Proton Irradiation Tolerance of Wide and Narrow Band Gap Mixed Organic-Inorganic Halide Perovskites: Implications for Power Generation in Space

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Outline

• Motivation
• Hybrid Organic-Inorganic Perovskites
• Temperature Dependent Device Characterization
• Proton Irradiated Solar Cells
• Conclusions and Acknowledgments
Motivation

Requirements for space applications:
- High specific power (W/kg)
- Withstand extreme temperature fluctuations and vacuum
- Tolerate high energy particles (mainly electrons and protons)

Perovskites adaptable to flexible architecture
- Low packing volume, lightweight, high specific power
- Composed of Earth abundant elements
- Low energy processing requirements

Juno and Artemis: www.nasa.gov
Hybrid Organic-Inorganic Perovskites

- ABX$_3$ composition
- A=methylammonium, formamidinium, or Cs
- B=Pb or Sn
- X=I, Br, or Cl
- Solution processable
- Tunable band gap
- 23% power conversion efficiency with polycrystalline thin film solar cells

Y. Yang, et al., Nature Photonics, 10 (2015) 53

1.24 eV
• >13% PCE (AM1.5)
• 3:2 FASnI$_3$:MAPbI$_3$ absorber layer
  FA=Formamidinium
  MA=Methylammonium
• SnF$_2$ antisolvent additive
• Organic-based electron and hole transport layers
• TmPyPB small molecule interfacial layer$^1$

$^1$M. Li, et. al., RSC Advances, 7 (2017) 31158-31163

Developed by Do Young Kim’s group at OSU Tulsa
Current Density-Voltage Curves

Fill Factor (FF) = \( \frac{V_{\text{max}} \times J_{\text{max}}}{V_{\text{o}} \times J_{\text{sc}}} \)

Power Conversion Efficiency (PCE) in %

\[
= \frac{V_{\text{max}} \times J_{\text{max}}}{P_{\text{in}}} \times 100
\]

\[
= \frac{J_{\text{sc}} \times V_{\text{o}} \times FF}{P_{\text{in}}} \times 100
\]

Spectrum is typically:
- AM1.5 (terrestrial)
- AM0 (outside atmosphere)
**JV, External Quantum Efficiency, Photoluminescence**

**AM0 (outside atmosphere)**

- **Voc**: 0.77 V
- **Jsc**: 31.4 mA/cm$^2$
- **FF**: 71%
- **PCE**: 12.8%

Absorption onset and Photoluminescence well matched = 1.24 eV

Organic layers low absorption and photocurrent

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Temperature Dependence

Reduced temperatures increase in Voc and Jsc

- Increased collection efficiency throughout absorber
- Decrease in band gap
- Parasitic barrier to carriers (also decrease in dark current)
- Probable phase transition <100 K

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Proton Irradiation

Solar Winds
www.nasa.gov

- Ejected from sun as solar winds
- Trapped in the magnetosphere (Van Allen Belt)
- Europa very high due to Io’s volcanic activity
- Non elastic nuclear scattering vs electronic ionization (nuclei recoil and displacement)
- 3 years GEO $\approx 10^{12} \text{ H}^+/\text{cm}^2$ accumulated fluence

Polycrystalline Thin Film Photovoltaics
- Thin absorber = less interaction length
- Diffusion lengths already lower

• Competing thin-film technology
• Unencapsulated flexible CIGS solar cells
• 1.5 MeV proton energy
• Radiation hard compared to III-V based technologies

Proton Irradiation:
\((\text{FASn})_{0.6}(\text{MAPb})_{0.6}\text{I}_3\)

3.7 MeV H⁺
(100 μm coverglass back encapsulation)

1E11 H⁺/cm² fluence

• Remarkably tolerant compared to CIGS
• Halide displacements less detrimental

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3.7 MeV H⁺
(100 μm coverglass back encapsulation)

1E12 H⁺/cm² fluence

Long-term and thermal stability issues remain
• Must tolerate vacuum
• Sn/Pb phase segregation
• Sn oxidation

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1.7 eV $E_g$

- 50 keV H\textsuperscript{+} (10's nm encapsulation)
- 1E12 H\textsuperscript{+}/cm\textsuperscript{2} fluence

Stopping and Range of Ions in Matter: 80 keV
Proton Irradiation: $\text{FA}_{0.8}\text{Cs}_{0.2}\text{PbI}_{2.4}\text{Br}_{0.6}$

- >50 keV deeper, can result in heating/ionization

Remaining Factor = $\frac{\text{Final Value}}{\text{Initial Value}}$

B Durant, G. Eperon, I. Sellers, *et al.*, *in preparation*
Conclusions

• Remarkable tolerance for both wide and narrow band gap perovskite based solar cells compared to other technologies
• All Perovskite tandem devices could be attractive candidates for high energy particle environments
• Prohibitive effects of low temperatures, thermal cycling and vacuum still need continued research efforts

Acknowledgements

The UNIVERSITY of OKLAHOMA

Cooperative Agreements for Research and Development Programs OK-19-EPSCoR-0004

Oklahoma Center for the Advancement of Science & Technology (OCAST) Program No.: AR18-052