Processing and Characterizing Flexible Perovskite Solar Modules for Lunar Applications

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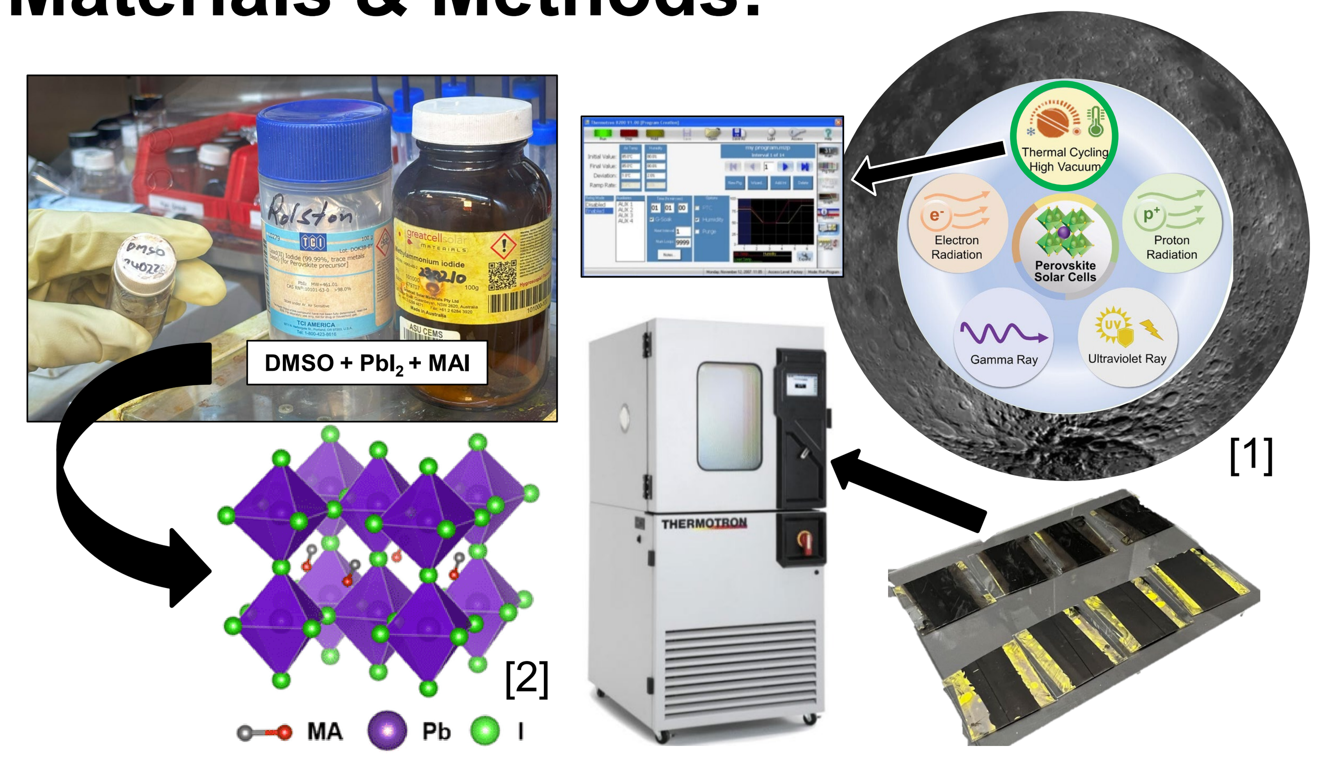
Abstract:

This research investigates the feasibility of designing low-cost, lightweight, and flexible perovskite solar modules (PSMs) for lunar applications. With a focus on addressing challenges inhibiting the scalability of plastic substrate-based perovskite solar cells to PSMs, the study explores processing techniques, photoluminescence comparisons, and the effectiveness of flexible PSMs under simulated lunar conditions. Results aim to guide the development of durable PSM arrays crucial for powering future lunar missions.

Research Questions:

1. Does a PSM on a flexible substrate exhibit improved durability in comparison to a PSM on a rigid substrate?
2. Will a carbon-electrode PSM on a flexible substrate be effective under lunar conditions?

