

INVESTIGATION OF THE PASSIVATION PROPERTIES OF  
PECVD-SILICON-NITRIDE LAYERS ON SILICON SOLAR CELLS

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**ABSTRACT:** The frontside of a silicon solar cell is usually passivated by a thermally grown thin oxide. An alternative possibility of passivation is using a PECVD SiN layer. The advantage of a SiN passivation is the qualitatively high surface and bulk passivation- especially for industrial multicrystalline silicon solar cells. In the present study first the interface trap density of PECVD SiN layers is measured with capacitance and conductivity measurements and compared to that of thermal oxides. The PhotoCurrent-Voltage Decay method is demonstrated to measure directly the emitter/frontside recombination velocity of solar cells. The improvement of surface passivation through the PECVD-SiN deposition even on low resistivity, industrial-emitter solar cells is investigated. Finally the frontside recombination of a mechanically V-textured surface is compared to a cell with an untextured front surface.

**Keywords:** Passivation - 1: Silicon-Nitride - 2: Lifetime - 3

**1 DETERMINATION OF THE INTERFACE TRAP DENSITY OF SiN LAYERS USING CV- AND GV-MEASUREMENTS**

The conventional way to measure the quality of a silicon-insulator interface is the determination of the interface-trap-density ( $D_{it}$ ) with capacitance/voltage (CV) measurements [1,2].

Fig.1 shows the quasistatic and high frequency (HF) CV-curves of a silicon - thin thermal oxide - PECVD silicon-nitride (SiN) sample.

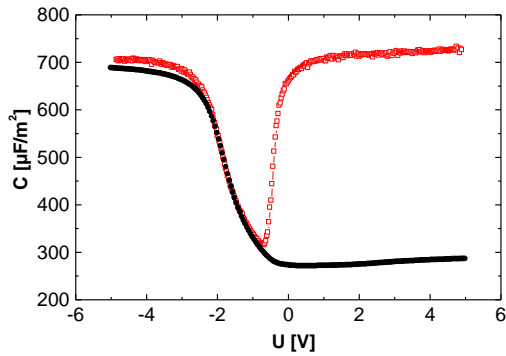


Fig. 1: Quasistatic and high-frequency CV-curves of a silicon-nitride on top of a thermal oxide.

The problem to measure PECVD SiN layers deposited without underlying oxide directly on the silicon surface is the relatively high porosity of the SiN with the consequence of a large leakage current at the quasistatic measurement. A better possibility to measure SiN-MIS-samples is the detection of the conductivity versus voltage and frequency (GV) at frequencies in the kHz range [1]. Fig. 2 shows a HF-CV and a GV measurement of two SiN-MIS samples. In order to extract the  $D_{it}$  from the

conductance signal, the conductance is measured as a function of the voltage and the frequency. The maximum of the conductance at a fixed bias voltage is proportional to the  $D_{it}$  at this bias voltage.

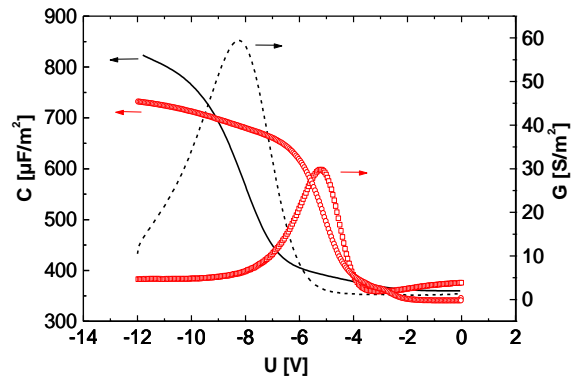


Fig. 2: HF-CV (left axis) and GV curves (right axis) of an unannealed (solid and dashed lines) and an annealed (data points) SiN-MIS sample. After the annealing the conductance peak is lower and appears at a smaller negative voltage.

Tab. 1: CV-results. Fixed charge and interface trap density of a typical thermally grown oxide, a PECVD SiN layer and a combination of both layers.

