NREL Thin Film PV Partnership

Phase I Quarterly Technical Report
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Project Title: High efficiency Narrow Gap and Tandem Junction Devices

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1.0 Thin Film Silicon tandem junction devices

1.1 Background: Micro-morph solar cells- two terminal devices

It is well known that the inherent degradation in amorphous silicon solar cells can be reduced, but not eliminated, with the use of tandem junctions. In this types of two-terminal (2-T) device structure, the current from each cell needs to be the same which necessitates that the upper most cell, facing the incident illumination, is still relatively thick (>2000A) leading to degradation.

The use of 2-T tandem (or multi-junction- MJ) solar cell with a micro- (or nano)crystalline Si (nc-Si:H) i-layer in the bottom cell and an a-Si:H i-layer in the top cell shows a promising technique in terms of providing an increased spectral response over a wide spectral wavelength range. Such solar cells (termed as "micromorph" solar cells) can produce an initial AM1.5 conversion efficiency of ~13% in small area and ~12% in large area modules [1,2,3]. However, these "micromorph" solar cells also contain a relatively thick (~ 4000A) a-Si:H layer in the junction (top cell), which is due to the current matching from the bottom nc-SiH device. As a result, majority of the power (~ 70%) comes from the unstable thick a-Si:H portion. It is therefore inevitable that the MJ undergoes a significant degradation under light illumination.

1.2 Four terminal device structure – thin film Silicon

We are in the process of developing a simpler 4 terminal (4-T) thin film silicon based multi-junction (MJ) solar cell as shown in Fig. 1, in which the current matching constraint is released from each constituent cell. The structure should thus allow the fabrication of efficient and stable MJ solar cells. For example, two cells (a-SiH and stable low band gap junction materials, such as micro (or nano)-crystalline Si (ncSiH)) are separated via an insulating material (e.g. glass, plastic or SiNx). This allows the use of ultra-thin (~300-1000A) a-SiH solar cell where instability should no longer be an issue. This 4-T design, has the potential to attain >15% conversion efficiency under AM1.5 light illumination, as shown in Fig. 2. In the calculation, we have assumed a fixed band gap of 1.9 eV for the top cell (a-SiH) and calculated the total efficiency of the MJ stack as a function of the thickness of the ncSiH bottom cell. The basic assumption in these calculations also involves that the Voc in the ncSi will be improved to 0.65 volts. In a 4-T configuration, as the current matching is no longer necessary, and as the top a-Si:H device can be made thin enough (~300-1000A) to eliminate the degradation, then a significant portion of the power could be generated from the stable (ncSiH) bottom cell.

1.3 Thin amorphous silicon solar cell and their stability.

Fig. 3 shows our attempt to increase the bandgap of a-Si intrinsic -layer using H2 dilution. The bandgap increases monotonically with an increase in the H2 flow rate used in the fabrication of the i-layer. Fig. 4 shows the performance of a-Si:H single junction device (with thickness of 900 A) for various H2 diluted i-layers. The structure used was glass/ZnO/pin/Ag. By changing the H2 dilution in i-layer fabrication, Voc was increased to 0.93 V, while the FF and Jsc were in the range 0.72 – 0.75 and 6 – 7 mA/cm2 respectively . With further optimization, it is realistic to expect that Voc~1V, FF~0.75 and Jsc of 6-7mA/cm^2 with the result that cell #1 of the stack should yield stable cells of ~5%.

Fig. 5 shows the stability data of the a-SiH cell of about 900A in thickness with Al and Ag as the back contact. Al contacted device reveals that, at least for the first 50 hours of illumination, the device remains stable. The figure also shows QE remains the same before and after 50hour of illumination.

1.4 Simulated 4-T device.

Fig 6 shows the QE of a typical nano-crystalline Silicon device with current density ~22.4mA/cm^2. The curve also shows the QE if a filter consisting of glass/ZnO/pin/ZnO (cell#1) with i-layer thickness of 300A were inserted in front of the nano-crystalline Si device. The filtered light leads to a Jsc of about 11.3mA/cm^2 as determined from the QE. It should be noted that in comparison with the 4-T structure, shown in Fig 1, use of the cell #1 filter results in additional reflection losses which would be absent in a real 4-T device. Further with the inclusion of ZnO/Ag back reflector in cell #2, there would be an increased response at the red end of the spectra. Hence in the real 4-T device, QE of ncSiH device would indeed be higher and we estimate that it could exceed 20mA/cm^2.

