Reliability evaluation of CIGS solar cells for space applications

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1. Introduction and Summary

- Idemitsu CIGS solar cells have extreme radiation tolerance owing to self-healing effect by Heat and Light Soak(HLS) [1)]. But the dynamics of HLS is still under research.
- We have investigated the dynamics of HLS with more detailed temperature range than the previous report [2)], which shows the recovery even at 45 °C.
- Development through thermal durability and in-orbit demonstrations are also presented.

2. Radiation Durability and Recovering Behavior

- Our CIGS cell exhibited higher durability against radiation damage than PERC Si cell. Annealing at 65 °C under light (HLS) recovers radiation-induced degradation, resulting in higher durability than GaAs cell.

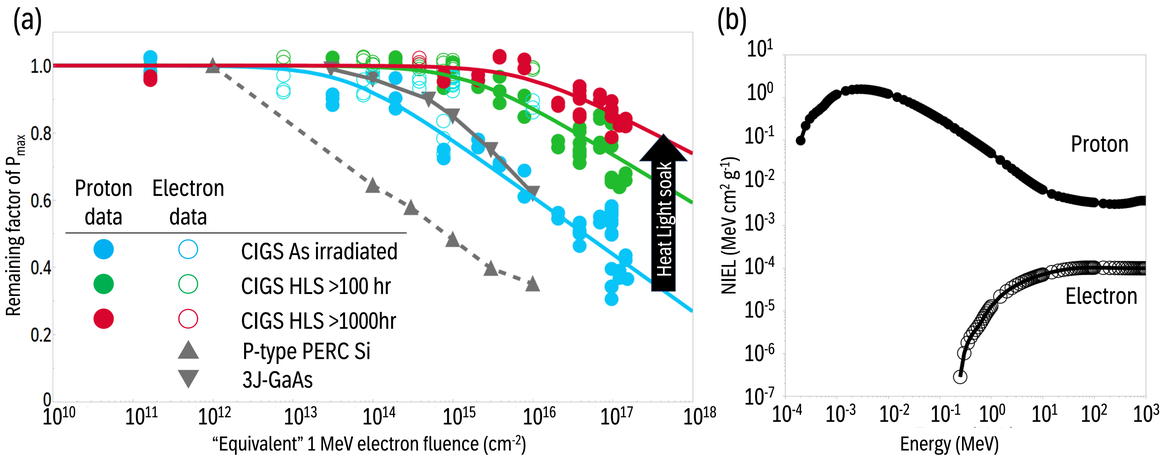
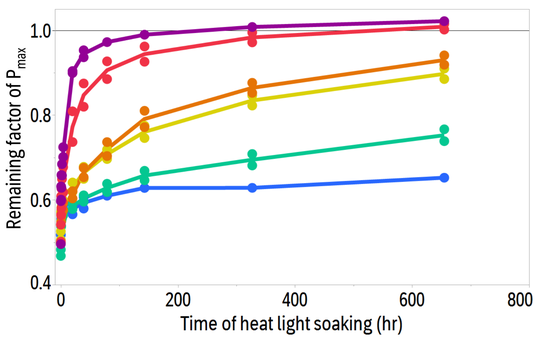


Figure 2.1. (a) Remaining factor of Pmax of our unshielded CIGS solar cells for equivalent 1 MeV electron beam irradiation; results for P-type PERC Si [3)], and 3J-GaAs [4)] , solar cells are plotted based on published materials from leading space solar cell manufacturers.
(b) NIEL value for proton and electron of CIGS solar cells obtained from SR-NIEL calculator [5)]. The equivalent 1 MeV electron fluence Φ' was calculated using the NIEL scaling relation: $\Phi' = \Phi \times NIEL(E) / NIEL(1\ MeV\ e^-)$,
where Φ is the particle fluence of the irradiation test and NIEL(E) is the non-ionizing energy loss at the corresponding particle energy.

- Recovery from radiation-induced degradation by heat light soaking is accelerated at higher temperatures and is confirmed to occur at temperatures of 45 °C or higher.



Surface temperature of CIGS solar cell while heat light soaking:
85 °C, 65 °C, 45 °C
75 °C, 55 °C, 35 °C

Experimental condition:
- Proton irradiation : 1 MeV, 1×10^{13} cm^{-2}, RT, dark
- Heat light soaking : Under metal-halide lamp (~ 60 mW/cm^2) and kept under open-circuit conditions.

Figure 2.2. Annealing behavior of our unshielded CIGS solar cells during annealing at various temperatures under metal-halide lamp illumination (~ 60 mW/cm^2). During annealing, the CIGS solar cells were kept under open-circuit conditions.

Please visit our website:
https://www.idemitsu.com/en/company/rd/cigs/index.html
Cell evaluation samples available upon requests under NDA☺

3. Thermal Durability

- Our monolithic module design with contact pad enables high packing factor
- CIGS CIC module showed 99% P_{max} retention ratio after -120 °C/+120 °C x 1313 cycle

Note: Test conducted on a CIC configuration (cell module with coverglass and interconnect pads) and **not** on a coupon or panel-level structure (e.g., CFRP/Al honeycomb). Cell module size may vary.