Materials & Methods:



Comparing Durability Under Partial Lunar Temperature Variation

1. Simulated extreme lunar temperature variation with thermal cycling in Thermotron chamber between -40 ºC to 85 ºC, humidity minimized (never exceeding 20%) for 150 cycles.
2. Photoluminescence measurements taken each 50 cycles with StellarNet spectrometer. Changes in intensity, peak wavelength, and curve shape used to compare durability.

Processing and Testing Effectiveness of Carbon-Electrode Structures

1. Carbon hand-coated over perovskite using razor blade, half of samples had additional PMMA spin-coated over carbon. Observed mixing of layer and thickness inconsistency in "PMMA + Carbon" samples
2. Initiated thermal cycling for 200 cycles, conductivity measurements taken initially and each 50 cycles with multimeter. Percent relative standard deviation used as key comparison for effectiveness.

Data Analysis:

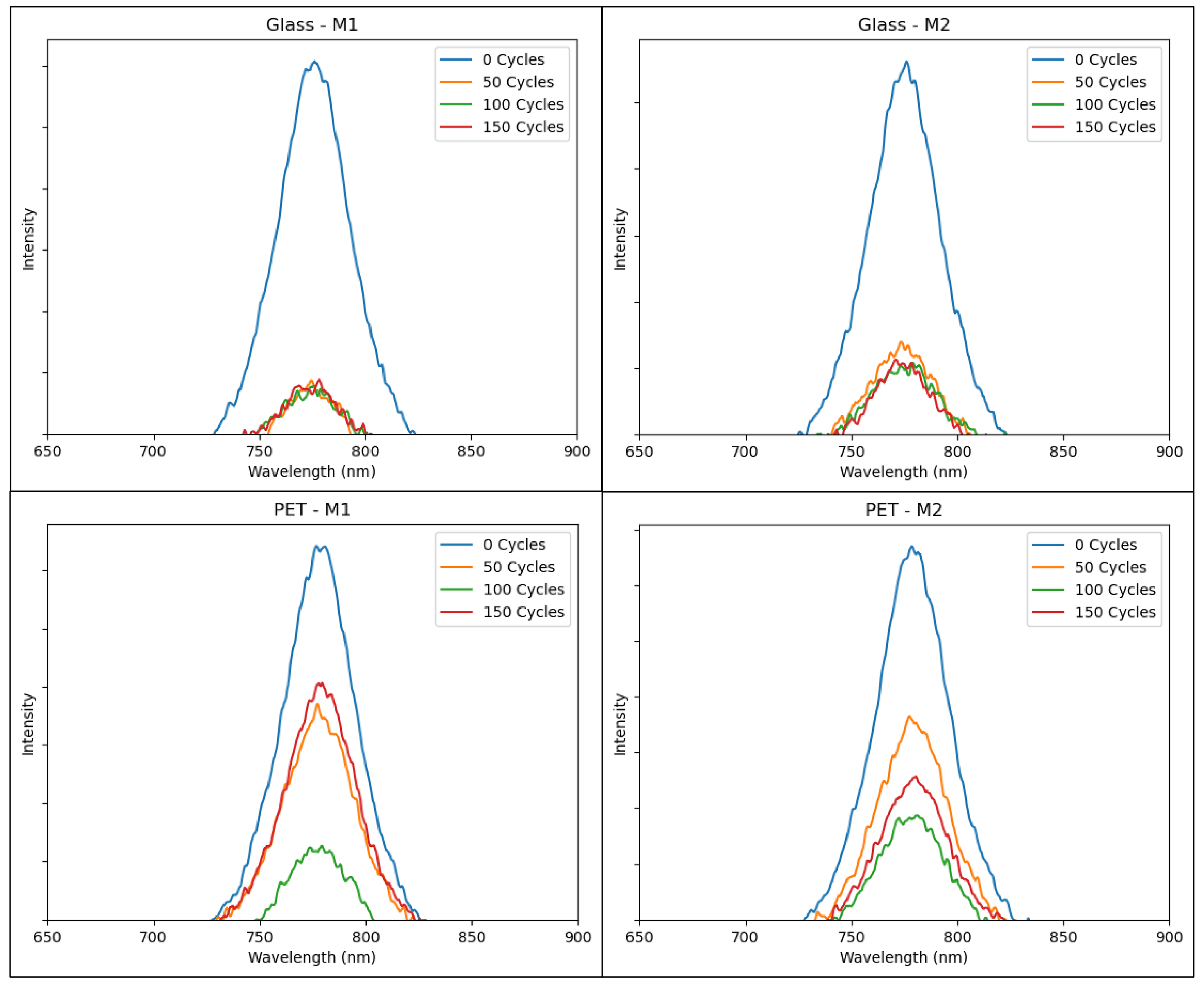


Figure 1: Measured photoluminescence spectrums of samples with PMMA / $MAPbI_3$ / SnO_2 / ITO / Glass and PMMA / $MAPbI_3$ / SnO_2 / ITO / PET structures at 0, 50, 100, and 150 elapsed cycles of temperature variation between -40 ºC to 85 ºC with minimized humidity.

