EFFECT OF PROTON IRRADIATION ON THE CHARACTERISTICS OF DIFFERENT TYPES OF THIN-FILM SILICON SOLAR CELLS

J. Kuendig [1], M. Goetz [1], J. Meier [1], P. Torres [1], L. Feitknecht [1], P. Pernet [1], X. Niquille [1], A. Shah [1], L. Gerlach [2], E. Fernandez [2]
[1] Institut of Microtechnology (IMT), University of Neuchâtel, A.-L. Breguet 2, 2000 Neuchâtel, Switzerland
tel. +41 32 718 32 00, fax + 41 32 718 32 01, e-mail: jamil.kuendig@imt.unine.ch
[2] ESA-ESTEC, Keplerlaan 1, NL 2200 AG Noordwijk, The Netherlands
tel. +31 71 565 4994, fax +31 71 565 4313, e-mail: lgerlach@estec.esa.nl

ABSTRACT: A proton irradiation campaign has been carried out on a series of samples including thin-film amorphous (a-Si:H), microcrystalline (µc-Si:H) and micromorph (tandem µc-Si:H/a-Si:H) silicon solar cells. The radiation hardness of microcrystalline and micromorph thin-film silicon solar cells is tested here for the first time. It is compared with the radiation hardness of thin-film amorphous silicon solar cells. The effect of annealing on solar cells degraded by proton irradiation is also investigated.
Keywords: Radiation damage – 1: Space cells – 2: Thin film - 3

1. INTRODUCTION

Solar cells used on satellites are highly exposed to proton radiations. Recently, it has been shown that CIS [1] and thin-film amorphous silicon [2] solar cells have good radiation hardness. Thin-film amorphous silicon (a-Si:H) on polyimide substrate has an excellent power/weight ratio (more than 500 W/kg). Thin-film microcrystalline silicon (µc-Si:H) solar cells and thin-film double junction solar cells using a-Si:H and µc-Si:H (i.e. so called "micromorph" cells [3-6]) could also be used for space applications, but their radiation hardness was sofar not known. The power/weight ratio of micromorph solar cells could be very high (over 1000 W/kg) if deposited on polyimide substrates.

Our test samples are thin-film amorphous, microcrystalline and micromorph silicon solar cells. After irradiation, annealing steps at increasing temperatures have been carried out on these different types of solar cells.

A comparison is made between the characteristics of these different types of thin-film silicon solar cells measured before proton irradiation, after proton irradiation, and after annealing.

2. EXPERIMENTAL APPROACH

We have studied single- and double-junction devices, that were all manufactured by the Very High Frequency Glow-Discharge (VHF-GD) technique [7] at IMT Neuchâtel. Amongst single-junction cells, we have irradiated thin-film n-i-p a-Si:H and n-i-p µc-Si:H solar cells.

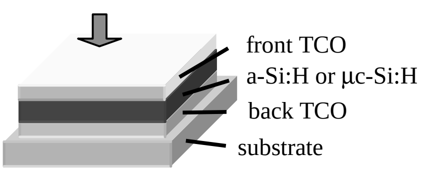

Fig. 1: Structure of n-i-p single junction solar cell

W.r.t. double-junction tandem devices, both n-i-p and p-i-n micromorph solar cells were irradiated. The structure of the devices is illustrated in fig. 2.

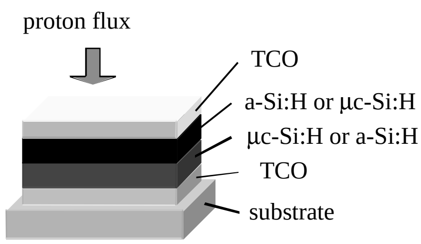

Fig. 2: Structure of double junction micromorph solar cell

For our single-junction a-Si:H n-i-p solar cells, we have chosen different substrates: glass, stainless steel sheet metal and polyimide. The preirradiation conversion efficiency varied from 7.5 to 8.5 % for these cells. Glass was the substrate used for all other cells tested (n-i-p µc-Si:H, n-i-p micromorph and p-i-n micromorph). For the double-junction p-i-n micromorph cells, the preirradiation conversion efficiency was between 10 and 11 %.

All the cells were irradiated by the European Space Agency (ESA) using a rocking equipment described in fig. 3.