1.5. Development of a fully functioning 4-T device.

We are now in the process of developing a fully functioning 4-T device, which involves many components including reduction of light losses as alluded to in Fig. 1. Specifically the following will be developed.

1. Low temperature ZnO or ITO as the front contact for the cell#1 (a-SiH) device.
2. Optimization of thicknesses of the two cell structures.
3. Development of a wide band gap amorphous silicon n-type layer contact for the cell#1 (a-SiH) device. .
4. Anti- reflection coatings.

In summary the advantage of the 4-T cells could very well be the following.

1. Current matching constraint is removed and hence it should lead to stable, high efficiency device structure.
2. Low cost production processes would emerge, as the number of layers involved is less than other types of MJ type devices.
3. The devices could be automatically deposited on either side of glass or a suitable plastic material.
4. MVSystems has applied for patent on 4-T type devices including their method of manufacture on rigid as well as flexible substrates. This approach would be equally applicable with use of other materials such as CdTe, CIS, crystalline or multi-crystalline Si.

2.0. Personnel: the following personnel have been involved in the project during the reporting period: A. Madan, U. Das, E. Valentich, Denis Mader, Ron Curry.

References:

[1] K. Yamamoto, M. Yoshimi, T. Suzuki, T. Nakata, T. Sawada, A. Nakajima, and K. Hayashi, IEEE PV conference (Anchorage, 2000) p. 1428.

[2] J. Meier, R. Fluckiger, H. Keppner and A. Shah, Appl. Phys. Lett. **65**, 860 (1994).

[3] J. Meier et al., Proc. Mat. Res. Soc. Symp. **507**, 131 (1996).

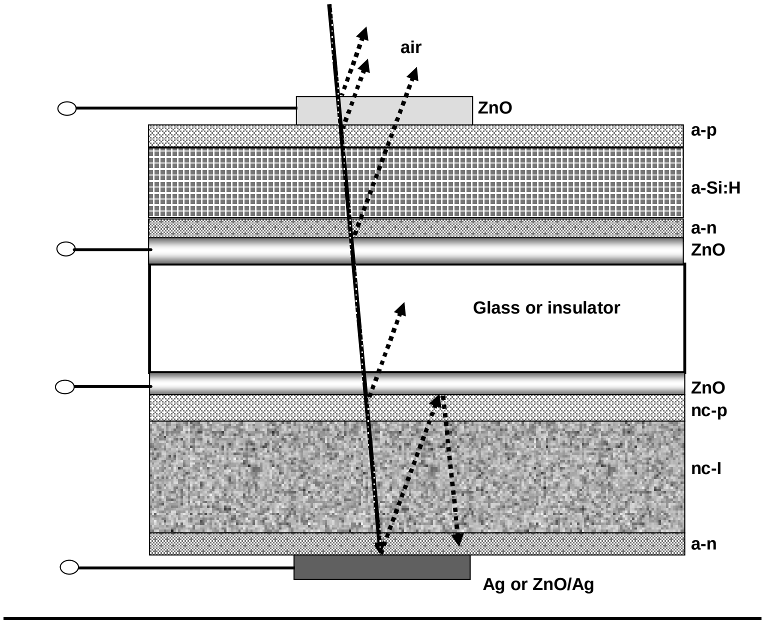

Fig. 1. Schematic of a typical 4 terminal solar cell using amorphous silicon and nano-crystalline Silicon.

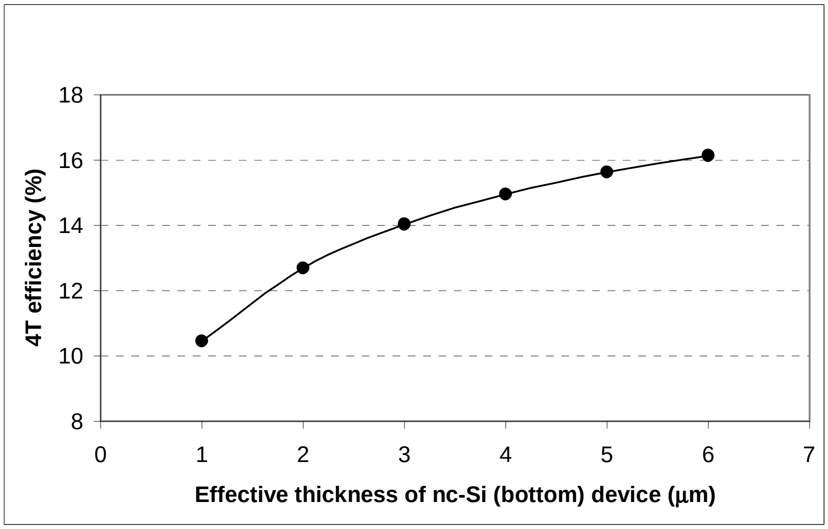

Fig. 2: Estimated AM1.5 efficiency of 4 terminal solar cell as a function of ncSiH bottom cell thickness.