Layer	$Q_{ss}$ [cm <sup>-2</sup> ]	$D_{it}$ [cm <sup>-2</sup> eV <sup>-1</sup> ]
thermal oxide	$2.5 \cdot 10^{11}$	$1.3 \cdot 10^{10}$
PECVD SiN	$3.5 \cdot 10^{12}$	$1.5 \cdot 10^{11}$
th. Oxide+SiN	$4 \cdot 10^{11}$	$4 \cdot 10^{10}$

Table 1 shows the result of our measurements on thermally oxidized silicon, SiN deposited on top of a thin (10 nm) thermal oxide and SiN deposited directly on the silicon surface.

The SiN on top of a thin thermal oxide does not change the fixed charge ( $Q_{ss}$ ) and the  $D_{it}$  of the thermal oxide. The silicon-SiN interface shows  $D_{it}$  one order of magnitude higher than the thermal oxide. The fixed charge is one order of magnitude higher, too. This large fixed charge results in an effective field effect passivation, which lowers the surface recombination velocity [3].

In the screenprinting solar cell process which is applied after a SiN film is deposited on the cell, the front metallisation is printed on the insulating SiN and an annealing step at temperatures around 800°C fires the metallisation through the SiN layer. The influence of this annealing step on the interface properties of the Si-SiN is shown in Fig. 2. The data points are the CV and GV curves of the annealed sample in comparison with the unannealed sample (solid and dashed lines). The curves of the former specimen are shifted to lower negative values, which means a reduction of the fixed positive charge. But the conductivity peak is lowered, too. The  $D_{it}$  is therefore reduced in the annealing step.

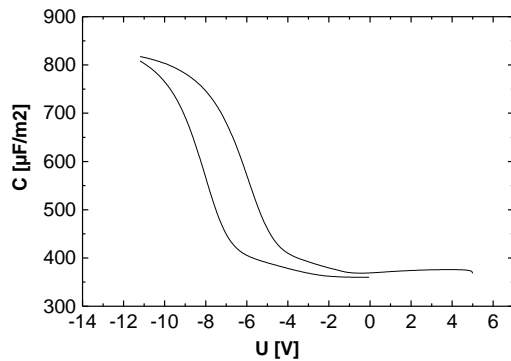


Fig. 3: HF-CV-curve of a SiN-MIS-sample before (right curve) and after applying a large negative bias voltage to the gate electrode (left curve). The curve has shifted by about 2 V to larger negative voltages.

Fig. 3 shows the shift of the HF-CV curve after applying a negative bias voltage of about 10 V to the sample. The curve shifts to a larger negative voltage. This means that the fixed charge is not really fixed but can be recharged through an external stress like a large bias voltage. In this example the effect is not very strong. A loss of the fixed charge in the SiN under illumination can be the reason for the sometimes observed fast initial degradation of solar cells after PECVD-SiN deposition and annealing. During the first few minutes under illumination the efficiency reduces until a stable value is reached.

## 2 THE PHOTOCURRENT-VOLTAGE DECAY METHOD

For practical applications it is often important to know the recombination velocity on the frontside of solar cells. Because the passivation of a solar cell front surface depends strongly on the properties of the emitter, it is important to measure the frontside recombination velocity directly in solar cells. In order to determine the passivation properties of a SiN-layer deposited on different solar cells, the frontside passivation is measured on the cells before and after the PECVD SiN deposition and the improvement

of the front surface recombination velocity through the deposition can be deduced.

The PhotoCurrent Voltage decay (PCVD) method [4,5] is used to determine the passivation of a solar cell through lifetime measurements. Fig. 4 shows the experimental setup. The solar cell is illuminated by a pulsed laser diode with a wavelength of 905 nm and a pulse width of 100 ns. The exponential decay of the short circuit current and the open circuit voltage are measured with a fast digitizing oscilloscope. The bias light defines the injection level and reduces the capacitive time constant of the cell. This capacitive time constant has to be shorter than  $\tau_V$ .