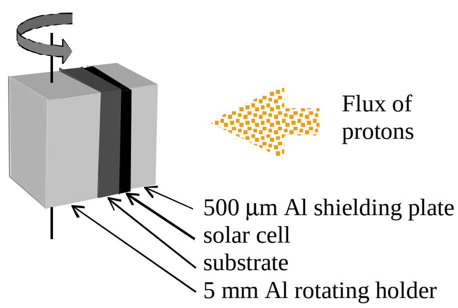

Fig. 3: Technique of irradiation

The solar cells are placed on a 5 mm aluminium holder so no proton enters the cell through the rear side. A 500 µm aluminium sheet is applied at the top of the cells, and the whole equipment is rotating compared to the proton flux. This is used to reduce the initial energy of the protons (10 MeV) to a lower value (several tenth of keV up to 5 MeV). The fluence (quantity of particles per area) is 1.5E13 p+/cm^2. The energy spectrum of the incident protons has been calculated and is shown in fig. 4.
The initial energy of the protons had to be reduced below 10 Mev, as protons of this energy pass through thin-film solar cells without being absorbed.

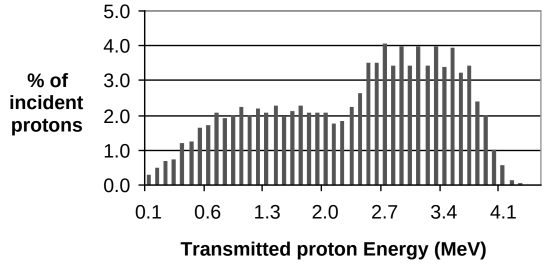

Fig. 4: Energy spectrum of the incident protons

Prior to starting the series of irradiations, all cells were annealed at 180 °C for 90 minutes. All cells were irradiated under open-circuit conditions.

The cells were characterized before and after irradiation, and after the post irradiation annealings. We have characterized the cells at the IMT with a solar simulator under AM1.5 conditions (100 mW/cm^2) and with spectral response measurements. Four parameters were investigated: the open circuit voltage (Voc), the fill factor (FF), the short circuit current (Isc) and the efficiency (η).

Note that the values of the parameters are measured at AM1.5 (illumination on earth) conditions. The change for AM0 (illumination in space: 136 mW/cm^2) conditions is an increase by 22 % of I_{sc} and a small reduction of FF.
Comparisons are made w.r.t. the mean value of the normalized conversion efficiency of 4 to 6 cells from the same substrate for each type of solar cells.

This was a first attempt to check the space compatibility of the solar cells that are manufactured at IMT Neuchâtel. Up to now only proton irradiation has been studied, other effects like atomic oxygen or heat cycles have not been investigated.

3. RESULTS

For the three types of **n-i-p** amorphous silicon solar cells (on polyimide, stainless steel sheet-metal and glass substrates), the results show that these cells are only very slightly damaged by the proton irradiations at the choosen fluence and energy.

Fig. 5 presents normalized efficiency of a-Si:H solar cells on glass substrate after the proton irradiation and annealing at different temperatures (100°C for 5 hours, 140°C for 2 hours, 180°C for 2 hours). Each data point is a mean value of 6 solar cells on the same substrate. For all thin-film amorphous silicon solar cells on the three different substrates, an excellent radiation hardness has been observed.

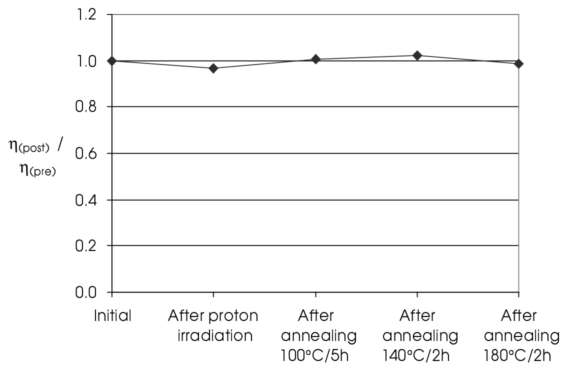

Fig. 5: Normalized efficiency of n-i-p a-Si:H solar cells on glass substrate

For the **n-i-p** microcrystalline and micromorph silicon solar cells, all parameters show a loss after the proton irradiation. After thermal annealing however, the four parameters reach their initial value (i.e. the value before irradiation). Fig. 6 presents normalized efficiency of microcrystalline and micromorph solar cells on glass substrates after proton irradiation and annealing at different temperatures (100°C for 5 hours, 140°C for 2 hours, 180°C for 2 hours). Each data point is a mean value of 4 solar cells on the same substrate.

