Performance evaluation and reliability analysis of perovskite solar cells under space environment

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Introduction

With the idea of commercial spaceflights and an increased number of spacecrafts launched over the past years, aerospace companies need to provide efficient and reliable energy provision to their space equipment. For future space missions, researchers want to further improve the solar cells that power satellites and start experimenting for missions to the Moon and Mars. With the benefits of thin film solar cells being more decisive, researchers are looking more into perovskite being one of the most interesting materials.

Perovskite solar cells have gained interest because of the following benefits:

- high efficiency
- tunable bandgap
- high defect tolerance
- lower manufacturing cost
- radiation resistance
- high power density
- increased light absorption

Although perovskite offers significant advantages for space, there are concerns that have yet to be investigated.

Perovskite crystal structure

In photovoltaics, perovskite refers to the crystal structure that has a cubic shape, like illustrated in Fig. 1. It consists of a small **organic cation** A, a larger **metal cation** M and a **halogen anion** X. Hence, they’re also called **organic/inorganic metal halide perovskites**

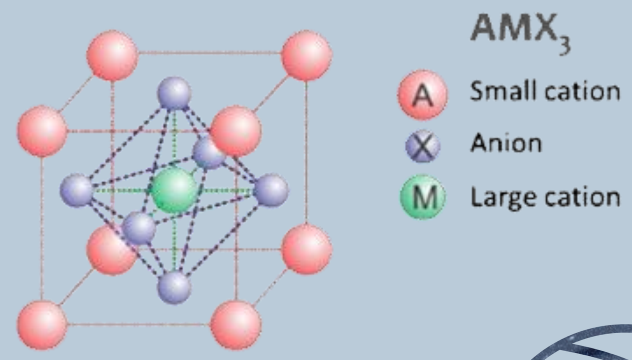

Fig. 1: Perovskite crystal structure

Problem statement

With perovskite showing characteristics that could be beneficial for extraterrestrial use, researchers are interested in their potential for future space applications. At this moment, there is a lack of standardized testing protocols for thin film materials because there has only been a recent interest and little research that has been done on thin film for applications in space.

Goals

1. Performance evaluation and reliability analysis of perovskite in space
2. Inspection of occurred degradation mechanisms

Methods

This thesis started off with an intense literature review, followed by practical lab work that consisted of laminating, characterizing and testing the solar modules for degradation. $FA_{0.8}Cs_{0.2}Pb(I_{0.94}Br_{0.06})_3$ perovskite was used for all experiments.

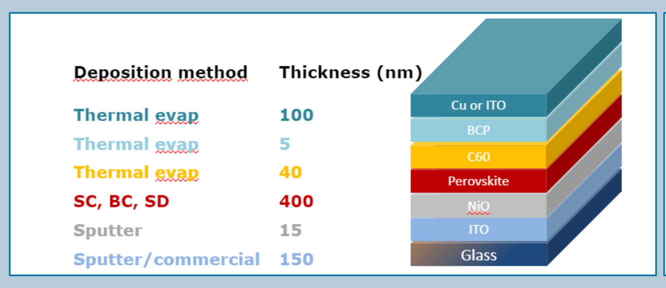

Fig. 2: perovskite module layer stack

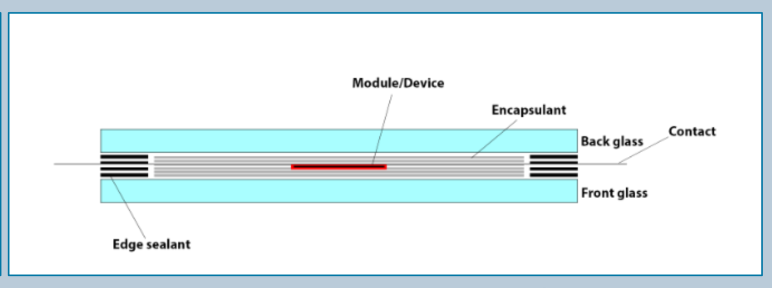

Fig. 3: Laminated module

All samples were exposed to representative space conditions that included:

- **Thermal cycling** under atmospheric pressure between -60°C and 110°C for 197 cycles;
- **Thermal cycling** in vacuum (3×10^{-6} mbar) between -60°C and 110°C for 197 cycles;
- **Ultra-high UV irradiation** (280 nm – 400 nm) for 550 equivalent sun hours ;
- 45kev and 950 keV **proton radiation** with 10^{11} and 10^{13} protons/cm²; [1]
- **Damp heat** testing for 30 days, at 60°C, 90% relative humidity.

By doing a full characterisation before and after each test, an evolution in module performance was observed. Characterisation included:

- **JV curve** measurements under AM0 and AM1.5 solar spectra;
- Steady-state and time-resolved **photoluminescence** spectroscopy;
- **Electroluminescence** spectroscopy;
- **External quantum efficiency** measurements (EQE);
- Regular **pictures**.

