On the Performance of $MAPbI_3$ in the Space Environment

Timothy J. Peshek, *Member, IEEE*[1*], Kyle M. Crowley[2], William Delmas[3], Sayantani Ghosh[3], Jennifer W. Williams[4], and Lyndsey McMillon-Brown, *Member, IEEE*[1]

[1]Photovoltaics and Electrochemical Systems Branch, John H. Glenn Research Center, The National Aeronautics and Space Administration, Cleveland, Ohio, 44135

[2]NASA Postdoctoral Program, John H. Glenn Research Center, The National Aeronautics and Space Administration, Cleveland, Ohio, 44135

[3]Department of Physics, University of California at Merced, Merced, California, 95344

[4]Wilberforce University, Wilberforce, Ohio 45384

[*]Corresponding author: timothy.j.peshek@nasa.gov

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***Abstract*—We show that a $MAPbI_3$ film that was encapsulated has survived the space environment on the International Space Station for a total of approximately 10 months on orbit with little to no chemical degradation. This effort is part of our ongoing efforts to determine the feasibility of $MAPbI_3$-bearing solar cells for space applications. This sample was part of the thirteenth flight of the Materials International Space Station Experiment (MISSE-13), which flew from mid-March, 2020 until mid-January, 2021. We determined the robustness of the material through the use of transmission spectrophotometry. To our knowledge this report represents the longest known flight in space of a $MAPbI_3$ film.**

***Index Terms*—Space photovoltaics, perovskite**

I. Introduction and Background

In an earlier abstract and proceedings we described the studies of encapsulated $NH_3CH_3PbI_3$ (methylammonium triiodo plumbate, or MAPI) on the feasibility of the material being space qualified [1]. Solar cells based on these materials hold great promise for space applications. In the environment of space there is no moisture or oxygen to react with the perovskite material and cause degradation to the binary constituents. However in order to be qualified for space applications, a series of tests outlined in the AIAA-S111 standard is typically followed and among these tests is an intense humidity test that prescribes soaking the solar cells at 95% relative humidity (RH) at 45° C for 1500 hours. These conditions would destroy most champion devices described in the literature without moisture barriers [2] [3], [4].

Although the AIAA-S111 prescribes a methodology for space qualification, novel material often benefit from a low barrier platform for actual in-space exposures. The Materials International Space Station Experiment (MISSE) platform provides one such avenue for exposure. The MISSE flight facility (MISSE-FF) is large sample holder with integrated electronics and analytical tools to allow for samples to be mounted in a space qualified structure that is owned and operated by Alpha Space Test Research and Alliance, LLC. The MISSE-FF allows for samples to be flown on the ISS and then be returned after a period on orbit.

We will describe how we flew an encapsulated MAPI film onboard MISSE-13, and characterized the material upon landing after approximately 10 months on orbit.

II. Experimental

The perovskite ink used was obtained from Sigma-Aldrich and consisted of MAI and PbI_2 dissolved in DMF in the ratio 1:1:1 respectively.

All of the following steps were performed in a nitrogen purged glove box:

1) Drop cast 30μl of ink onto a 1” by 1” borosilicate glass microscope slide (1mm thick)
2) Spin at 2000 RPM for 90 seconds
3) Anneal on a hotplate at 100° Celsius for 10 minutes. The grey film transitions to black seconds after being placed onto the hotplate
4) The encapsulant DC-93500 is a two-part silicone, mixed thoroughly in a 10:1 ratio and then degassed.
5) the encapsulant is applied to the perovskite layer
6) a matching 1” by 1” borosilicate glass microscope slide is laminated to the perovskite/glass substrate by pushing into the wet bed of silicone encapsulant.

Samples were exposed to high humidity conditions using an environmental test chamber (ETC) programmed to mainatain an ambient environment of $95 \pm 5\%$ RH and $28 \pm 2^\circ$ C. The samples were periodically removed from the ETC and characterized by collection transmission spectra and optical imaging. Transmission spectra were collected using a Lambda 950 spectrophotometer with a spot size of about 1 cm^2. We have acquired transmission spectra periodically across 880 hours of high humidity testing. The transmission spectra serve as a non-contact, non-destructive method of probing material quality as the MAPI film will degrade into PbI_2, easily discerned by UV-Vis spectrophotometr, via numerous pathways [5].

Very little degradation is observed over time as evidenced by minimal changes in the transmission spectra [1].

