

CONTACTLESS INVESTIGATION OF ELECTRICAL PROPERTIES AND DEFECT SPECTROSCOPY OF MC-SI AT LOW INJECTION LEVEL

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ABSTRACT: With an innovative measurement technique termed “microwave detected photo induced current transient spectroscopy” (MD-PICTS) and “microwave detected photoconductivity” (MDP) it is possible to investigate defects of solar wafers contact less and topographically by evaluating photoconductivity transients detected via microwave absorption. Thus it is possible to obtain the electrical key parameters (e.g. diffusion length, lifetime, non equilibrium mobility) in a contact less, non destructive and topographic way. Wafers from different positions of a Si-ingot were investigated with these methods to obtain a deeper understanding of the observed sharp transition in the electrical properties of wafers prepared from the bottom-, the middle- or the top part of a Si-ingot. It could be shown that there are on the one hand great differences in the defect content of these wafers and one the other hand, varieties in the topographically resolved diffusion lengths and lifetimes. Furthermore, one of the observed defect peaks characterises the thermal donors in p- multicrystalline silicon. By examining this peak it is possible to obtain information on the cooling behaviour of the ingot. Additionally, the destruction free measurement system enables the investigation of process induced defects and also to measure the final solar cell.
Keywords: multi-crystalline silicon, lifetime, defects

1 INTRODUCTION

The main objectives of the photovoltaic industry are the reduction of costs and the production of solar cells with high efficiency. To reduce the production costs, cast multicrystalline silicon (mc-Si) is widely used for terrestrial solar cell applications. The main disadvantage of this material is the large number of defects and impurities which degrade the efficiency of the solar cells.

Furthermore, well established electrical characterisation methods like μ -PCD exhibit several disadvantages. Some of them can be overcome by the development of contact less spatially resolving methods with high detection sensitivity like microwave detected photoconductivity (MDP) and microwave detected photo induced current transient spectroscopy (MD-PICTS). These techniques allow photoconductivity measurements also at very low injection levels. Thus it is possible to obtain a deeper understanding at the differences of the electrical properties of wafers prepared from the bottom-, middle- or top part of a mc Si-ingot.

2 EXPERIMENTAL DETAILS

2.1 Experimental setup

The experimental setup which was used for the MDP and MD-PICTS measurement is already published elsewhere. [1][2]

2.2 Physical back round

Figure 1 illustrates a typical photoconductivity signal.

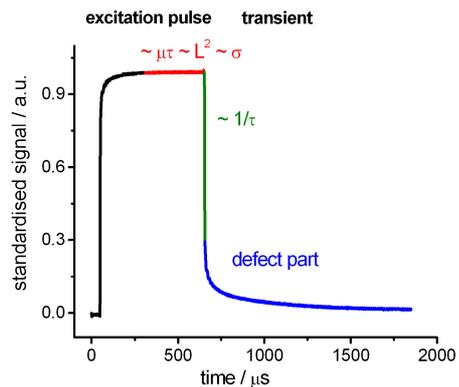


Figure 1: typical photoconductivity signal for a rectangular light pulse, mc-Si wafer

Through band to band excitation (IR-Laser 975 nm for Si) excess carriers are generated, which interact with the microwave penetrating the sample. Therefore the excess carriers can be detected via microwave absorption with a very sensitive microwave detection system.

The height of the photoconductivity signal is proportional to the square of the diffusion length (L) and, due to the Einstein relation, it is proportional to the product of non equilibrium mobility (μ) and lifetime (τ).

The generated carriers can recombine (via recombination centers) or can be trapped by defects. The first part of the transient after the light source is switched off (see figure 1) contains information about the free carrier lifetime. This information is basically also obtainable with μ -PCD, however, usually at much higher injection levels. (Rather low injection levels are, however, typical for typical working conditions of solar cells). Because of the high sensitivity of the detection system, it is furthermore possible to detect the thermal reemission of charge carriers out of defects as a second part of the transient. Such information is not obtainable with e.g. μ -PCD.

The MD-PICTS is derived from analyzing the

transients measured at different temperatures with the help of the double gate technique. Like DLTS one obtains spatially resolved information (activation energy, capture cross section) about defects, however, again in a non destructive way. Furthermore, the investigations are not restricted to deep levels, nor do they require special doping. In contrast to DLTS, with MD-PICTS the defects are filled by carriers from the valence- or conduction band or both. Thus it is possible to obtain information about defects invisible with DLTS.

The MD-PICTS measurements were carried out in the temperature range from 50 to 450 K. The multicrystalline samples were measured with an IR-Laser 950 nm at an optical cw-output of 5,5 mW. The electronic grade silicon samples were measured with an IR-LED with some μ W optical cw-output.

The aim of the MDP measurements is to visualize electrical inhomogeneities in the diffusion length, lifetime and non equilibrium mobility of solar wafers and solar cells which may influence the function of the solar cells. Because of the destruction free measurement system it is also possible to investigate the defects on the same wafer following processing steps.

The spatial resolution is only limited by the diffusion length of the generated carriers and not by the spot size of the excitation source. The use of different wavelengths yields some information about depth profiles of the investigated electrical properties.