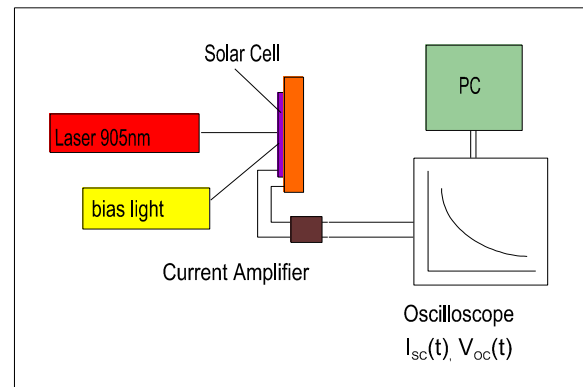


Fig. 4: The experimental setup: The cell is illuminated by a pulsed laser diode. The time dependent current and voltage are digitized in the oscilloscope and transferred to a computer. The bias light determines the injection level and lowers the cell capacitance for the voltage measurement.

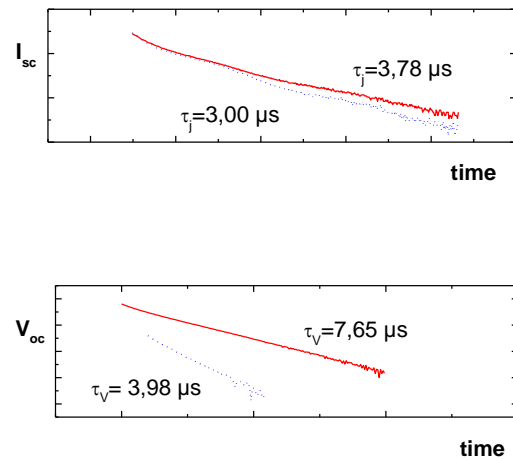


Fig. 5: The logarithmic decay curves of the short-circuit current (above) and the open-circuit voltage (below) of two multicrystalline silicon solar cells. The solid curve shows an oxide passivated cell, the dotted one a cell with a screenprinted emitter without a frontside passivation.

Fig. 5 shows the logarithmic plots of the current (above) and the voltage time dependence (below) of an oxide passivated multicrystalline solar cell (solid line) and a cell with a screenprinted emitter (dotted line).

From the decay constants for the current  $\tau_j$  and the voltage  $\tau_V$  and with an independently measured bulk diffusion length the backside recombination velocity  $S_b$  and the

frontside/emitter recombination velocity  $S_{\text{eff}}$  can be calculated (Tab. 2).

The  $\tau_j$  depends on the bulk diffusion length and  $S_b$ .  $\tau_v$  additionally on the frontside/emitter recombination  $S_{\text{eff}}$ . Table 2 shows the extracted  $S_b$  and  $S_{\text{eff}}$  from the two cells of Fig. 5. The oxide passivated cell (cell 1) has an  $S_{\text{eff}}$  one order of magnitude lower than the unpassivated cell.

Tab. 2: The extracted recombination parameters of the two cells from fig. 5. The diffusion-length was measured with the Spectral Response method.

cell	$L_{\text{diff}}$ [ $\mu\text{m}$ ]	$S_b$ [ $\text{cm/s}$ ]	$S_{\text{eff}}$ [ $\text{cm/s}$ ]
1	195	20000	100
2	120	6000	1000

### 3 PECVD passivation of different solar cells

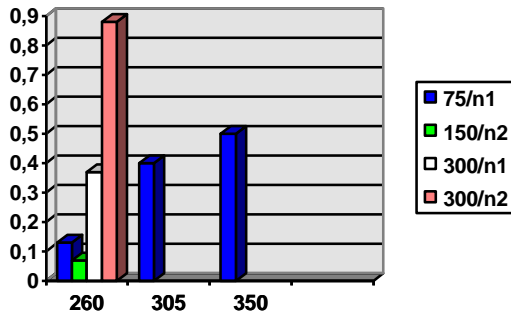


Fig. 6: The improvement of passivation through the SiN deposition as a function of the deposition temperature for different plasma powers (75-300 W) and two refractive indices ( $n_1$  and  $n_2$ ). The y-axis gives the change in  $\tau_v$  before and after nitride deposition. See the text for more details.

