IMPACT OF TRANSITION METALS IN FEEDSTOCK ON MULTICRYSTALLINE SILICON SOLAR CELL PROPERTIES

G. Coletti[1], P. Bronsveld[1], R. Kvande[2], L.J. Geerligs[1], L. Arnberg[2], H. Habenicht[3], W. Warta[3], C. Knopf[4]

1. ECN Solar Energy, Westerduinweg 3, NL-1755 LE Petten, the Netherlands,
2. Norwegian University of Science and Technology, Alfred Getz vei 2, N-7491 Trondheim, Norway,
3. Fraunhofer Institute for Solar Energy Systems (ISE), Heidenhofstr. 2, 79110 Freiburg, Germany,
4. Deutsche Solar AG, Geschäftsbereich Solar Material, Alfred-Lange-Str. 18, D-09599 Freiberg, Germany

ABSTRACT

The effect of metal contamination in multicrystalline silicon ingots is investigated. The impurities have been added on purpose to the silicon feedstock and the solar cell performance of each contaminated ingots has been compared to a reference uncontaminated ingot. A larger crystal defect density is observed in the top and in the bottom of the contaminated ingots with respect to the reference. Adding 50 ppmw of iron or 40 ppmw of nickel or chromium to the silicon feedstock in p-type ingots, the solar cell performances are comparable to the reference in the range 40 to 70 % of the ingot height. This means that about 10 ppmw of Fe, Cr and possibly Ni will be allowed in the silicon feedstock. This is a value which is at least 2 orders of magnitude larger than previously thought.

1. INTRODUCTION

Due to a shortage in silicon feedstock, the PV industry is considering the option of using less pure silicon, Solar Grade silicon (SoG-Si) for the production of solar cells. Also, SoG-Si made through the direct or metallurgical purification route is approaching the market. Therefore, the PV industry should address the question how cell parameters are affected by, and cell processes can be best adapted to less pure material which are the main topics of our present investigation.

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

In this work we study the impact of Fe, Ni and Cr intentionally introduced in the silicon feedstock on the solar cell performance of p- multicrystalline silicon (mc-Si) ingots in comparison to reference uncontaminated material. We choose to investigate Fe because is a dominant metal impurity in silicon wafers and Ni and Cr because are present in stainless steel.

2. EXPERIMENTAL

Several pilot scale 12 kg ingots have been grown for this study, using a Crystalox DS 250 furnace designed to solidify mc-Si ingots by Bridgman-type directional solidification method. In order to study the impact of the intentionally introduced contaminant, other sources of contamination (e.g. feedstock, crucible, and coating) have been kept as low as possible. Thus, virgin polysilicon, high purity (HP) crucibles [2] and purified Si_3N_4 [3] have been used. The dopant and impurity were introduced in the feedstock charge according to TABLE I.

A full description of the crystallisation and solar cell process and characterisation can be found in Ref. [4, 5].

From each ingot a centre block of 125×125 mm^2 was cut and sliced into 200-240 μm thick wafers, of which 20 representative wafers were processed into solar cells. The p-type solar cell process is the state of the art industrial P diffusion Al-Back Surface Field (BSF) SiN_x:H firing through.

In the following, the p-type and n-type ingots contaminated with Fe (Ni or Cr) will be referred to as p-type Fe (Ni or Cr) and n-type Fe (Ni or Cr), respectively.

Table 1: Ingot descriptions:

Label	p-type	Contamination
Ref	1 Ω×cm	Reference
Fe 50	1 Ω×cm	Fe 53 ppm wt
Ni 40	1 Ω×cm	Ni 40 ppmwt
Cr 40	1 Ω×cm	Cr 40 ppmwt

3. RESULTS

3.1 Solar cells

In Figure 1 the solar cell efficiency is reported as a function of vertical position in the ingot. In the range 40 % to 70 % of the ingot height all the solar cell perform good and at an average value of 98 % cell efficiency in comparison to reference uncontaminated material. In the bottom half and in the top of the ingot, the solar cell performance are reduced due to a

reduction of both $J_{sc} \times V_{oc}$ and FF. From spectral response and reflectivity measurements the internal quantum efficiency (IQE) and the effective average minority carrier diffusion length (L_{eff}) were calculated. The main differences between the references and Fe and Cr doped ingots are in the long wavelength response while for the Ni the differences are in the short wavelength.
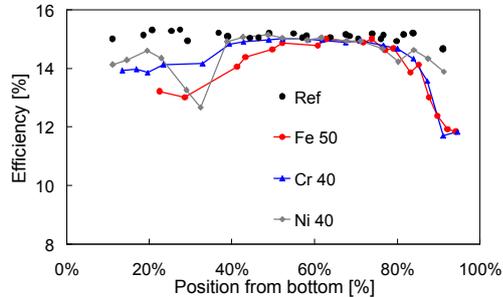

Figure 1. Efficiency versus ingot position from the bottom of the ingot for ingot intentionally contaminated with Fe, Ni, and Cr and reference uncontaminated.

3.2 Crystal Structure

Effective diffusion length maps were carried out on solar cells at different ingot height for each investigated ingot [5]. The L_{eff} maps qualitatively represent the crystal structure (grain boundaries and dislocation density), because high defect density areas show a relatively low L_{eff}. Clearly, there is a difference in the crystal structure development for the contaminated ingots compared to the reference ingot. At the bottom and top of the ingot the crystal defects is higher, both in comparison to about 70 % ingot height in the same ingots, and in comparison to the reference ingots.

3. DISCUSSION

The solar cells of the ingots grown with addition of Fe and Cr results in a lower diffusion length in the bottom and in top which is in agreement with the efficiency reduction in these regions.

For cells from the top of the ingot, as is demonstrated in Ref [5], this trend, can be related to a Scheil-like distribution of impurities.

In case of Ni no reduction in the diffusion length is experienced. Instead the short wavelength response of the IQE is affected. The IQE at 400 nm reduces with the ingot height in the top region. This confirms that its relation with the Ni concentration which segregates towards the top of the ingot during the crystallisation.

In the maps of the diffusion length a difference in the crystal structure development for both the contaminated ingots compared to the reference ingots was observed. The Fe 50 ingots display an increased crystal defect density in the bottom and top and a comparable level of defects at ~70 % ingot height. This

is reflected in the solar cell efficiencies, which are reduced in the bottom and top, but are comparable to the reference at around 70 % height. A similar behaviour is reported for Cr and Ni.

Assuming a segregation dominated performance in the top and excluding the effect in the bottom about 10 ppmw of Fe, Cr and possibly Ni can be allowed in the silicon feedstock. This is a value which is at least 2 orders of magnitude larger than previously thought.

4. CONCLUSIONS

The solar cell performance of Fe and Cr contaminated wafers follows a trend similar to that of the diffusion length as a function of vertical position in the ingot. In the top, this trend can be related to the segregation of impurities through the ingot. In the case of Ni the lower performance in the top are due to a reduced IQE at short wavelength. For all the contaminated ingots in p-type ingots the solar cell performance are comparable to the reference in the range 40-70 % of the ingot height.

In addition we found that the impact of impurities does not only cause a reduction of diffusion length due to interstitial point defects, but also seems to affect the crystallisation process, contributing to a further reduction of the performance of the solar cells [5]. Assuming a segregation dominated performance in the top and excluding the effect in the bottom about 10 ppmw of Fe, Cr and possibly Ni can be allowed in the silicon feedstock. This is a value which is at least 2 orders of magnitude larger than previously thought.

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