At last, data was analysed using OriginPro. This allowed the evaluation of optical and electrical properties, degradation mechanisms and internal material structure.

Results

A large decrease in PCE of 14,3% was observed after thermal cycling, while on average J_{sc} and V_{oc} decreased 3,8% and 4,2% respectively. Although only 30 cycles were done for thermal cycling in vacuum, the first impression suggests that this samples experienced an accelerated degradation based its J_{SC} and PCE. Sample LTTC1 had a large drop in EQE while the other modules had smaller decrease in EQE after 197 cycles. The trPL time-constants did not change significantly during the experiment which indicates that there were no changes in the charge recombination speeds.

Ultra-high UV irradiation shows a large PCE decline after its first 48 hours of testing due to the “Burn-in” effect. Overall, the V_{oc}, FF and PCE dropped between 20-30%. Also, an increase in shunt and series resistance was observed over time. Most importantly the samples showed significant damage in EL-imaging.

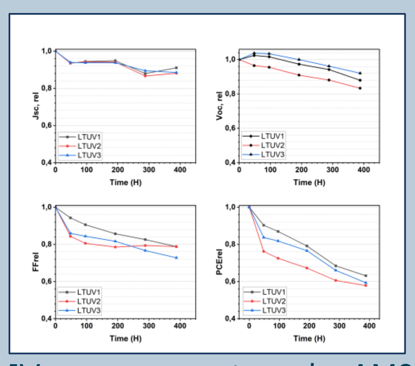

Fig. 4: JV-measurements under AM0 after 388 hours of ultra-high UV irradiation

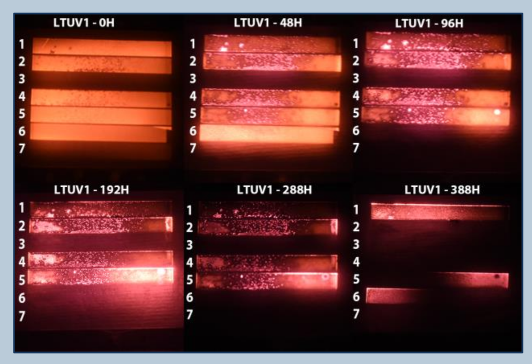

Fig. 5: EL images after 388 hours of ultra-high UV irradiation

Damp heat testing showed a linear decrease in J_{sc} of less than 8% and a drop in PCE 15,1% after 638 hours of testing. Furthermore, the EQE intensity was reduced by 12,0% between 400 and 700nm which could indicate degradation of the bulk perovskite. Lastly, EL-imaging remarkably showed an improvement of the luminescence after 638 hours which was not expected.

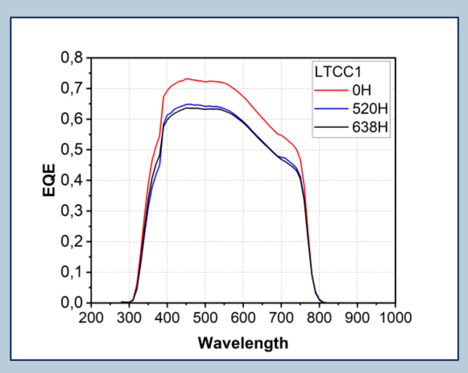

Fig. 6: EQE spectrum after 638 hours of damp heat testing

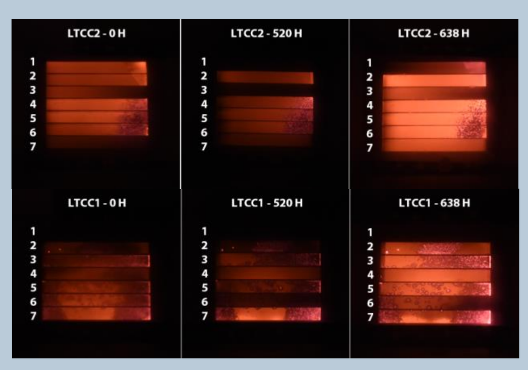

Fig. 7: EL images after 638 hours of damp heat testing

In general, a resilience of the perovskite modules when assessed across varying proton energy levels and fluences could be observed. There was also an increased series resistance found under 45keV 10^{13} protons/cm² and 950keV 10^{11} protons/cm².

Conclusion

Thermal cycling may have caused delamination together with slight potential bulk perovskite degradation. **Damp heat** caused moderate degradation visible by increased shunt resistance and potential damage to bulk perovskite. **Ultra-high UV** has led to ITO-blistering, potential Iodide composition change and bulk perovskite and interface degradation. **Proton radiation** [1] shows signs of charge extraction restrictions at perovskite-ETL/HTL interfaces.

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[1] Khanal et al., “Radiation versus environmental degradation in unencapsulated metal halide perovskite solar cells.” Journal of Physics: Energy.

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