The MDP measurements were carried out at room temperature with an IR-laser (975nm) at an optical cw-output of 13 mW.

2.3 Samples

The samples were cut from different parts of a p-type mc-Si ingot. The position of the wafer is indicated for the different MDP-topograms. The specimens are about 270 μ m thick and were measured as cut.

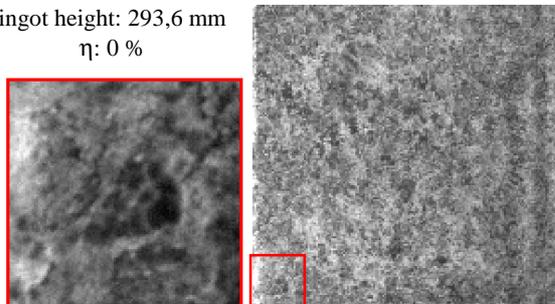
For comparison, electronic grade p-type CZ-Silicon (12-20 Ohmcm) was also measured.

3 EXPERIMENTAL RESULTS AND DISCUSSION

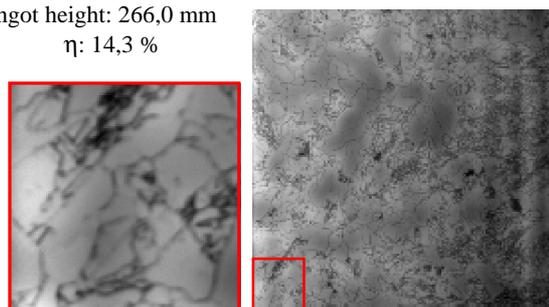
3.1 Photoconductivity maps of a mc-Si ingot

MDP topograms exhibit characteristic differences in the photoconductivity and the effective lifetime of carriers for wafers from different positions in the ingot (figure 2).

ingot height: 293,6 mm
 η : 0 %



ingot height: 266,0 mm
 η : 14,3 %



ingot height: 6,6 mm
 η : 11,9 %

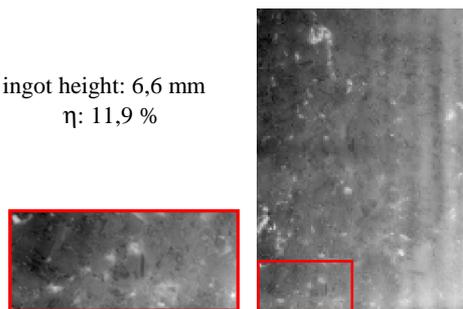


Figure 2: photoconductivity maps of different as grown mc-Si wafers (139,5 x 139,5 mm² size, except ingot height 6,6 mm 99 x 139,5 mm² size)

All wafers are measured with the same spatial resolution (900 μ m for the 139,5 x 139,5 mm² topograms or 200 μ m for the detail maps) but they show dramatic differences in the resolution of the grain boundaries. The diffusion lengths of the generated carriers in the three wafers are quite different. The best resolution occurs in the wafer from the good part of the ingot (ingot height 266,0 mm). The grain boundaries in the wafers from the bottom and the top part of the ingot are not clearly resolvable in both cases, but there are still differences between the two wafers. The photoconductivity in the boundaries of the top wafer is partially higher than in the grains. The reason for this behaviour presumably is a conductivity path along the boundaries. But there exists no clear correlation between this phenomenon and the ingot height or a process of the solar cell fabrication.

It is only possible to detect an effective carrier lifetime consisting of the bulk- and surface lifetimes because it is not feasible to effectively passivate the cut wafers chemically with an iodine alcohol dilution. The measured lifetime correlates with the ingot height as expected. The wafers from the bottom and top of the ingot show an average lifetime below 2 μ s. The wafer of the middle part shows lifetimes at about 5 μ s. However, this lifetime is clearly dominated by surface recombination.

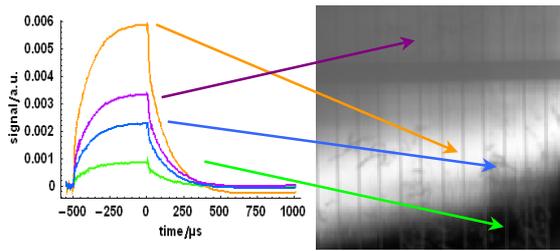


Figure 3: photoconductivity map of a solar cell (ingot height 266,0 mm) with some photoconductivity signals (size 25 x 25 mm², IR-Laser 976 nm, optical cw-output 68 mW)

It was feasible to measure a final solar cell device with the MDP microwave detection system without problems (figure 3). The front- and backside contacts do not disturb the measurements. The photoconductivity transients are characterized by a very striking defect part, which probably originates from shallow defects. Because of this defect part it is not possible to detect a lifetime of the free charge carriers.

By the use of the destruction free measurement tool it is possible to measure the same wafer after different processing steps of the solar cell and to compare the efficiency (η) of the final solar cell with the electrical properties due to the different production steps.