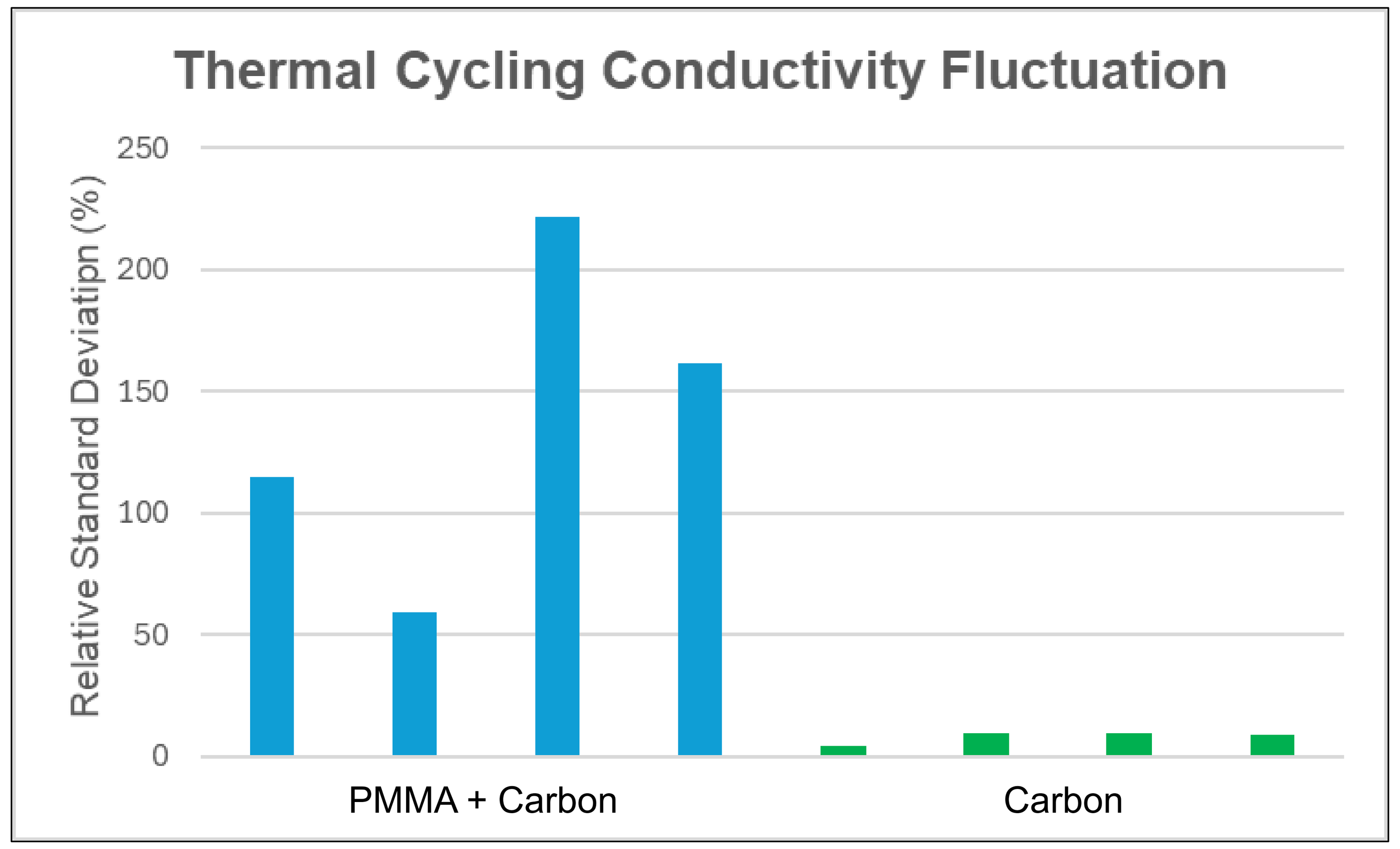


Figure 2: Percent relative standard deviation in measurements of conductivity of samples with (PMMA + Carbon) / $MAPbI_3$ / SnO_2 / ITO / PET and Carbon / $MAPbI_3$ / SnO_2 / ITO / PET structures at 0, 50, 100, 150, and 200 elapsed cycles of temperature variation between -40 ºC to 85 ºC with minimized humidity.