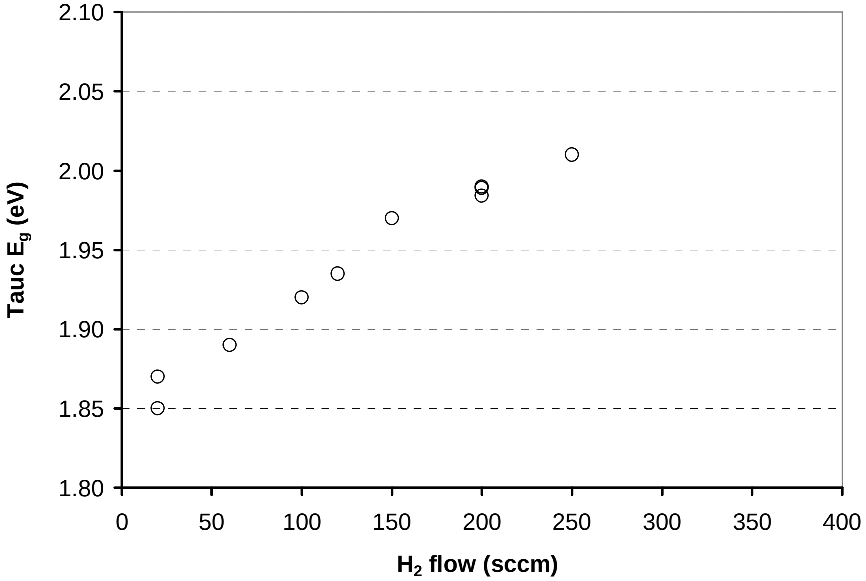

Fig. 3: The bandgap (Tauc Eg) of a-Si:H i-layer as a function of H2 flow.

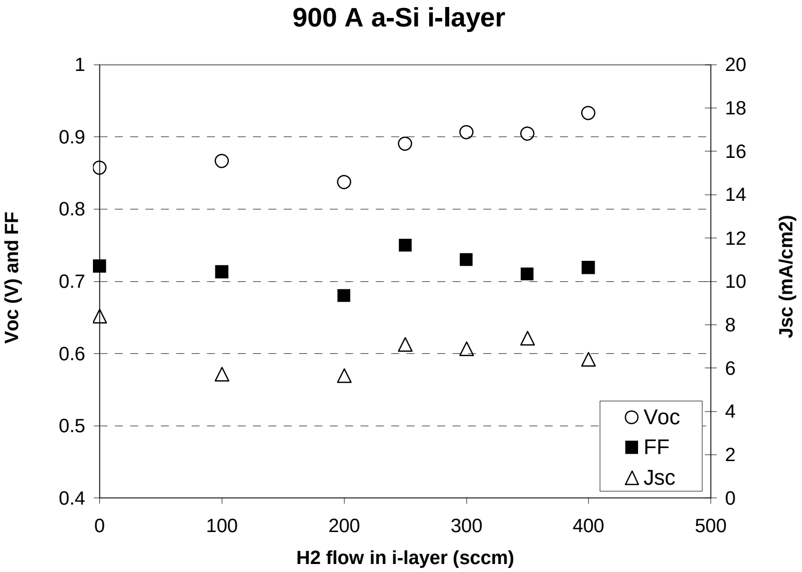

Fig. 4: A-Si:H single junction device parameters (open circuit voltage, Voc, Fill factor, FF and short circuit current density, Jsc) as a function of H2 flow in the i-layer.

