BSG source, sheet resistance close to 20 Ω/sq was achieved at the laser fluences in the range, 2.5–5 J/cm^2. The PECVD-BSG layers with a relatively higher thickness resulted in a lower sheet resistance of 20 Ω/sq with a junction of depth of ~1 μm at a moderate laser fluence of 2.5 J/cm^2. In the case of BSG deposited by spin-on source, a deeper junction of depth of ~2.7 μm with a plateau profile of 1 μm was formed at a laser fluence of 3.1 J/cm^2 that resulted in a lower sheet resistance of ~31 Ω/sq. Redistribution of the dopant with pulse repetition was observed for the BSG deposited by BCl_3 gas source.

Pulse repetition at relatively lower laser fluences (>threshold energy) resulted in the best electrical results in combination with a limited laser induced damage in the silicon crystal. Also, multiple laser annealing resulted in redistribution of the dopant profiles in terms of enhanced junction depth.

1. Introduction

Laser processing of semiconductors has been widely used in the field of microelectronics and opto-electronic devices. Particularly, it is prominent in the field of photovoltaics for edge isolation [1], surface texturing [2], grooving [3] and selective doping [4]. It is very attractive in contrast to the conventional thermal processing in terms of throughput, avoiding contamination, etc. Laser processing is localized, well defined and offers a wide range of flexibility to tailor the process parameters to achieve efficient doping. Therefore, it is very attractive and alternative method to expensive photolithographic technique, usually adopted in laboratory cells and to the screen printing technology used for the high efficiency passivated emitter, rear locally-diffused (PERL) solar cells [5]. Such cell structure utilises selective emitter (SE) and localized back surface filed (LBSF) in addition to optimized surface texturing and anti-reflection coating (ARC). A selective emitter (heavily diffused regions underneath the metal contacts) on the front surface minimizes both contact resistance and contact area recombination, whilst the rest of the photoactive area is lightly diffused to improve "blue response". A point contacted structure on rear surface (LBSF for p-type cells) is formed through the dielectric, which passivates the non-contacted rear surface regions and is covered with Al. It is therefore, selective laser diffusion is very efficient to realise SE and LBSF structures suitable for high efficiency cells.

Laser-induced diffusion of boron-/phosphorous in silicon from surface layers containing dopant atoms involves surface melting and subsequent diffusion in liquid phase, resulting in the formation of junction with a depth and sheet resistance depending on the processing parameters. Processing conditions like laser characteristics, physical characteristics/nature of the dopant layers on silicon layers, additional layers, if any, at the interface etc., modify the dopant profile enormously [6]. In this regard, laser doping from solid dopants sources is not only make the process simple, but also enhance the laser energy coupling into silicon due to interference effect. Therefore, it is important to study the laser diffusion characteristics using different dopant source layers. In our earlier investigations, phosphorous diffusion characteristics were studied using spin-on sources, and the advantage of using an intermediate barrier layer as well as its effect on the diffusion kinetics was studied [7].

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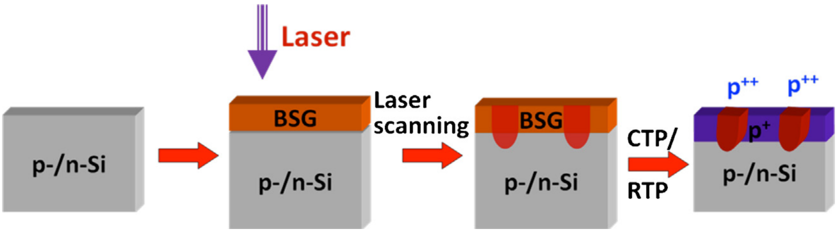

Fig. 1. Schematic representation of the process flow to realize the selective doping of boron using different dopant source layers (BSG) deposited by PECVD, spin-on solution and BCl_3 gas source.

In the present investigation, the doping behavior of boron from different source layers deposited by PECVD, spin-on solution and BCl_3 gas source was studied using KrF laser in a view to achieve efficient doping at lower laser power density to minimize laser induced defects. The boron dopant profiles in silicon as a function of the excimer laser fluence and the pulse number are analysed using secondary ion mass spectroscopy (SIMS) and optical microscopy.

2. Experimental

In the present investigation, n-type ⟨1 0 0⟩ Si with a thickness of ~250 μm and resistivity in the range, 10–40 Ω cm was used to study the diffusion of boron from different source layers. The source layers of BSG were deposited by PECVD, spin-on solutions and BCl_3 in gas phase were used. The samples were coated with 100 nm and 200 nm thick B-doped SiN (SiN:B) layers, which were grown by adding trimethyl borine (TMB) gas flux during the PECVD [8]. spin-on-dopant (SoD) source, PBF, procured from Filmtronics (USA), was spun onto the silicon substrates.

