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Overview of phosphorus diffusion and gettering in multicrystalline silicon

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Abstract

This paper gives an overview of phosphorus emitter diffusion and gettering as experienced in multicrystalline silicon solar cell processing. The paper gives a brief summary of the diffusion properties of phosphorus in silicon, explaining the nature behind the characteristic kink-and-tail profiles often encountered in silicon solar cells. Then, phosphorus diffusion gettering is discussed with particular focus to the inhomogeneous nature of multicrystalline silicon, and it is discussed how the abundant presence of dislocations in the areas of the material having a low recombination lifetime can cause only

minor lifetime enhancements in such areas upon phosphorus diffusion. Attributed to dissociation of precipitated impurities in combination with longer effective diffusion lengths of the impurities, it is then seen that even poor areas of multicrystalline can exhibit a noticeable improvement by phosphorus diffusion gettering when applying a lower diffusion temperature for a longer duration.

Introduction

Multicrystalline silicon (mc-Si) wafers are widely used for manufacturing of solar cells due to their relatively low price and high performance. Mc-Si is commonly produced by directional solidification from polycrystalline Si chunks in a quartz crucible, causing relatively high concentrations of impurities to be incorporated in the bulk material [1]. Due to the generally high charge carrier recombination activity of especially transition metals and their precipitates [2], the presence of such contamination may limit the efficiency potential of mc-Si solar cells [3]. The enhancement of the minority carrier recombination lifetime after high concentration phosphorus (P) in-diffusion is now a well-known phenomenon [4], [5], [6]. Referred to as P diffusion gettering, a reduction of the transition metal contamination in the bulk of the material may occur upon P diffusion [7], [8]. The efficiency of such gettering is of crucial importance during mc-Si solar cell processing due to the detrimental effects on the solar cell performance of even relatively small amounts of electrically active transition metals.

During p-type Si solar cell processing, the n–p junction is commonly formed by high concentration P in-diffusion from a gaseous, liquid, or solid source. The emitter profiles then obtained generally consist of the characteristic kink-and-tail shape, in which a high concentration plateau region near the surface is surpassed by a deeper tail at lower concentrations [9], [10]. This anomalous P diffusion has been extensively investigated over several years, and it is argued that a changeover between two different diffusion mechanisms involving point defects with different charge states is responsible for the kink-and-tail profile [11], [12], [13]. The effective diffusivities describing the high and low concentration regions of such kink-and-tail profiles experience considerably different temperature dependencies [11], [13], [14], indicating that the shape of such profiles are largely dependent on the applied diffusion temperature.

P diffusion is, both with respect to emitter formation and gettering of impurities in the material, a crucial aspect of mc-Si solar cell processing. Due to the vast complexity and inhomogeneity of the defect kinetics and interactions experienced during solar cell processing, an increased understanding of the evolution of the material properties upon P emitter diffusion is essential in order for mc-Si to continue to play an important role in Si photovoltaics in the future. This paper investigates the diffusion and gettering response of P emitters in mc-Si solar cells, with particular focus to the inhomogeneous response to high concentration P in-diffusion as well as the influence of the diffusion parameters on the gettering behavior of the material and ultimately on the properties of screen-printed mc-Si solar cells.

Section snippets

Experimental details

All samples investigated in this study were processed on ~1 Ωcm boron (B) doped mc-Si wafers, acquired from commercial production by directional solidification in a quartz crucible and consequent wire sawing. For reasons of comparison, neighboring wafers were selected when appropriate, and divided in sets according to the processing applied. Details on the sample preparations are given when relevant in Section 3 upon discussion of the results.

Mapping of the recombination lifetime was performed…

Fundamentals of phosphorus emitter diffusion in silicon

As mentioned above in Section 1, high concentration P diffused emitters generally consist of the kink-and-tail shape, *i.e.*, having a shallow high concentration region surpassed by a deep tail at lower concentrations. As an example of such emitter profiles, see Fig. 1. The profiles exhibited in Fig. 1 were obtained by P in-diffusion from a spin-on dopant (Filmtronics P509), diffused at different temperatures and durations in an IR heated belt furnace. Upon such high concentration in-diffusion of …

Conclusions

In this paper, an overview of P diffusion and gettering in multicrystalline silicon has been given. The fundamental properties of high concentration in-diffusion of phosphorus in silicon was first summarized, and the dual point defect interactions occurring upon such diffusion was presented. It was also seen that the apparent activation energies of diffusion are largely different between the high and low concentration regions. Furthermore, the spatially resolved response of multicrystalline…

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2022, Materials Science in Semiconductor Processing

Citation Excerpt :

…At present, thermal diffusion of phosphorus (P) using phosphorus oxychloride (POCl3) as gaseous doping source has been widely explored in PV industry [6–18,20–22,25–27]. During formation process of emitter, a highly doped phosphosilicate glass (PSG) layer is firstly formed on the surface of silicon wafer in the pre-deposition step, and then the P atoms in PSG layer diffuse into silicon matrix at a high temperature under the drive force of concentration gradient in the drive-in step [10,21,26–28]. Thus, the P doping profile in silicon prepared by thermal diffusion always exhibits an extremely high concentration at the surface-near emitter bulk [27] where the P atoms tends to act as precipitate defects and cause the Shockley-Read-Hall recombination [29,30].…

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Citation Excerpt :

…The ability to electrically neutralize crystallographic defects is therefore important if a solar cell is to achieve a high open circuit voltage (Voc), fill factor (FF) and efficiency. It has been reported that a low-temperature diffusion (LTD) step following the emitter diffusion can getter metal defects and dislocations in silicon wafers [26–29]. Phang et al.[26] have shown that a 650 °C diffusion following the screen print diffusion can getter significantly more iron.…

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…After STD diffusion, the lifetime of IW is much improved from 2 μs to 31 μs, and Fe concentration is much decreased from 3.1E12 to 2.1E11; And after LDE recipe, the lifetime of IW is improved from 2 μs to 11 μs, and Fe concentration is decreased from 3.3E12 to 1.0E12; The improvement of STD recipe is higher than that of LDE recipe, indicating that the gettering of STD recipe is better than LDE recipe due to highly doped with P. The gettering mechanism should be the segregation into a second phase in which the impurity solubility is significantly higher, such as in a region very highly doped with B or P [9]. All samples were fabricated to cells to analyze the relationship among wafer qualities, emitter qualities and cell properties as shown in Table.1.…

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2016, Solar Energy Materials and Solar Cells

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> …Phosphorous diffusion gettering (PDG) has been proven to be an effective method to improve the Eff of solar cells based on p-type crystalline silicon wafers, especially for multi-crystalline (mc) silicon wafers. It has been revealed that the effective minority carrier lifetime (τeff) of the wafers is significantly improved as the concentration of transition metal impurities is obviously reduced by the PDG process [1–3]. However, PDG for n-type crystalline silicon wafers has not been reported in literatures so much.…

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