A. *MISSE-13*

Two identical samples were retrieved from the humidity exposure study, that displayed no apparent degradation and were

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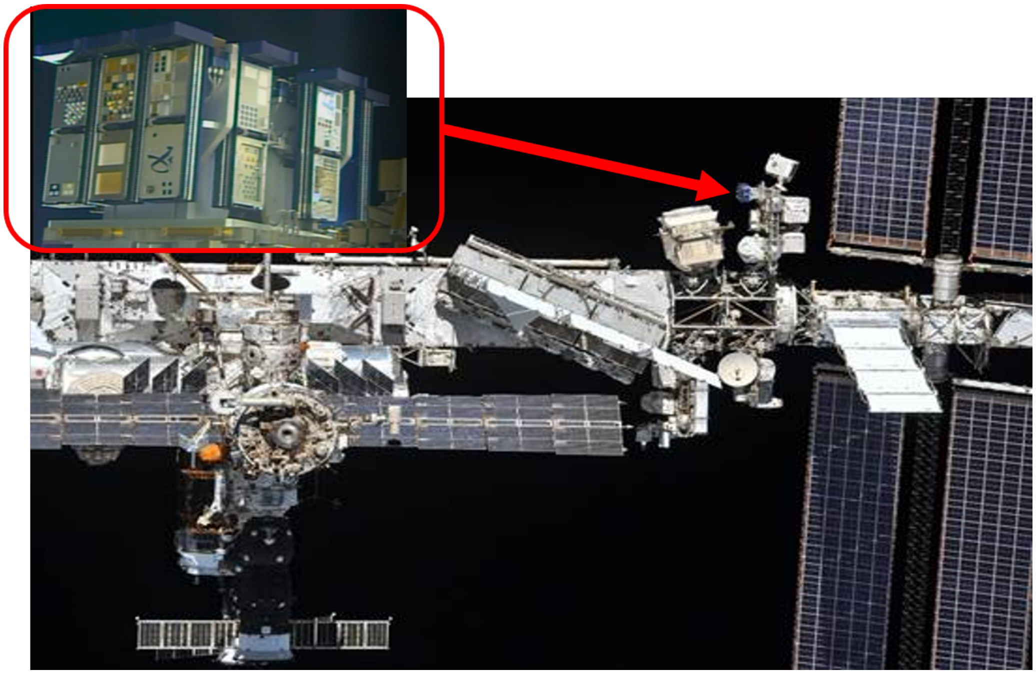

Fig. 1. An image of the International Space Station in orbit, showing the location of the MISSE-FF (red arrow) and an image from the ISS camera of the MISSE-FF platform (red box inset) which holds research samples.

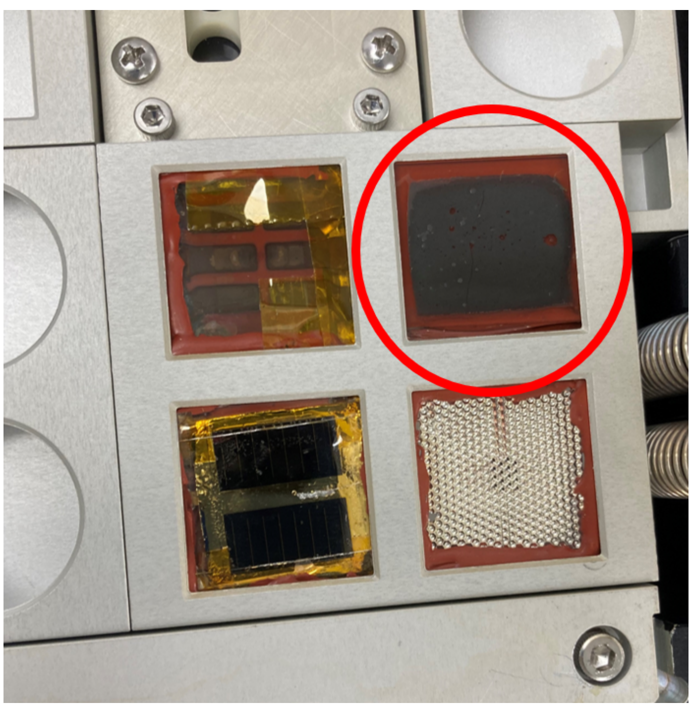

Fig. 2. An image of our MAPI sample (circled in red) as integrated onto the MISSE-FF pre-flight. Courtesy Alpha Space Test and Research Alliance, LLC.

fabricated under equal conditions. One sample was randomly selected to be the flight sample, and to preclude shattering, the sample was laminated to a copper-clad FR4 glass-filled epoxy board with Momentive Performance Materials RTV 566 red silicone adhesive, which was applied according to the manufacturer's specifications. The wet red silicone squeeze-out grouted the edges of the laminated glass/MAPI/glass stack.

This sample was shipped to Houston/TX, location of Alpha Space Test and Research Alliance, LLC who is contracted with NASA to provide the MISSE-FF services, on approximately October 10, 2019. The sample was integrated into the MISSE-FF, shown in Figure 2, and then subjected to environmental testing. The environmental testing including a high vacuum bakeout at 60 °C for 25 hours, and 3 axis vibration testing at 4.5 grms. Approximately 5 months later the samples were launched aboard SpaceX Falcon, on the 20th Commercial Resupply Mission (CRS20) on approximately March 7, 2020. The samples were returned to Earth aboard SpaceX CRS-21, which landed on January 14, 2021. Samples were de-integrated and delivered to NASA approximately 2 months later.

