

Impact of Metal Contamination in Silicon Solar Cells

Gianluca Coletti

ECN Solar Energy

Westerduinweg 3, 1755 LE Petten, The Netherlands

Email: coletti@ecn.nl, Tel.: +31 224 56 4382, Fax: +31 224 56 8214

Summary

The impact on solar cell performance of transition metals like iron, chromium, nickel, titanium and copper is the topic of this extended abstract. Each impurity has been intentionally added to silicon feedstock used to grow p-type directionally solidified multicrystalline silicon ingots. A state of the art screen print solar cell process has been applied to wafers cut from the bottom to the top of these ingots. Adding 50 ppmwt of iron or 40 ppmwt of nickel or chromium to silicon feedstock, results in comparable solar cell performances to reference uncontaminated material in the range 40% to 70% of the ingot height. Addition of 10 ppmwt of titanium dramatically reduces the efficiency along the entire ingot. Impurities like iron, chromium and titanium cause a reduction in the diffusion length. Nickel does not reduce the diffusion length. On the other hand affects strongly the emitter recombination reducing the solar cell performance significantly. Copper has the peculiarity to impact both bulk recombination as well as emitter recombination.

A model based on Scheil distribution of impurity has been derived to fit the degradation along the ingot. Solar cell performance has been modeled as function of base bulk recombination and emitter recombination. The model fits very well the experimental data and has been also successfully validated. Unexpectedly, the Scheil distribution of impurity along the ingot leaves its finger-print also at the end of the solar cell process. A measure of impurity impact has been defined as the level of impurity which causes a degradation of less than 2% up to 90% of the ingot height. The advantage of this parameter is that comprises the different impurities physical characters in one single parameter, easy to compare.

1. Introduction

The groundbreaking research performed in the 1970's and 1980's by Westinghouse Corp [1] is still used as a reference for the effect of impurities on solar cell performance. However, because of numerous improvements in cell processes since then, and the increased use of directionally solidified multicrystalline ingots instead of single-crystalline ingots, there is a need for updated and more detailed studies.

In this work we study the impact of iron, chromium, nickel, titanium and copper on p-type multicrystalline silicon (mc-Si) ingots, with particular emphasis on the properties of the solar cells and the detrimental effect on

solar cell performance. We believe our studies are representative and useful for assessment of the impact of unwanted impurities in feedstock and crystallisation materials (e.g. crucible, Si_3N_4 coating, construction material, etc.).

2. Method and main results

We intentionally contaminated silicon feedstock with known amounts of single impurities. The amounts of impurities added have been chosen targeting typical levels of impurities in commercial produced directionally solidified multicrystalline silicon wafers [2, 3], while aiming for a noticeable effect on both the wafer and cell levels⁴ in comparison to uncontaminated reference material. The prepared contaminated feedstock has been used to produce several 12 Kg ingots in a Bridgman-type Crystalox DS 250 furnace.

Together with the chosen metal impurity, boron was added targeting a base p-type doping level of about $1.2 \times 10^{16} \text{ cm}^{-3}$. In order to minimize and, even more importantly, to control any unintentional contamination, prime quality polysilicon feedstock, electronic grade crucible made of fused quartz and purified silicon nitride coating have been adopted for the ingot solidification.

A state of the art screen print, $\text{SiN}_x\text{:H}$ firing through solar cell process has been applied to representative wafers along the ingots.

The approach used in this work has the advantage of revealing the impurity impact along the entire production chain from feedstock to solar cells [5, 8].

For all contaminated ingots, the solar cell performances are comparable to the reference uncontaminated solar cells in the range 40-70% of the ingot height [6, 7]. Roughly, the efficiency results along the contaminated ingots can be divided into 3 regions: a bottom region up to 40% where the efficiency is lowered, a middle region from about 40 to 70% where the performance is comparable to the reference, and a top region above 70% of the ingot height where again the efficiency decreases towards the top.

Iron, chromium and titanium show an increase in the bulk recombination. Nickel does not show any increase in the bulk recombination. Even the highest concentration introduced in the feedstock does not cause any effect at long wavelengths IQE. On the other hand, the IQE at 400 nm decreased in the Ni contaminated ingots.

The efficiency reduction increases towards the top of all contaminated ingots due to the impurity segregation in the liquid phase confirming that this reduction is indeed caused by the presence of impurities, and it scales with its concentration as well.

Copper shows an increase in the bulk recombination towards the top of the ingot in a similar way to Fe, Cr and Ti. However an increased recombination in the emitter especially in the top of the ingot is observed.

A model based on the segregation of impurities has been developed to verify that segregation is the leading mechanism explaining the degradation trend observed at the top of the ingots. A first model is based on the degradation due to the reduction in the base bulk diffusion length to model the behavior of iron, chromium and titanium while in a second model the emitter bulk recombination is taken into account to model the behavior of nickel. The combination of the two models is considered to model the degradation of copper. The Scheil distribution of impurities along the ingot is the common mechanism considered in all the models.

The effect of impurities like Fe, Cr, Ti, Ni and Cu has been modelled and the fitting parameter estimated. We use the model to classify the dangerousness of each impurity and to estimate the impact of a certain amount of impurities on the solar cell performance. We define C_L as the concentration of impurities in the molten silicon which results in a $J_{sc} \times V_{oc}$ product with less than 2% degradation with respect to the reference uncontaminated ingot up to 90% of the ingot height. Each impurity has a characteristic value of C_L . The meaning of C_L is that each single-impurity element when present at this level causes the same impact on the solar cell performance along the ingot. It therefore represents a measure of impurity dangerousness. The higher the C_L value, the lower is the impact on the solar cell level.

More information about the results and the model can be found in [8].

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