Fig. 6 shows the result of a deposition optimisation study. The SiN was deposited on finished solar cells without a thermal oxide passivation. The cells were immersed in deionized water before deposition without any further cleaning step. The temperature, plasma power and refractive index of the SiN were varied.

The quality of the surface passivation is expressed in the  $\Delta\tau_v = \tau_v$  (before the deposition) -  $\tau_v$  (after the SiN deposition and annealing). A positive value of  $\Delta\tau_v$  means a passivation through the deposition.

For a constant plasma power the passivation increases with increasing deposition temperature. The SiN with the higher refractive index ( $n_2$ ) contains more hydrogen and the increase of  $\tau_v$  is higher than for the SiN with less hydrogen content. At the lower temperature a high plasma power passivates better than a lower one.

If the SiN is deposited on top of a passivating thermal oxide, higher deposition temperatures result in a surface degradation. Only a low deposition temperature keeps the good passivation properties of the thermal oxide.

Table 3 shows the result of passivating different solar cells with a PECVD SiN layer.

These cells are not oxide passivated. Lower quality industrial emitters on multicrystalline silicon has also been studied. The aim was to investigate if a sufficient surface

passivation through a PECVD SiN was possible even for those cells with a simple surface cleaning process. The cells were measured with PCVD and Spectral Response before and after the SiN deposition.

- A:  $\text{POCl}_3$  emitter, FZ silicon
  - B: low resistivity  $\text{POCl}_3$  emitter, multicrystalline silicon
  - C: screenprinted emitter, multicrystalline silicon, chemically textured surface
- 1: before and 2: after the SiN deposition.

Tab. 3: Emitter/frontside recombination velocities of differently processed solar cells before (1) and after (2) a PECVD SiN deposition.

cell	$\tau_v$ [ $\mu\text{s}$ ]	$S_{\text{eff}}$ [ $\text{cm/s}$ ]	$V_{\text{oc}}$ [ $\text{mV}$ ]	$\eta$ [%]
A 1	7,92	1400	583	10,1
A 2	7,99	1300	605	15,2
B 1	5,26	1600	587	9,9
B 2	5,36	1400	601	13,5
C 1	3,98	1100	591	10,5
C 2	4,12	1000	592	12,4

Table 3 shows the result of the PCVD and IV measurement. Fig. 7 shows the Spectral Response of cell A before (dotted line) and after (solid) the SiN deposition. The Spectral Response of cell B is shown in Fig. 8.

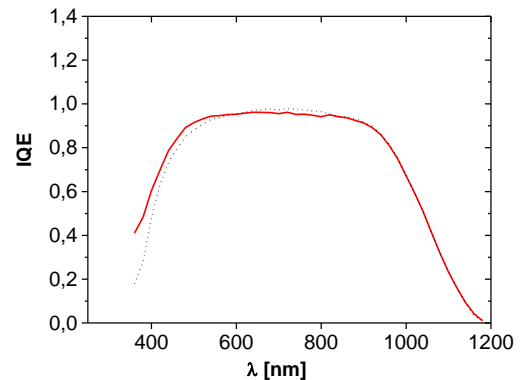


Fig. 7: The Spectral Response (internal quantum efficiency IQE) before (dotted line) and after (dashed line) the PECVD SiN deposition.

All cells show an improvement of  $\tau_v$  and therefore a reduction of  $S_{\text{eff}}$  through the SiN deposition. The relatively small increase of  $\tau_v$  of cell A is also visible in Fig. 7 as a small increase of the response at short wavelengths. A more effective passivation shows cell B: The  $S_{\text{eff}}$  is lowered by 13% and the blue response of the cell is clearly better than before the deposition. Also cell C with the screenprinted emitter shows a reduction of  $S_{\text{eff}}$ . An identical processed cell shows an increase in  $V_{\text{oc}}$  of 7 mV through the SiN deposition.

Certainly, a passivation comparable with thermal oxidation is not observed. But it is demonstrated that even on simple industrial solar cells a SiN deposition after the process without an expensive cleaning step is useful to passivate the front surface.

