

# Relationship between interstitial oxygen, substitutional carbon, resistivity and minority carrier lifetime in metallurgical multicrystalline silicon

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**Abstract.** In this study we try to identify relation between carrier lifetime, resistivity and two main impurities concentration in a p-type upgrade metallurgical multicrystalline (UMG) silicon ingot. Thanks to this relation, we could prevent the Light Induced Degradation (LID) phenomenon and the SiC particles formation which are, respectively, at the origin of Voc losses and shunts in solar cells. So these 2 parameters are important for photovoltaic panels' efficiency. Lifetime measurements are achieved by means of the Microwave Photoconductivity Decay “ $\mu$ w-PCD” technique, and concentration measurements are determined by FTIR. We demonstrate that resistivity variations depend on oxygen's concentration but carbon analyses must be continued.

## Key words

Metallurgical multicrystalline silicon, low-cost, minority carrier lifetime, interstitial oxygen, substitutional carbon.

## Objectives and interests

Silicon based Photovoltaics is a way to convert solar light to electricity. It represents more than 80 % of photovoltaic installation. Its full development involves a drop of module's price and an increase of the raw materials cost.

This induces studies of low cost silicon substrates simultaneously with cells processes optimizations.

In this paper, the upgrade metallurgical silicon is analyzed (UMG). It's a purification of the cheapest silicon, called metallurgical silicon (MG), which has an excess of metallic impurities. This UMG is a good compromise between the raw material and the electronic grade [1]. But in solar cells based on UMG, the light induced degradation is more important [2]. It might be linked to the presence of both boron and interstitial oxygen  $O_i$ .

Our aim in this work is to establish relations between oxygen  $O_i$ , minority carrier lifetime ( $\tau$ ) and resistivity ( $\rho$ ) in UMG wafers before the LID phenomenon to prevent

it. Thus we have performed concentration measurements by FTIR.

In this material, carbon could form SiC particles during crystallization. It seems to be at origin of shunting in solar cells [3]. Moreover, an excess of oxygen with carbon saturation can be expressed by a coprecipitation which will create recombination centers. This could be an efficiency limitation of solar cells [4].

Therefore substitutional carbon, [Cs], analyzes have been also performed by FTIR.

For these tests, wafers have been sawed vertically along the brick to compare the crystallization progress, electrical properties and concentrations parameters.

## Main contributions

Two samples have been chosen and sawed along one UMG ingot. One is placed at 5,5 cm near the crucible, the second is placed closer (at 2 cm near the crucible) to study crucible effects on to the ingot. Concentration measurements by FTIR require thick and polished samples: 1cm thick wafers have been chosen.

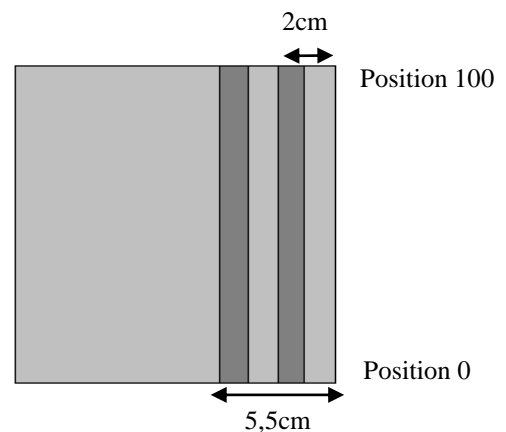


Figure 1: samples in the brick

On figure 1, positions are numbered from 0 (bottom of ingot) to 100 (top of ingot). Measurements by FTIR are made in the center of samples.

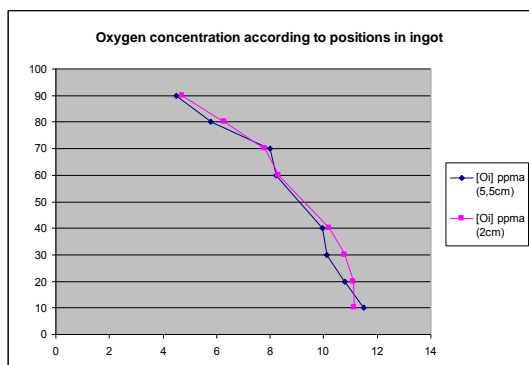


Figure 2: FTIR interstitial oxygen concentration

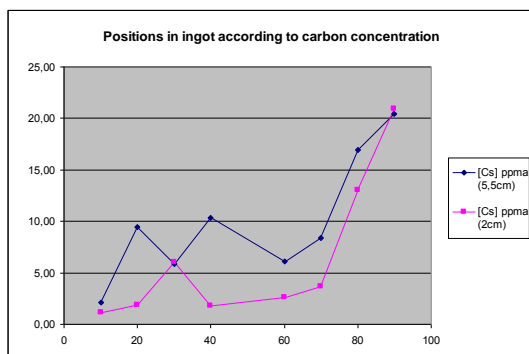


Figure 3: FTIR substitutional carbon concentration

On figure 2, we observe a decrease of interstitial oxygen concentration from the bottom to the top. Curves are similar for both samples. On contrary, [Cs] concentrations increase (figure 3). So, all curves follow the Scheil's law.