3.2 defect spectroscopy

The MD-PICTS spectra (figure 4) show characteristic differences between the different wafer positions. There is no clear correlation between the temperature position or intensity of peaks in the MD-PICTS spectra and the position of the corresponding wafer in the Si-ingot. The basics of the peak assignment are published in [1].

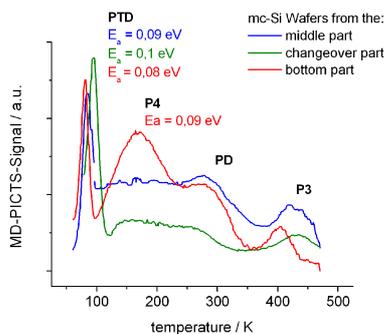


Figure 4: MD-PICTS spectrum for different mc-Si samples (IR-Laser 950 nm, opt. cw-output 5,5 mW)

PTD stands for thermal donor peak. This peak is believed to be due to the well known thermal donors (TDs) in silicon, which cannot be detected by DLTS in p-Si because of the position of the Fermi level. This peak will be discussed in comparison with electronic-grade silicon having shown figure 5.

The peak P4 is only detectable in the wafer from the bottom part of the Si-ingot. Its emission maximum lies at 170 K with an activation energy of 0,09 eV. The atomistic structure of the corresponding defect is not yet known. Because of the low activation energy, the large width of the peak and the position of the corresponding

wafer in the Si-ingot it may be ascribed to defect cluster involving nitrogen.

The presumable origins of this PD peak are dislocation clusters. The PD peak is only detectable as a shoulder. Therefore it is not possible to determine its activation energy. The emission maximum lies between 244 K and 270 K. For annealed ec Si samples a similar peak exhibits activation energies between 0,33 – 0,48 eV and the emission maximum lies between 271 – 295 K depending on the temperature of the annealing process [1]. The concentration of the defect increases with increasing annealing temperature. For mc-Si samples a similar correlation is not possible. The wafer from the middle- part exhibits the highest defect concentration, followed by the wafer from the bottom- and changeover part (changeover means the crossover part between the poorly bottom and the good middle part of the ingot). The reason for this behaviour is probably an overlap with other defects [1][2].

The peak P3 is also detectable in ec-silicon. The emission maximum lies between 423 and 430 K. Neither for mc-Si nor for ec-Si activation energies can be deduced. The origin of the peak may be also a cluster of bulk defects, because different surface treatments do not influence the peak.

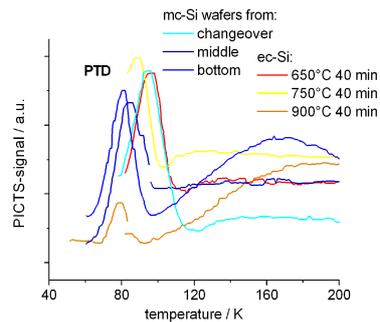


Figure 5: comparison of the MD-PICTS spectrum for different mc-Si samples (IR-Laser 950, nm opt. cw-output 5,5 mW) and wafer annealed ec-Si samples (IR-LED, opt. cw-output some μ W)

The emission maximum of the thermal donor peak (PTD) in mc- Si lies between 80 - 95 K with an activation energy between 0,08 eV and 0,1 eV (figure 4). The different temperature positions of this thermal donor peak correlate with those obtained for electronic grade (ec) Si after different annealing steps (figure 5). In the case of ec-Si the TD-peak shifts its position to lower temperature with increasing annealing temperature. Nearly the same behaviour was found for different wafers with positions of decreasing ingot height in mc-Si. The different positions of the thermal donor peaks in the MD-PICTS spectra can thus be calibrated to measure the cooling behaviour of the ingot. The TD peak of the wafer from the bottom part is equivalent to the peak of ec-Si annealed at 900°C, the PTD of the wafer from the changeover part is common to 650°C annealing and the thermal donor peak of the wafer from the middle part is nearly equivalent to the peak found in ec-Si annealed at 750°C. The discrepancies in the sequence of the mc Si wafers are not yet well understood. Further investigations are going on. It seems that there is no simple correlation

between the wafer position in the ingot and the emission maximum of the TD peak. [1][2][3]

4 CONCLUSION

Both methods MDP- and MP-PICTS are used to obtain a deeper understanding of the observed sharp transition in the electrical properties of wafers prepared from different positions of a Si-ingot. It could be shown with these methods that there are characteristic differences in the defect contents of the different wafers. One peak is only observable in the bottom part and for the other peaks there are differences between the different ingot positions. But there exists no simple correlation between the ingot height and the temperature position of the peaks.

The thermal donor peak allows for information about the cooling behaviour of the silicon ingot. But it is not possible to correlate the temperature position of the peak with the ingot height in a very simple way.

At the same time, corresponding changes in carrier lifetime, diffusion length and photoconductivity are topographically observed.

Even finally processed solar cells can be investigated with the MDP and MD-PICTS detection system.

Because the technique is destruction free and topographic, it is also an ideal tool for inline investigations of process induced defects.

5 REFERENCES

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6 ACKNOWLEDGEMENT

Financial support and the supply of samples by the Deutsche Solar AG, Freiberg, Germany is gratefully acknowledged.