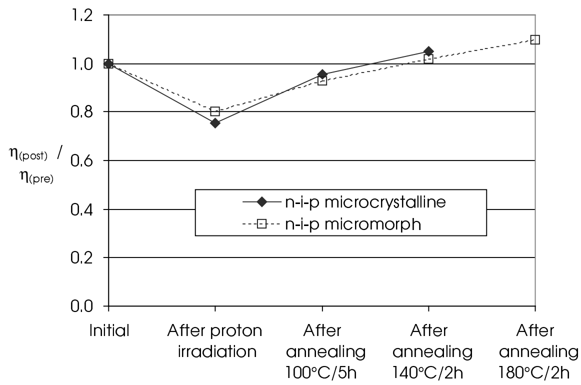

Fig. 6: Normalized efficiency of n-i-p microcrystalline and n-i-p micromorph solar cells on glass substrates

As the normalized conversion efficiency of **n-i-p** microcrystalline and of **n-i-p** micromorph silicon solar cells looks similar after proton irradiation and after the different annealings, we suppose that it is the µc-Si:H cell of the micromorph tandem solar cell that is damaged by the irradiation.

The normalized efficiency of **p-i-n** micromorph solar cells looks quite similar with the one of n-i-p micromorph solar cells (fig. 7). The annealing time and temperature are the same for both types of cells (**p-i-n** and **n-i-p** micromorph).

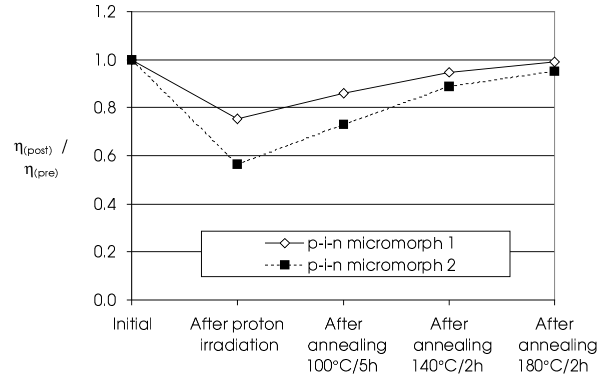

Fig. 7: Normalized efficiences of p-i-n micromorph solar cells on glass substrate

As shown in fig. 7, the degradation due to proton bombardment could be partly recovered with post-irradiation isothermal annealings. Irradiation results of two different substrates are illustrated, and each data point is a mean value of 4 solar cells on the same substrate. Note that the p-i-n micromorph solar cells were irradiated through the n-side.

For the **p-i-n** micromorph tandem solar cell, the spectral response measurements show that it is the microcrystalline bottom cell that is damaged after the proton irradiation (fig. 8).

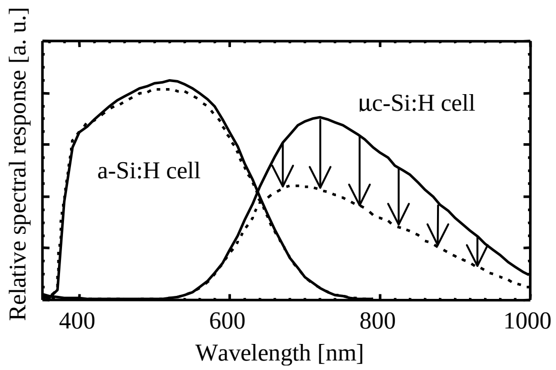

Fig. 8: Relative spectral response [a. u.] versus wavelength [nm] for the p-i-n micromorph cell (dotted line = measurement after proton irradiation)

The cells which irradiation results are illustrated in fig. 7 have been exposed a second time to the same proton bombardment, but after that we have annealed the samples at lower temperatures (70 °C, 100 °C and 130 °C, each annealing step during 10 hours). Irradiation results of the same two different substrates are illustrated in fig. 9. Each data point is a mean value of 4 solar cells on the same substrate.