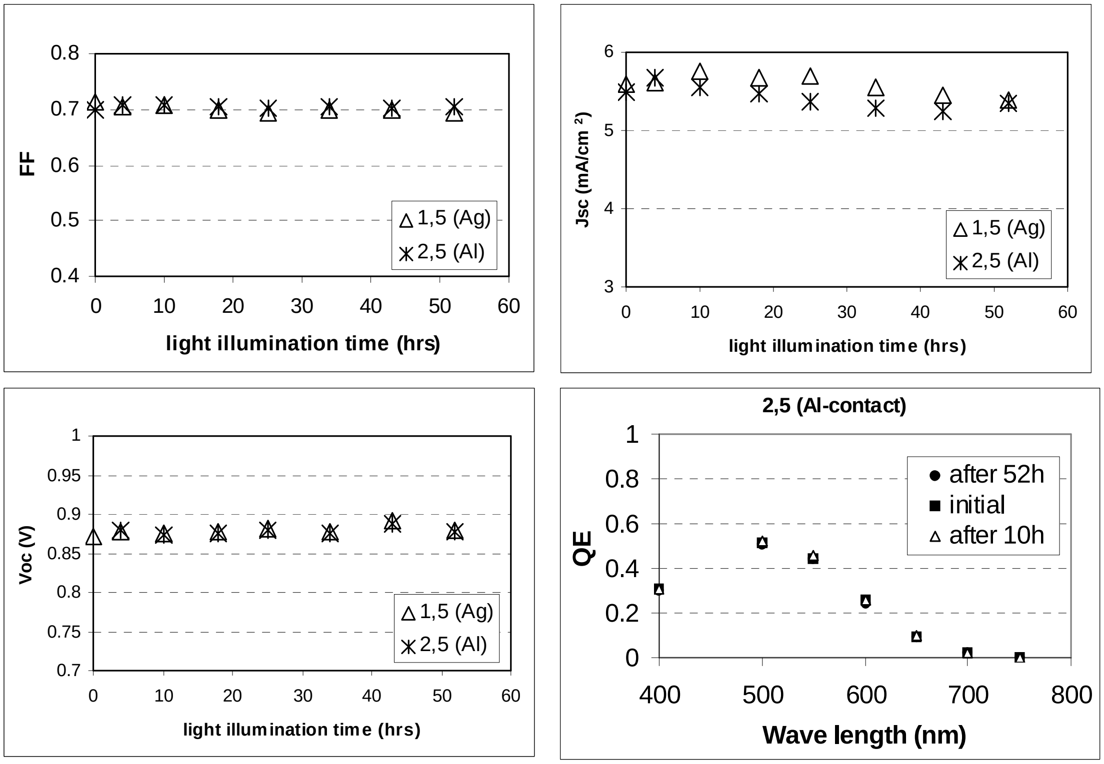

Fig. 5: The variation of FF, Jsc, Voc and the quantum efficiency (Al contact) of 900 A thick a-Si:H as a function of illumination (with intensity 100mW/cm2) time.

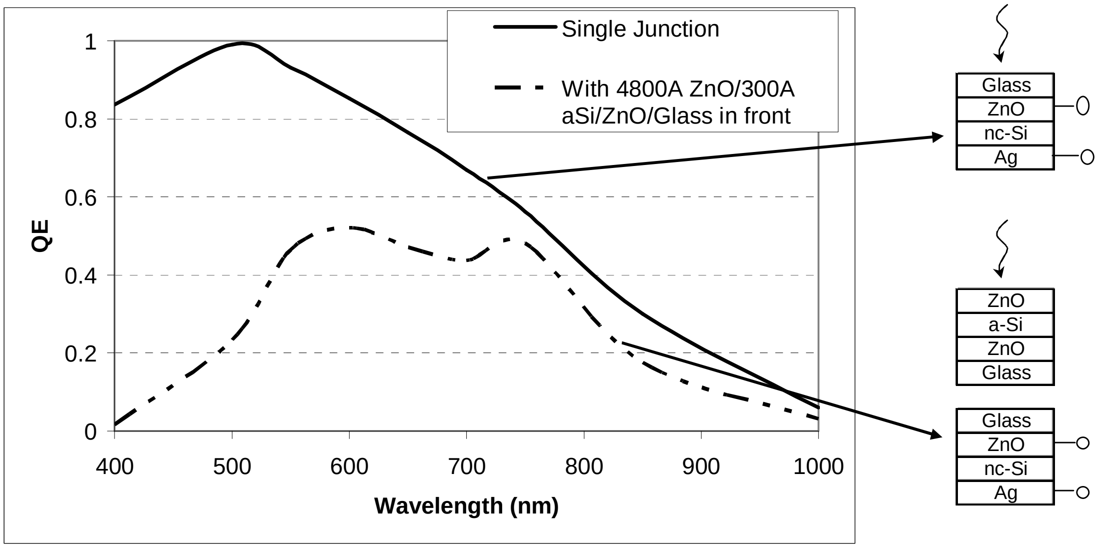

Fig. 6: The quantum efficiency of a typical nano-crystalline Silicon device. The figure also shows the QE if a filter consisting of glass/ZnO /pin/ZnO (cell#1 filter) with i-layer of 300A in thickness were inserted in front of the nano-crystalline Si device.