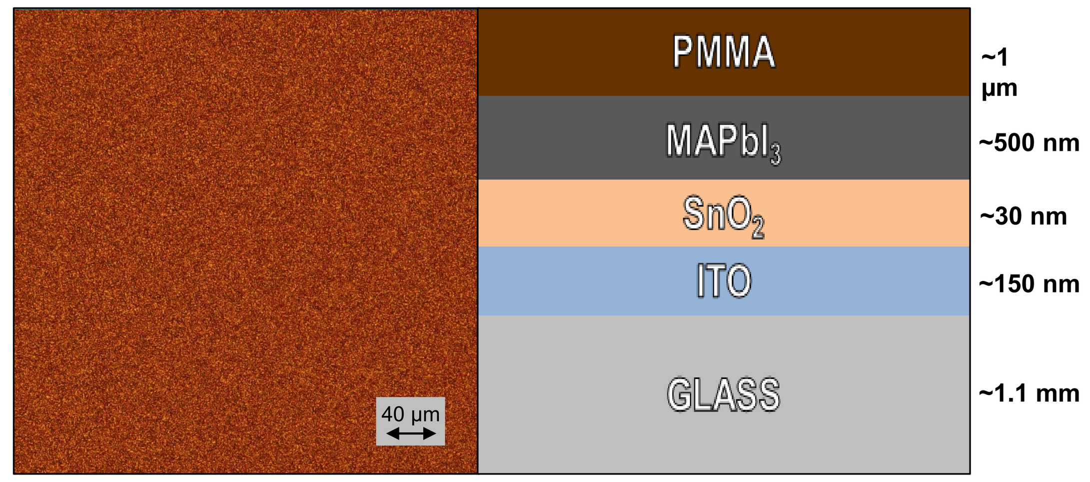


Figure 1a: Microscope close-up of the Glass M1 module sample accompanied by a diagram depicting the layered PMMA / $MAPbI_3$ / SnO_2 / ITO / Glass structure.

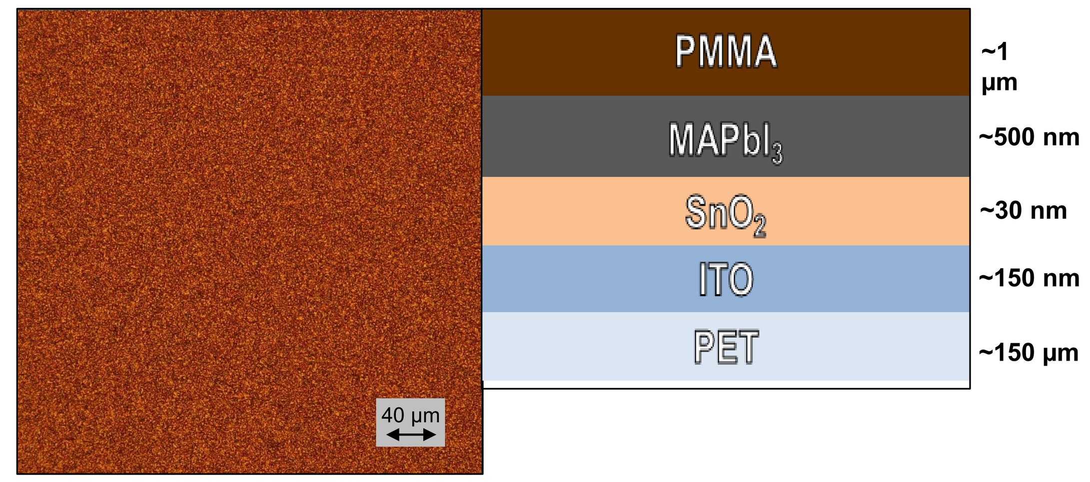


Figure 1b: Microscope close-up of the PET M1 module sample accompanied by a diagram depicting the layered PMMA / $MAPbI_3$ / SnO_2 / ITO / PET structure.