Comparisons between samples show that interstitial oxygen concentration is practically the same for both positions. In this ingot, variations don't depend on the brick's width and crucible.

On positions 10 and 20, at the bottom, oxygen is around the solubility limit. Consequently, the probability to have more centers recombination is increased and minority carrier lifetime in this part must be less important.

For carbon concentration, a homogeneous progression has been expected like oxygen's curves. It's not the case. Although the curves evolutions are the same throughout the height, there are some variations in the bottom of the brick. It's interesting to focus on the position 30 where the two samples have the same concentration. In addition, it is noted, in position 80, that substitutional concentrations are over the solubility limit, consequently,

it is expected to have more recombination centers in this part.

To understand why behaviours are not linear, resistivity and minority carrier lifetime mappings have been realized.

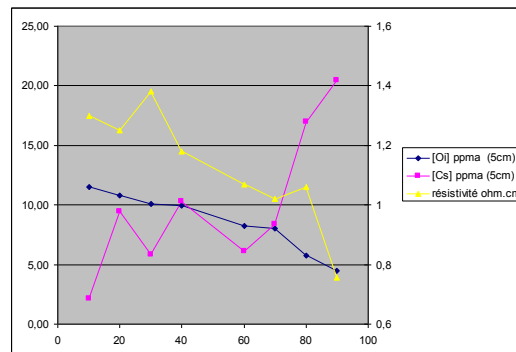


Figure 4: resistivity measurements according to brick's height in sample 1

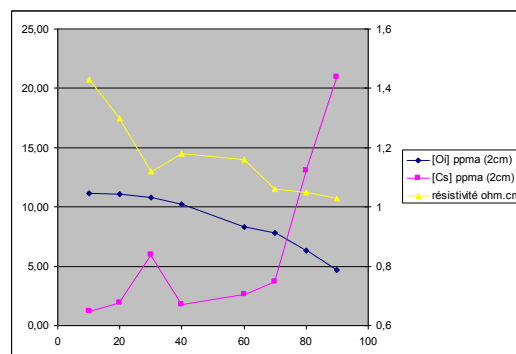


Figure 5: resistivity measurements according to brick's height in sample 2

In these two graphs (figure 4 and 5), resistivities decrease according to the height in the brick. This behaviour is similar to the concentration variation of interstitial oxygen except for 2 positions in the ingot which correspond to peaks variation of substitutional carbon concentration. In position 30, in one side, when peak of [Cs] is down, peak of resistivity is up and, in the other side, it's the opposite. Another peak is noted around the position 80 from the first band and 70 from the second. So, except these peaks where something happen, it seems that resistivity depends on interstitial oxygen [O<sub>i</sub>] concentration.

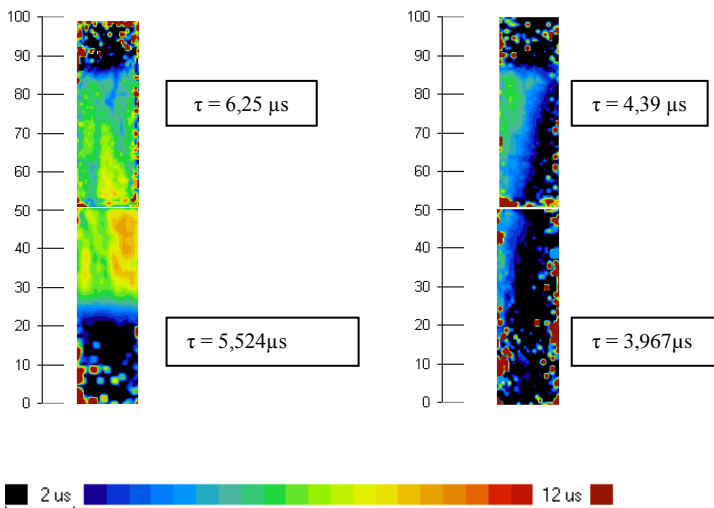


Figure 6: minority carrier lifetime mappings, first sample to 5,5cm of crucible, the second to 2 cm of crucible

The minority carrier lifetime average in the first sample (5.5 cm near crucible) is between 5.5 and 6.25 μs, in the second sample, it is between 3.9 and 4.4 μs (figure 6). As a consequence, there is little difference between two samples. On this figure 6, three parts are identified thanks to a graduation of positions throughout the height. Furthermore, the second sample has “more dark” zone with a low minority carrier lifetime. This is due to its position in the ingot, near the crucible.

In respect to resistivities, peaks around position 30 seems to be explained by a transition zone between a bad lifetime ( $< 2 \mu\text{s}$ ) and a correct lifetime. For position 80 in the first band and for position 70 in the second band, peaks are certainly due to the resistivity measurements which were performed in the band’s center.

In order to explore this hypothesis we plan to realize concentration of [Cs] mappings and to compare them with mobility carrier lifetime mappings.

## References

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