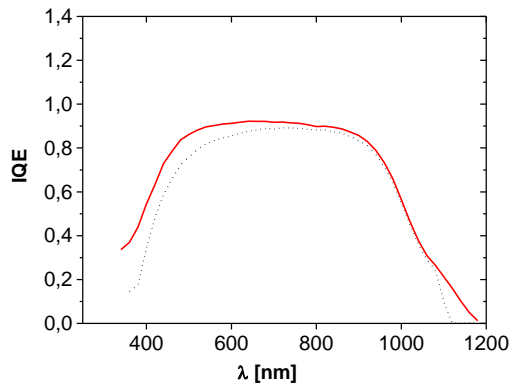


Fig. 8: The improvement of the blue response of a cell with a highly doped emitter with SiN deposition (solid line).

The absolute value of  $S_{\text{eff}}$  depends critically on the diffusion length of the material. On multicrystalline cells the bulk diffusion length varies over one wafer, such that it is difficult to give exact absolute values of  $S_{\text{eff}}$ . But the relative improvement in  $S_{\text{eff}}$  of one cell through the SiN deposition is a precise quantity, because  $\tau_j$  does not change through the SiN deposition.

Table 4 shows the corresponding results of a SiN deposition on top of a passivating thermal oxide. Cell D shows a small increase of  $S_{\text{eff}}$  which can be explained by some plasma damage of the surface during the deposition.

Tab. 4: The influence of a PECVD SiN deposition on top of thermal oxide passivated solar cells.

cell	$\tau_v$	$S_{\text{eff}}$ [cm/s]	$V_{\text{oc}}$ [mV]	$\eta$ [%]
D 1	7,65	100	603	10,7
2	7,00	400	611	14,8
E 1	4,14	1000	599	10,5
2	4,50	300	620	15,5

Cell E has a large  $S_{\text{eff}}$  before the deposition and shows a lowering of the surface recombination through the deposition. The passivation due to the oxide seemed to be insufficient before the SiN deposition. This low quality oxide passivation could be improved through the SiN deposition.

#### 4 V-TEXTURED SURFACES

Table 5 shows a comparison of a mechanically V-textured cell (V-groove depth 60 $\mu\text{m}$ ) with an identically processed cell with a flat surface. The frontside was passivated with a thermal oxide and it was interesting to see whether the mechanical texturization affects the surface passivation.

The  $S_{\text{eff}}$  value of the textured cell is lower than the corresponding value of the untextured one. Even the  $\tau_j$  and therefore the bulk diffusion length of the textured cell is lower than the diffusion length of the untextured reference cell. Dicing damage of the bulk during texturization can also be excluded.

The passivation through a thin thermal oxide on a mechanically V-textured cell is comparable to an oxide-passivation on a flat surface.

Tab. 5: The emitter/frontside recombination velocity and the deduced diffusion length of identically processed cells, one with a flat surface (F) and the other with a V-textured surface (G).

cell	$\tau_i$ [ $\mu\text{s}$ ]	$\tau_v$ [ $\mu\text{s}$ ]	$L_{\text{diff}}$ [ $\mu\text{m}$ ]	$S_{\text{eff}}$ [ $\mu\text{m}$ ]	$\eta$
F	2,82	4,79	150	530	10,3
G	2,87	5,51	165	320	14,1

#### 5 CONCLUSIONS

A PECVD SiN deposition on different - even industrial-like processed - solar cells was investigated. CV/conductivity measurements, Spectral Response and the PCVD-method were used to characterize the passivation properties of the Si-SiN interface and the frontside/emitter recombination velocity of solar cells.

On the different emitters studied and with an SiN deposition on finished solar cells without a special cleaning step an improved passivation of the frontside through the SiN deposition has been observed. The SiN passivation is useful even in an industrial process to increase the efficiency of silicon solar cells.

PCVD measurements on mechanically V-textured cells show a good passivation through a thin thermal oxide comparable to flat cells.

#### ACKNOWLEDGEMENTS

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