Intensity dependent surface photovoltage used for interface characterization of c-Si surfaces and a-Si:H/c-Si heterojunctions

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Abstract: Bare p-doped wafers of crystalline silicon, c-Si(p), with different insulating passivation layers (SiO_2, SiN), and non-insulating passivation layers (a-Si:H), i.e. amorphous/crystalline silicon heterostructures, a-Si:H(n)/c-Si(p), have been investigated by means of intensity dependent surface photovoltage, ID-SPV. Additionally, numerical computer simulation have been performed. ID-SPV allows to extract the c-Si(p) built-in voltage in case of studying insulating passivation layers with a low interface state density D_{it}. In case of studying a-Si(n)/c-Si(p) heterostructures, V_{bi}^{cSi} can no longer be extracted due to electron injection into the a-Si:H(n) passivation layer.

Key Words: Simulation, Heterojunction, Experimental Methods, Thin Film.

1 Introduction

Amorphous/crystalline silicon heterojunctions, a-Si:H/c-Si, produced by plasma enhanced chemical vapour deposition (PECVD) of ultrathin (5-10 nm) layers of hydrogenated, amorphous silicon layers on a crystalline silicon substrate, attract an increasing interest in order to realize low cost, low process temperature, high efficiency solar cells. The suppression of interface recombination at the a-Si:H/c-Si interface is very important in order to obtain good solar cell performance. This can be done (1) by using adequate wafer pre-treatments, thereby reducing the c-Si interface state density prior to the a-Si:H deposition, (2) by optimizing the a-Si:H deposition conditions, and (3) by applying a post-treatment, i.e. thermal annealing or H_2 plasma passivation. The resulting c-Si build in voltage, V_{bi}^{cSi}, and the a-Si:H/c-Si interface state density $D_{it}(E)$ are the physical quantities, which determine interface recombination. Thus, a fast and non destructive characterization method is needed, measuring V_{bi}^{cSi} and $D_{it}(E)$ prior to the a-Si:H deposition as well as after the a-Si:H deposition. In this paper, we discuss the ability of intensity dependent surface photovoltage (ID-SPV) to give access to V_{bi}^{cSi}.

2 Experimental methods / sample preparation / simulation

The ID-SPV signal of p-doped c-Si(p) wafers before and after the deposition of a 10 nm thick n-doped a-Si:H(n) emitter layer is investigated. Performing intensity dependent SPV, excess carriers are generated in c-Si(p) by a short laser pulse (i.e. at 900 nm wavelength and a pulse length of 10 ns) and the light induced change in surface potential is monitored as a function of laser intensity. Two different series have been investigated: (I) Variation of the c-Si(p) band bending by using c-Si(p) wafers with different resistivity, (II) Variation of the c-Si(p) interface state density by using different wafer pre-treatment procedures prior to the a-Si:H(n) deposition or by using different insulating passivation layers. In order to support the measurements, numerical computer simulations have been performed, using the AFORS-HET simulation program [1]. The simulation is able to reproduce the SPV measurements qualitatively. However, it assumes steady-state conditions in order to calculate the light induced change of the surface potential. These conditions are not reached experimentally, using a laser pulse length of 10 ns. Thus, one cannot quantitatively fit simulated to real measurements.

3 Bare c-Si(p) surface

With increasing wafer resistivity, the c-Si(p) equilibrium band bending increases, if one assumes the same interface state density $D_{it}(E)$. Fig.1 shows the corresponding measured and simulated ID-SPV signal for c-Si(p) wafers with different wafer resistivities.

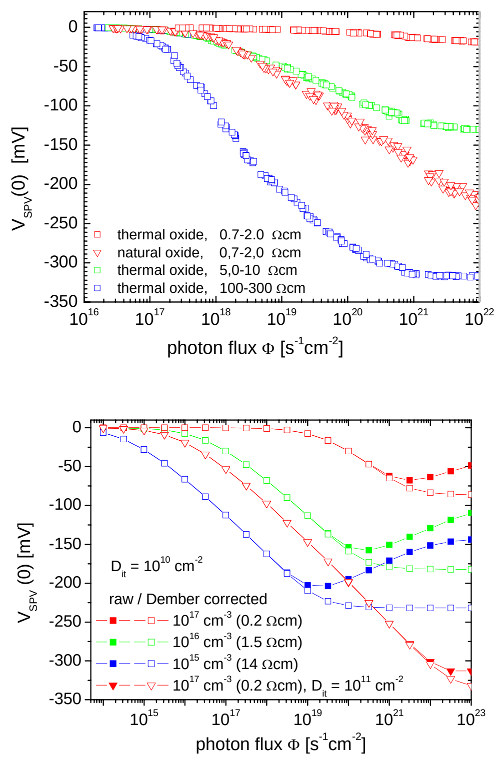

Figure 1: Measured (top) and simulated (bottom) ID-SPV signal for c-Si(p) wafers with varying wafer resistivity.

The Dember corrected ID-SPV signal saturates at high intensities. This saturation directly corresponds to V_{bi}^{cSi}, as the c-Si(p) band bending achieves flatband conditions with increasing laser intensity, see Fig.2. Thus by analyzing the bare c-Si(p) surface by means of ID-SPV, the c-Si(p) build in voltage V_{bi}^{cSi} can be determined. However, this saturation can only be observed if the surface defect state density $D_{it}(E)$ is not too high (compare Fig.1). Additional defects will still be recharged with increasing laser intensity. Therefore the flatband conditions are not observable within the experimentally accessible range (intensity $<10^{22}$ $cm^{-2}s^{-1}$). Thus V_{bi}^{cSi} can no longer directly be extracted, i.e. if $D_{it} > 10^{13}$ cm^{-2}. Experimentally, one observes a saturation of the ID-SPV signal only in case if a thermal oxide is used for passivation of the c-Si(p) wafer, but not if a natural oxide or a SiN layer with a high interface state density D_{it} is used, see Fig.1.