III. Data Analysis

For rapid data collection on the returned sample, we proceeded to use a razor blad to separate the laminated glass/MAPI/glass stack from the FR4 carrier sheet, and remove the remainder MPM RTV 566 adhesive. The sample was cleaned with a isopropanol wash to remove residues and then transmission spectra on the post-flight sample as well as the pre-flight witness sample were acquired using an Ocean Optics USB 4000 UV-Vis mini fiber optic spectrometer, with an approximately 1mm diameter spot size.

The comparison transmission spectra are showed overlaid in Figure 4. The low transmissivity is due to the small spot size and internal reflections from the glass. However, it is clear that no PbI_2 band edge absorption is observed.

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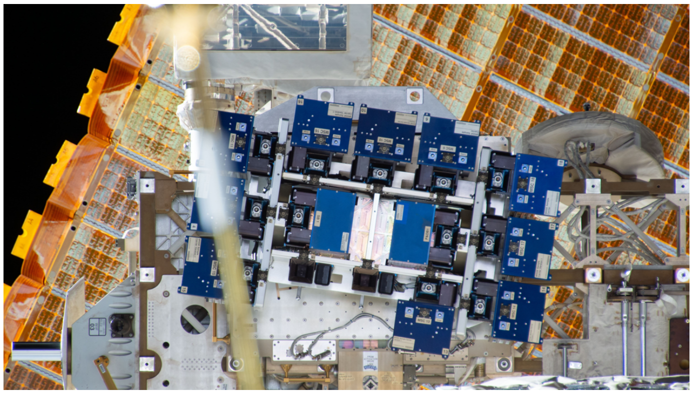

Fig. 3. An image of the MISSE-FF on the ISS showing the decks of the MISSE-FF that hold research samples.

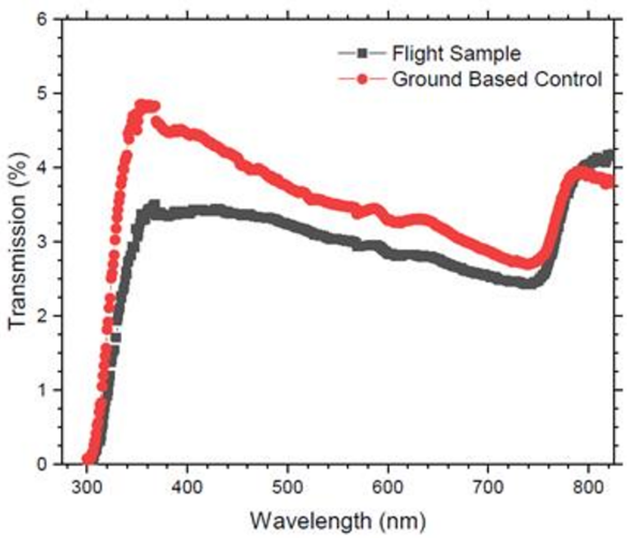

Fig. 4. Transmission spectra as acquired post-flight and on the control samples for comparison. Here we see no major differences between the samples save for a modest broadband decrease in transmission for the flight sample.

Overall the two spectra are very similar, and these spectra are representative of the several spots that were measured on the samples. These data indicate two suggested conclusions: First, The MAPI sample is essentially unchanged from the witness sample, which was held in a nitrogen-purged dry box in Cleveland, Ohio for the duration of the on-orbit flight; Second, the borosilicate microscope glass slide is potentially darkened by the modest radiation on the LEO flight, however the loss in broadband transmission is modest, and therefore may make a suitable low-cost substrate for future, MISSE studies if a control is used for calibration of the transmission. This effort is ongoing and will be presented more clearly for the PVSC presentation.

These data are strongly suggestive that the moisture uptake by the DC 93-500 is sufficiently low to protect the devices from fabrication time to launch times if stored properly. Further, although MAPI chemical composition is not the only, or primary predictor of device performance, these data also suggest the the MAPI film alone is robust to the space environment, both vacuum and thermal stressors. It is thus possible that device quality material is not inherently unstable under the conditions required for on-ground fabrication of solar cells for space.

IV. Conclusions

We have shown preliminary data that are strongly suggestive that MAPI films can survive the space environment in LEO for approximately 10 months with no signs of chemical degradation. These data represent the longest time period to our knowledge that a perovskite absorber material for solar cells has flown in space. These preliminary data are encouraging that the MAPI films are chemically robust enough to withstand the LEO environment while encapsulated. Follow-on experiments are planned for future MISSE flights, which will include functional solar cells based on MAPI, as well as a host of hole transport and electron transport materials.

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