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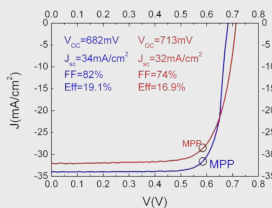


HIGH QUALITY SURFACE PASSIVATION AND HETEROJUNCTION FABRICATION BY VHF-PECVD DEPOSITION OF a-Si:H ON c-Si THEORY AND EXPERIMENTS

Motivation

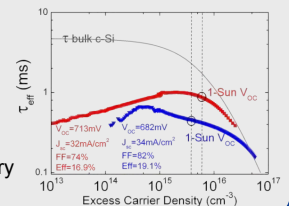
- Reach high V_{oc} -high efficiency with a-Si:H/c-Si heterostructures: need of high quality c-Si surface passivation.
- Investigation of a-Si:H layers passivation properties: analysis of lifetime measurements using an amphoteric model.
- Double side passivating layer structures speed up the development of high efficiency solar cell.

Best Efficiency Solar cells



Wafer Type	V_{oc} (mV)	FF	η (%)
n 1 Ω cm	682	82	19.1
n 1 Ω cm	713	74	16.9
p 0.5 Ω cm	690	74	16.3

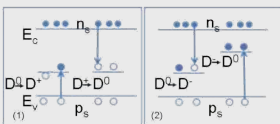
- High efficiencies are achieved on both p and n-typed c-Si, partially due to high V_{oc} 's
- A trade-off exists between V_{oc} and FF. However, c-Si surface passivation is necessary to achieve high efficiency.



Passivation theory

Modeling interface recombination through amphoteric defects at the a-Si:H/c-Si interface¹.

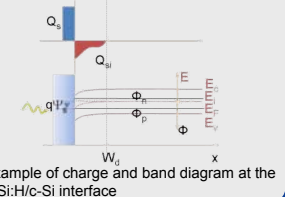
Deposition of VHF PECVD a-Si:H on c-Si \rightarrow Surface passivation



Recombination through amphoteric states: 2 paths coexist.

- This passivation scheme is based on the recombination through amphoteric defects on a-Si:H, at the a-Si:H/c-Si interface.

- Dangling bonds at the interface (N_s) \rightarrow Recombination.
- Average charge density at the interface (Q_s) \rightarrow Field effect passivation.

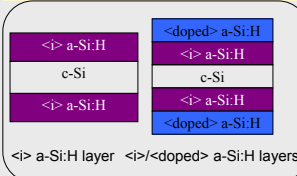


(1) S. Olibet, E. Vallat-Sauvain, C. Ballif, *Phys. Rev. B* 76 (2007) 35326.

From double side passivation...

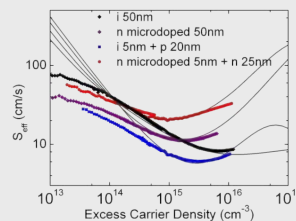
- Effective lifetime (τ_{eff}) measured by QSSPC \rightarrow injection level (ECD) dependent effective surface recombination velocity S_{eff} .

Example of symmetrical structures on FZ 2.5 Ω cm p-type c-Si.



$$S_{eff} = \left(\frac{1}{\tau_{eff}} - \frac{1}{\tau_b} \right) \cdot \frac{W}{2}$$

τ_b bulk lifetime
 W wafer width.



Fit to measured S_{eff} for various a-Si:H layer

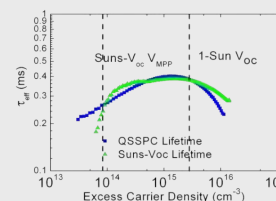
$N_s \downarrow Q_s$

Sample	N_s (10^9cm^{-2})	Q_s (10^{10}cm^{-2})
i 50 nm	5.2	-7
n- μ doped 50 nm	53	-85
i 5 nm + p 20nm	3.2	150
n- μ doped 5 nm + n 25nm	40	-50

Fit parameters

- Symmetrical passivation structures \rightarrow determine quality of the passivating layer.
- Fitting of S_{eff} (ECD) curves using the physical model.
 - \rightarrow Intrinsic a-Si:H layer \rightarrow Low N_s .
 - \rightarrow Doped a-Si:H layers \rightarrow Q_s tuning.
 - \rightarrow Combination of both \rightarrow Low S_{eff} .
- S_{eff} : down to 6 cm/s with <i>a-Si:H</i>/<p> a-Si:H layers.
- The optimization of the passivation layers is facilitated.

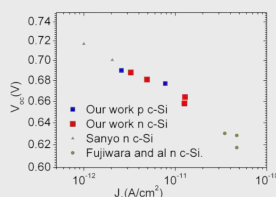
...to final solar cell



Lifetime measured by QSSPC and Suns- V_{oc} of a solar cell based on previous layers.

- High quality stacked layers allow the fabrication of high V_{oc} solar cells.
 - \rightarrow In this example: $V_{oc} = 675\text{mV}$.
 - \rightarrow Limited by the <i>a-Si:H</i>/<n> a-Si:H stack.
 - \rightarrow Suns- V_{oc} measurements are made after front and back contact depositions.
 - \rightarrow To check if the contact deposition damages the a-Si:H passivating layers.

Relation between 1-Sun V_{oc} and J_0



- Dark IV characteristics of the cells are fitted by the 1 diode equation.
- 1-Sun V_{oc} depends on J_0 and n .
- Set of a-Si:H/c-Si solar cells on various c-Si substrates:
 - \rightarrow n constant ≈ 1.2 .
 - \rightarrow $\ln(J_0)$ is linearly dependent to 1-Sun V_{oc} .
- Dark IV characteristics (J_0): supplementary tool for passivation quality control?

$$J = J_0 \left[\exp\left(\frac{qV}{nkT}\right) - 1 \right] - J_{ph}$$

$$V_{oc} \approx \ln\left(\frac{J_{ph}}{J_0}\right) \times \frac{nkT}{q}$$

J_0 : saturation current density
 J_{ph} : photogenerated current density
 n : diode ideality factor

Conclusion

- Development of deposited a-Si:H layers is facilitated by analysis of the passivation property using an amphoteric model.
- Solar cells benefit from the development of these passivating layers, resulting in V_{oc} and efficiency improvement.