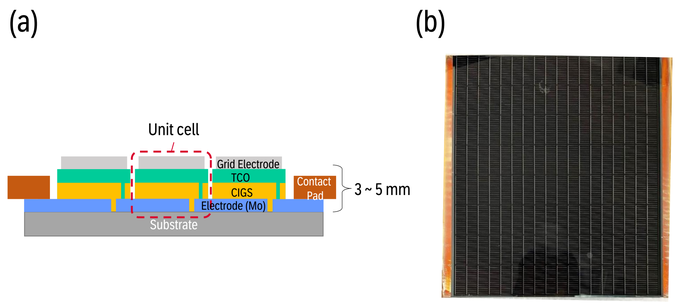


Figure 3.1 (a) Cross-section schematic, and **(b)** top-view of Idemitsu CIGS CIC test module (e.g. 120 mm x 130 mm x 0.4 mmt, Coverglass: 50 µmt)

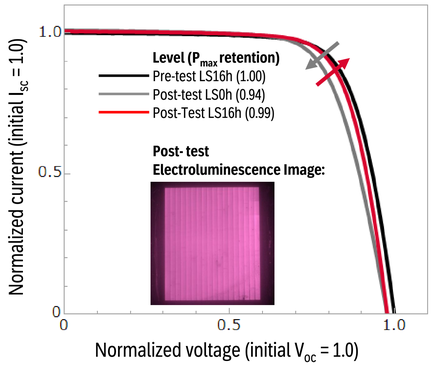


Figure. 3.2 Thermal cycle test result of CIGS CIC module (-120 °C/+120 °C at ~7 min/cycle, 1313 cycle)

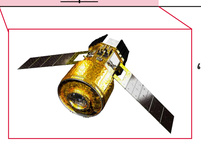
4. In-orbit Demonstration

- Idemitsu CIGS has been demonstrated for LEO & GTO thorough joint research programs
- More demonstrations ongoing & planned

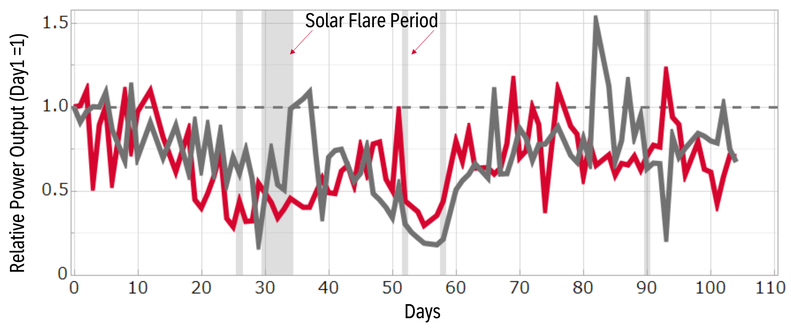
Table 4.1 List of former and up-coming Idemitsu CIGS in-orbit demonstrations.

Spacecraft	MDS-1	XI-V	BOTAN	HTV-X1	MOMIJI	Ten-Koh 3
Operation	JAXA	Tokyo Univ.	Chiba Inst. Tech.	JAXA	Chiba Inst. Tech.	Nihon Univ.
Launch Year	2002 Finished	2005 Finished	2025 Finished	2025 Ongoing	2026 (Plan)	2027 (Plan)
Orbit	GTO	LEO	LEO	LEO	LEO	LEO
Satellite size	2.7m^3	1U	1U	ISS supply ship	2U	3U
Reference	M.Imaizumi et al., Prog. Photovolt: Res. Appl., 13 (2005).	S.Kawakita et al., Trans. JSASS Space Tech. 7, 26, (2009)	https://sites.google.com/p.chibakoudai.jp/gardens-04/home	https://www.idemitsu.com/jp/news/2025/251017.pdf	S.Inoue et.al., 69th SSTC Japan (2025)	-


Chiba Inst. Tech. "BOTAN"


JAXA "HTV-X"

- Unshielded Idemitsu CIGS maintained operational throughout 100+ days mission even after the occurrence of a large solar flare (> class-X) .



Solar cell type:
- CIGS (active area ~ 54 cm^2, unshielded, metal substrate)
- 3J-GaAs (Azur 3G30A with 100 µm coverglass)

Demo condition:
- Mission period: 2025/10/10-2026/02/27 (JST)
- CIGS cell body-mounted to 1U cubesat
- Released from ISS "KIBO"

Figure. 4.1 "BOTAN" mission data of daily averaged power output from solar cells.

References:

1) S. Kawakita et al., Jpn. J. Appl. Phys. 41, L797 (2002).
2) H. Tomita et. Al., 42nd SPW (2025).
3) M. Yamaguchi et al., *2019 IEEE 46th PVSC*, 2377-2380 (2019).
4) P. Sharps et al., 11th Europwan Space Power Conference (2017)
5) M.J. Boschini, et. Al., SR-NIEL–7 Calculator(2014), : https://www.sr-niel.org/ as of Apr.2026