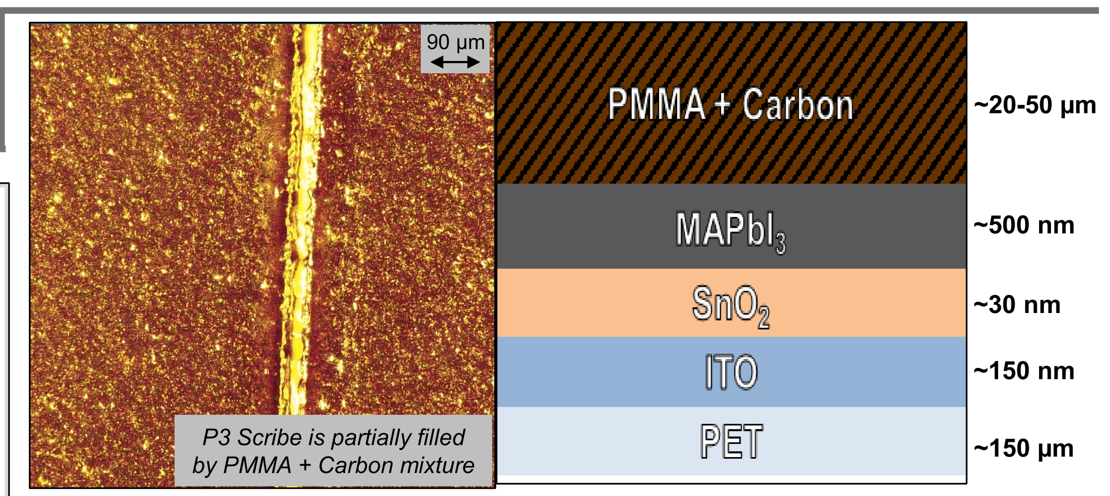


Figure 2a: Microscope close-up of PET PMMA + Carbon module sample accompanied by a diagram depicting the layered (PMMA + Carbon) / $MAPbI_3$ / SnO_2 / ITO / PET structure.

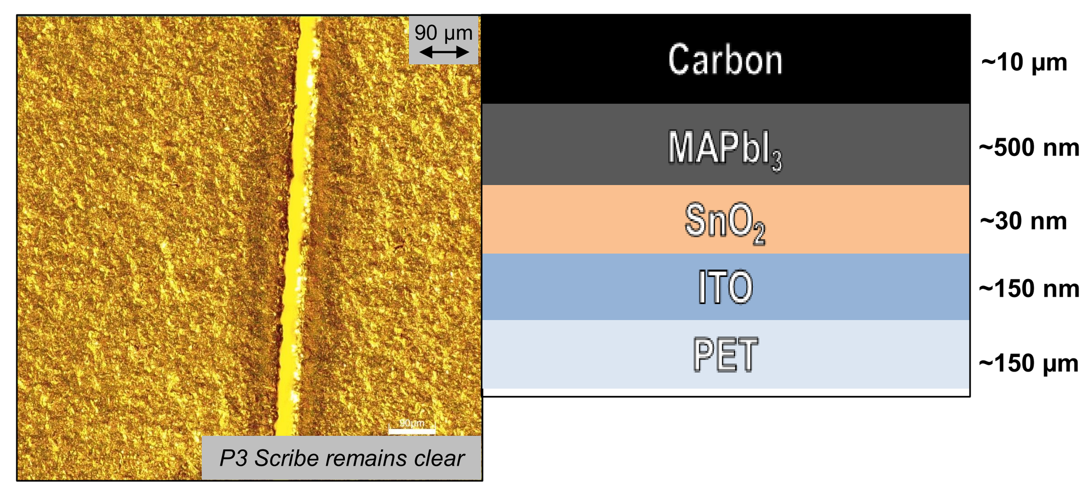


Figure 2b: Microscope close-up of PET Carbon module sample accompanied by a diagram depicting the layered Carbon / $MAPbI_3$ / SnO_2 / ITO / PET structure.