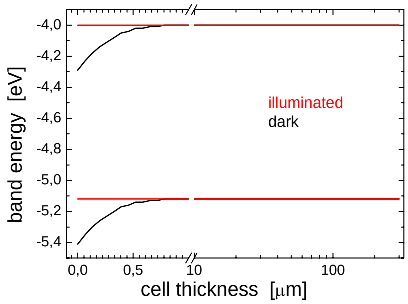

Figure 2: Simulated energy bands of a p doped c-Si(p) wafer in the dark (black lines) and under high illumination ($\geq 10^{21}$ $cm^{-2}s^{-1}$, red lines).

4 a-Si:H(n)/c-Si(p) heterostructures

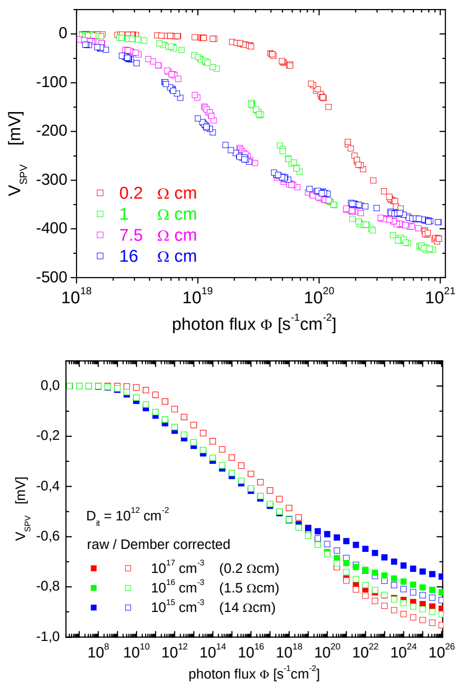

Figure 3: Measured (top) and simulated (bottom) ID-SPV signal for a-Si:H(n)/c-Si(p) heterostuctures with varying wafer resistivity.

It is well known that a-Si:H can provide a good interface passivation with a low $D_{it}(E)$. However, analyzing a-Si:H(n)/c-Si(p) heterostructures, a saturation of the ID-SPV signal is not observed, see Fig.3.

Assuming thermionic emission across the a-Si:H/c-Si interface, this behaviour is also reproduced by numerical simulation (Fig.3). As electrons can now cross the interface as they are injected into the a-Si:H emitter, the c-Si(p) band bending will no longer saturate with increasing laser intensities, but will change from downward bent to upward bent (Fig.4). So the ID-SPV signal is constantly increasing. Thus, the c-Si(p) band bending V_{bi}^{cSi} can no longer be directly extracted in case of studying a-Si:H(n)/c-Si(p) heterostructures.

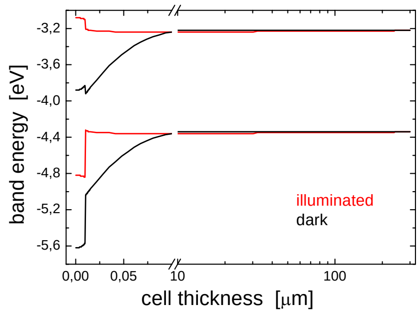

Figure 4: Simulated energy bands of a a-Si:H(n)/c-Si(p) heterostructure in the dark (black lines) and under high illumination (10^{21} cm^{-2}, red lines).

Furthermore, the measured ID-SPV signal for samples with a high wafer resistivity crosses the ID-SPV signal for those with a smaller wafer resistivity, see Fig.3. This behaviour can only be reproduced by simulation if one assumes an a-Si:H/c-Si interface state density in the range of $10^{11}cm^{-2} > D_{it} > 10^{12}cm^{-2}$. Note that within the simulation, steady-state conditions have been assumed in order to obtain the light induced change in surface potential. Measuring a-Si:H/c-Si heterostructures, these conditions are not reached experimentally during the 10 ns laser pulse. Thus the “onset” of the ID-SPV signal differs several orders of magnitude, comparing measurements to simulation.

5 Summary

The intensity dependent surface photovoltage (ID-SPV) signal is quite sensitive to the bare c-Si(p) or the aSi(n)/c-Si(p) interface state density D_{it}. In case of a sufficiently low D_{it} $D_{it} < 10^{13}$ cm^{-2}, the build in voltage V_{bi}^{cSi} of a bare c-Si(p) wafer can be determined by means of ID-SPV, if an insulating passivation layer (like SiO2 or SiN) is used. However, if using a-Si:H(n) as passivation layer, dispite the fact of expecting a low D_{it}, ID-SPV is no longer able to extract V_{bi}^{cSi}. Due to electron injection into the a-Si:H(n) layer, a light induced saturation of the ID-SPV signal can not be observed. Comparing measurements to simulation, one might conclude that for the samples under consideration D_{it} is in the range of 10^{11} $cm^{-2} > D_{it} > 10^{12}$ cm^{-2}.

6 References

[1] Stangl, Kriegel, Schmidt, this conference, PVO281-02