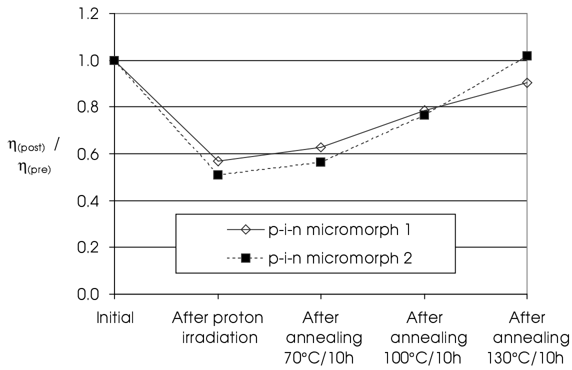

Fig. 9: Normalized efficiencies of p-i-n micromorph solar cells on glass substrates

Fig. 9 shows that after annealing at relatively low temperatures (70 °C, 100 °C and 130 °C) the degradation due to proton bombardment could be partly recovered. We suppose that longer annealing times at temperatures around 70 to 100 °C may allow the full recovery of the degradation

4. DISCUSSION

Thin-film a-Si:H solar cells have excellent radiation hardness. For thin-film μc-Si:H and "micromorph" (μc-Si:H/a-Si:H tandem) solar cells, an important loss of conversion efficiency was seen after proton irradiation. But almost the full degradation could be recovered after annealing during a short time. The spectral response measurement has shown that, for the micromorph tandem solar cell, it is the microcrystalline cell that was mainly damaged by the proton irradiation.

An important result of this study is that almost the full degradation due to proton irradiation could be recovered within some hours at relatively low temperatures (70 to 130 °C). It may also be possible to reach a steady state (in space) where simultaneous degradation and annealing come to a balance. More research on this aspect is needed.

Actually, space cells operate typically at 70 to 80 °C, when a heat shied is used (IR-reflector) to keep the cells cool. It may be interesting for thin-film silicon solar cells to work at higher temperatures (around 100 °C), so they could reach the steady-state (annealed state) described above.

5. CONCLUSIONS

Good power/weight ratio can be provided by a-Si:H solar cells deposited on polyimide. But their power/area ratio is not so attractive.
It would be possible to improve this by depositing thin-film "micromorph" (μc-Si:H/a-Si:H tandem) silicon solar cells on light weight polyimide.

The thermal history of the solar modules in space is very important , especially for "micromorph" tandem solar cells with their excellent power/weight potential (over 1000 W/kg).

6. ACKNOWLEDGMENTS

The authors are grateful to Mr. Emilio Fernandez, Anton Robben and Petteri Nieminen from ESTEC for their contributions to the proton irradiation tests and to the proton spectrum modelling. This work was supported by ESA-ESTEC.

7. REFERENCES

[1] H. Schock, K. Bogus, Proceedings 2nd WCPEC, Vienna, Austria, 1998, pp. 3586-3589

[2] S. Guha, J. Yang, A. Banerjee, T. Glatfelder, G. J. Vendura, A. Garcia, M. Kruer, Proceedings 2nd WCPEC, Vienna, Austria, 1998, pp. 3609-3613

[3] N. Wyrsch, P. Torres, M. Goetz, S. Dubail, L. Feitknecht, J. Cuperus, A. Shah, B. Rech, O. Kluth, S. Wieder, O. Vetterl, H. Stiebig, C. Beneking, H. Wagner, Proceedings 2nd WCPEC, Vienna, Austria, 1998, pp. 467-471

[4] J. Meier, H. Keppner, S, Dubail, Y. Ziegler, L. Feitknecht, P. Torres, Ch. Hof, U. Kroll, D. Fischer, J. Cuperus, J. A. Anna Selvan, A. Shah, Proceedings 2nd WCPEC, Vienna, Austria, 1998, pp. 375-380

[5] J. Meier, E. Vallat-Sauvain, S. Dubail, U. Kroll, J. Dubail, S. Golay, L. Feitknecht, P. Torres, S. Fay, D. Fischer, A. Shah, to be published in Proceedings PVSEC 11, Sapporo, Japan, (1999)

[6] L. Feitknecht, O. Kluth, Y. Ziegler, X. Niquille, P. Torres, J. Meier, N. Wyrsch, A. Shah, to be published in Proceedings PVSEC 11, Sapporo, Japan, (1999)

[7] H. Curtins, N. Wyrsch, A. Shah, Electron. Lett. **23**, (1987), p. 228