Research Center for Photovoltaics

Passivation properties of hydrogenated amorphous silicon thin films applied to heterojunction solar cells

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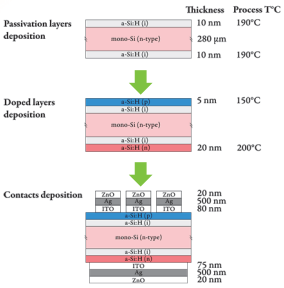
1 – 研究の目的

- Our main objective is to reach high conversion efficiency for heterojunction solar cells:
  1. Conversion efficiency above **20%** under AM1.5G.
  2. V_{oc} above **720 mV**, FF above **80%**.
- Investigation of fundamental properties of amorphous silicon:
  1. Improve both the **passivation** and the **conduction** of hydrogenated amorphous silicon intrinsic layer.
  2. Enhance the **effective lifetime** ($\tau_{eff.}$) of minority carriers, which is function of traps/hydrogen concentrations.
  3. Estimation of Hydrogen and traps **concentrations**.

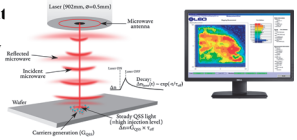
2 – 実験

Fabrication process:
Films deposited by **PECVD** on Silicon wafer substrate (Topsil)
Oriented <100>, 280 µm, 1-5 Ωcm

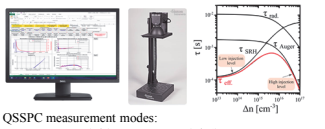


Effective lifetime measurement

A) Micro Photoconductance Decay (**µ-PCD**) technique:
☑ Effective lifetime mapping
☒ High injection level only



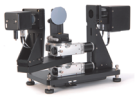
B) Quasi Steady-State Photoconductance (**QSSPC**) technique:
☑ Effective lifetime measurement for a broad resistivity range
☑ Measurements at low and high injection level (Δn : 10^{14} to 10^{17} cm^{-3})
☒ Analysis on the full wafer area only



QSSPC measurement modes:
QSS ⟷ (1/1) **Generalized** (1/64) ⟷ **Transient**

$\tau = \frac{\Delta n}{G}$ Low injection level $\tau = \frac{\Delta n}{G - \frac{d\Delta n}{dt}}$ High injection level $\tau = \frac{-\Delta n}{\frac{d\Delta n}{dt}}$

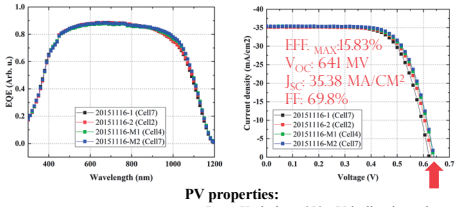
Optical analysis:



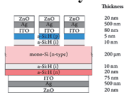
Ellipsometry, fit of n and k using Tauc-Lorentz model to determine:
- (i) a-Si:H thickness
- Optical bandgap

3 – 予備的な結果

Preliminary PV properties of HIT solar cells:



Preliminary structure:



Substrate:
Silicon wafer (Topsil), Textured, Oriented <100>, 200 µm, 1-5 Ωcm

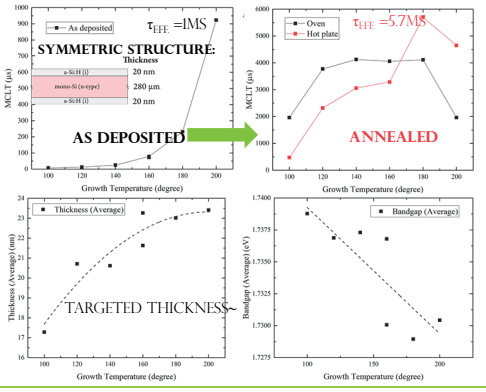
PV properties:
- Poor V_{oc} below 650mV indicating a low quality of the passivation layer at interface a-Si / c-Si.
- Poor FF below 70%, I-V characteristics presents a strong series resistance indicating further problem related to ohmic contacts.

⇒ Thus, main first objective is to focus on these characteristics by improving the passivation of **(i) a-Si:H** layer.