Discussion:

Processing Challenges

- Spin-coating on PET requires method of flattening. Pre-heating hardens the substrate, however challenges in achieving uniform SnO_2 and $MAPbI_3$ distribution are discouraging. Observed improvement when using tape to artificially flatten against glass slide before spin-coating.
- Hand-coating carbon onto PET with a razor blade also requires method of flattening. Artificially taping to surface to flatten allows completion of processing, however uniformity of carbon layer and precise thickness remained unknown.
- Layering PMMA over the carbon layer via spin-coating led to re-liquification of carbon layer and unintended mixing of layers. Observed heavy inconsistency in uniformity and thickness.

Key Outcomes

- Processed film and module samples of similar quality on glass and polyethylene terephthalate (PET) substrates. Minimal differences in initial quality observed via photoluminescence spectrums and microscope imagery. Improved tolerance to thermal cycling observed with use of flexible substrate.
- Observed minimal change to conductivity of carbon-electrode PSM on flexible substrate throughout extensive thermal cycling. More characteristics must be measured to validate effectiveness under lunar conditions beyond temperature variation.

Future Work:

Improve Flexible Processing Techniques: The method of flattening the PET substrate onto a glass slide with tape is inconsistent. Investigate other methods to build consistent PSMs of flexible substrates for higher confidence in comparisons to rigid substrates.

Compare Silver and Carbon Electrodes on PET Substrate: Repeat similar experimentation with comparisons of these two electrodes to confirm effectiveness of a carbon electrode compared to the common silver electrode.

Modeling a Flexible PSM Array for the Moon: With building evidence for the benefits of implementing flexible PSMs in space, investigate how to design a single array or system of flexible PSM arrays with considerations of maximizing light exposure and efficiency.

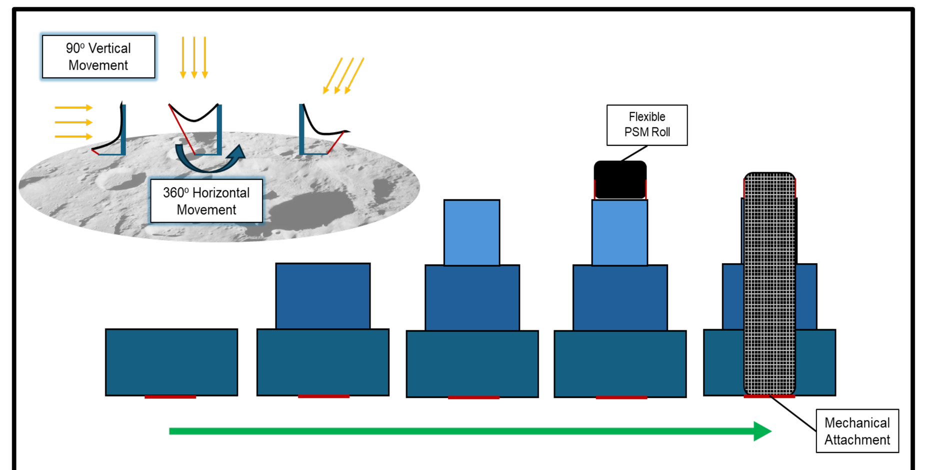


Figure 3: Potential design features of a flexible PSM array on the moon.

References:

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2. Lee, W., Lee, J., Lee, H.-D., Kim, J., Ahn, H., Kim, Y., Yoo, D., Lee, J., Lee, T.-W., Kang, K., & Lee, T. (2020). Controllable deposition of organic metal halide perovskite films with wafer-scale uniformity by single source flash evaporation. *Scientific Reports*, 10(1), 18781. https://doi.org/10.1038/s41598-020-75764-5

Acknowledgements: This research was completed in collaboration with undergraduate researcher Grace Salazar ("Processing and Laser Scribing Flexible Perovskite Modules for Lunar Applications") with mentorship from Dr. Nicholas Rolston, training and guidance from graduate mentor Marco Casareto, and key contributions from researchers Muneeza Ahmad, Erin Burgard, Kausar Khawaja, Mason Mahaffey, Vineeth Penukula and Favian Tippin.

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