Doping process was carried out using KrF laser of 248 nm with a pulse width of 50 ns at different laser fluences ranging from 0 to 5 J/cm^2. The spot size used in this study is of the order of 5 × 5 mm^2 in order to make it feasible to measure the sheet resistance using four-probe method, and the repetition rate is 1 Hz. Finally, shallow emitter was formed by classical/rapid thermal annealing at 900 °C for 30 min. Similar process was applied for all the structures with different dopant sources in the present investigation. The process flow of realizing selective emitter structures is schematically represented in Fig. 1. The dopant profiles and electrical sheet resistance of the laser doped (LD) emitters were characterized by secondary ion mass spectrometry (SIMS) and four-point probe measurements, respectively with respect to experimental parameters.

3. Results and discussion

The laser doping is a very fast process that involves melting of silicon surface with a depth that is a function of laser wavelength and fluence. The dopant atoms generated by pyrolytic reaction diffuse all over the molten zone prior to the solidification of silicon due to the very high diffusivity of dopant atoms in the liquid phase ($D = 10^{-4}$ cm^2/s) [9,10]. However, the resultant sheet resistance/dopant profile is dependent on several parameters as mentioned in the previous sections. Therefore, in this study, diffusion kinetics of boron was studied with respect to laser fluence and pulse number of the laser source, 248 nm, employing different dopant source layers (BSG) deposited by PECVD, spin-on solutions, BCl_3 gas source and the results are discussed in following sections.

3.1. Optical characteristics of dopant sources

The interaction of laser with silicon involves a complex sequence of processes, such as excitation of optically active states via electronic/vibrational, relaxation of absorbed laser energy involving thermalization, structural and phase transformations due to melting, boiling, generation of crystal defects [11]. These mechanisms should be optimized for both the silicon and the dopant source to achieve efficient laser doping. In this connection, a knowledge of optical reflectance of silicon surface at the laser wavelength in the presence of dopant source layers gives the additional control over the laser diffusion process in terms of laser parameters to be used for the doping. The optical reflectance of Si with different dopant source layers such as BSG deposited PECVD (BSG/PECVD) of 100 nm, 200 nm, BSG/spin-on and BSG/BCl_3 is shown in Fig. 2, and the surface reflectance of these structures at the laser (KrF) wavelength (248 nm) is found to be 85%, 70%, 90% and 61%, respectively. The figure clearly shows interference pattern depending on the nature and thickness of the surface layer. In the case of BSG/BCl_3 and BSG/PECVD (200 nm), more energy could be absorbed by silicon due to the lower reflectance and hence the targeted SR could be achieved at lower laser fluences.

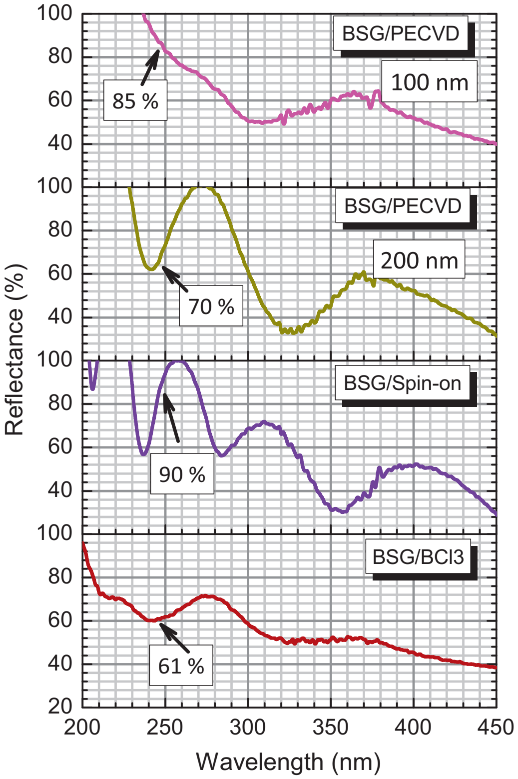

Fig. 2. Reflectance of silicon substrate with the surface dopant source layers of BSG deposited by PECVD (BSG/PECVD) of 100 nm and 200 nm, spin-on sources (BSG/spin-on) and BCl_3 gas source (BSG/BCl_3).