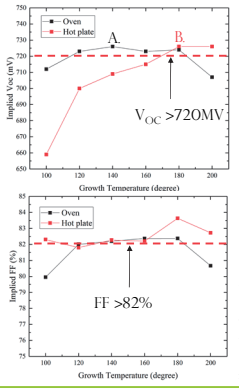
4 – Minority carriers lifetime (MCLT) evolution with annealing temperature

Investigation of oven (vacuum, 240°C, 2h) and hot plate (ambient air, 180°C, stabilized) annealing:

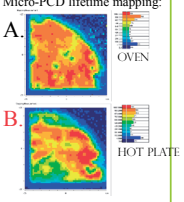
PASSIVATION STUDY DEPENDING ON THE **GROWTH**



Implied open-circuit voltage (V_{oc}) and Fill faction (FF):



Micro-PCD lifetime mapping:



- After annealing, hydrogen atoms diffuse and passivate defects in a-Si (dangling bonds)

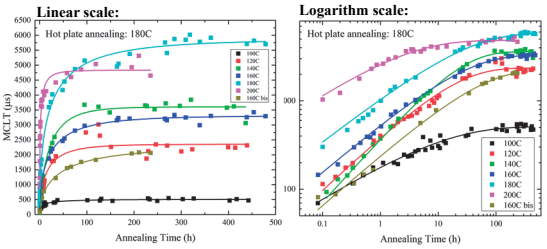
☑ Oven annealing, τeff. > 4ms for growth temperature 140-180° C

☑ Hot plate annealing, narrower window of temperature 180-200° C allows to reach τeff. > 5ms

☒ Poor homogeneity of teff. revealed by micro-PCD mapping.

5 – Investigation of the passivation properties over time

Monitoring of the effective lifetime via hot plate annealing:

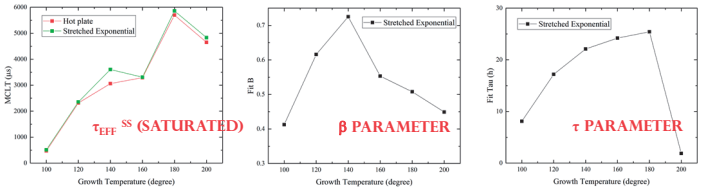


⇒ The effective lifetime evolution follows a **stretched exponential**. [1,2]

Stretched exponential function that describes the relaxation of disordered systems [1,2]:

$$\tau_{eff}(T_{ann.}) = \tau_{eff}^{SS}\left[1 - \exp\left[-\left(\frac{T_{ann.}}{\tau}\right)^{\beta}\right]\right]$$

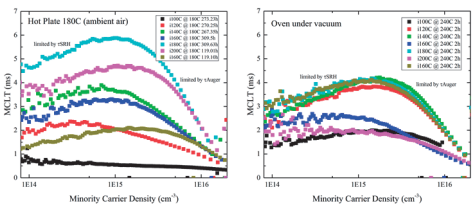
With the following parameters:
- The saturated effective lifetime τ_{eff}^{SS}
- β is the dispersion parameter (0<β<1)
- τ is the effective time constant



References:
[1] S. De Wolf, chapter 7, book *Physics and Technology of Amorphous-Crystalline Heterostructure Silicon Solar Cells*, editors W. van Sark, L. Korte, and F. Roca (2012).
[2] S. De Wolf, S. Olibet, and C. Ballif, Appl. Phys. Lett. **93** (2008) 032101.

6 – Lifetime analysis at low injection level

The **effective lifetime** in function of the injection level is used to underline the **limiting parameters** depending on the **injection level**:



- At **high injection level**, the effective lifetime is limited by **Auger recombination**
- At **low injection level**, the effective lifetime is limited by **Shockley-Read-Hall recombination** (SRH)
- The slope where SRH recombination predominates depends on two main parameters inside (i) a-Si:H and at interface a-Si / c-Si
  - Traps concentrations
  - Hydrogen concentration that contribute to the passivation

7 – まとめと謝辞

☑ This work presents the passivation of (i) a-Si:H layer with enhanced properties: an **effective lifetime between 4-6 ms** was obtained with an **implied V_{oc} > 720 mV**, and an implied **FF > 82%**.

- Passivation properties over time is analyzed by stretched exponentials.
- The slope of effective lifetime at low injection level is under investigation to evaluate the traps and hydrogen concentration.

Acknowledgments:
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