Jet Propulsion Laboratory
California Institute of Technology

# Virtual Research Presentation Conference

## High-Temperature Solar Array for Venus Surface Missions

PI: Andreea Boca (346)
Co-Is: Terry Hendricks (353), Joel Schwartz (346), Ike Chi (346), Mark Osowski (MicroLink)

Program: Topic

RPC-236

# Tutorial Introduction

*Abstract:*

This FY20-21 task is developing a solar array that will enable long-lived landers to operate on the surface of Venus for up to one solar day (equivalent to 58 Earth days). Such long-duration landed platforms will play a decisive role in the exploration of Venus, through in-situ geochemical, temperature, pressure, wind speed/direction, major-species and seismic measurements performed on the surface. In addition to landers, this solar array technology could also be used to power aerial platforms for performing geophysical and atmospheric observations at higher altitudes.

The challenge to developing this solar array is the uniquely harsh environment on the Venus surface, most notably the 465C ambient temperature, the 92bar atmospheric pressure, and the presence of highly corrosive compounds [1-2]. To address this challenge, the team is taking a cross-disciplinary approach, leveraging materials and processes from thermoelectrics and high-temperature electronics packaging, and adapting them for use in photovoltaics.

# Problem Description

*Context:*

- Currently no long-lived power sources are available, that would be capable of operating or surviving on the surface of Venus

*Comparison to State-of-Art (SoA):*

- SoA power source for Venus landers is primary battery
  - Venera, Vega and Pioneer (1970-1985) perfor[illegible] surface operations limited to 1-2 hours each
  - no lander mission at Venus has been conducted[illegible]nce then
- The high-temperature solar array will be capable of operating on Venus surface for 1-2 Earth months
  - part of a high-temperature power subsystem including rechargeable batteries [3]
  - would enable Venus landers with extended life and significantly higher science payback than SoA systems
- SoA space solar arrays are unsuitable for Venus-surface operation
  - highest temperature capability (e.g. Parker Solar Probe, BepiColombo missions) rated to only 200-250C
  - limited by polymeric and solder interfaces that fail catastrophically well below 465C
- The new technology will leverage materials/processes selected specifically for ability to operate in Venus surface environment

*Relevance to NASA and JPL:*

- Enables long-lived landed capability at Venus, providing JPL with a significant competitive advantage in future proposal rounds

# Methodology

*Formulation, theory or experiment description:*

- Our approach is to leverage recent progress at device level from NASA-funded HOTTech project, in which JPL is developing a solar cell technology capable of extended-duration operation at 465C [4]
  - This R&TD task integrates the HOTTech solar cell *component* into an array-level *system*
- Make use of materials, designs, and processes borrowed from field of thermoelectrics; prior work at JPL on electronics packaging for Venus-surface environment [5-6]; and NASA Glenn work on material survivability in the Glenn Extreme Environments Rig [7-8]
- In FY20, this task has been primarily focused on development, design and fabrication of solar cell assemblies, and on testing them under selected individual Venus-surface environments
- During FY21, will increase level of integration by designing and fabricating small-scale solar array prototype coupon, and will validate its performance through test in a combined-effects Venus-surface laboratory environment

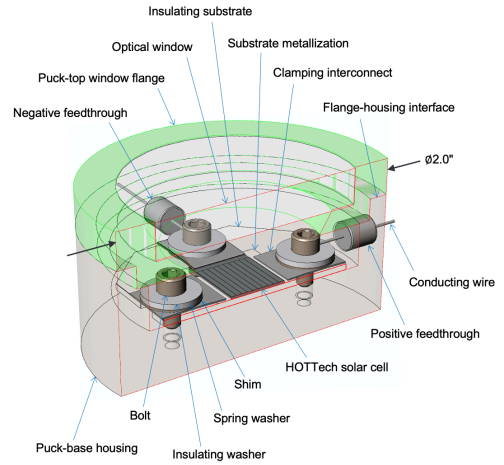
*Innovation, advancement:*

- This will be the first demonstration of a high-temperature solar array capable of surviving and operating for ~1 month in the uniquely harsh environment on the Venus surface

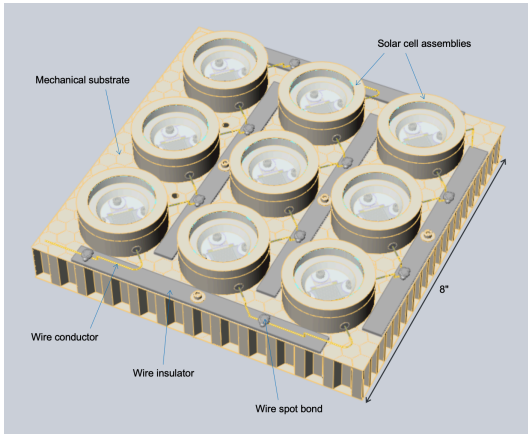
# Results

*Accomplishments versus goals (1 of 2):*

- Developed and released preliminary requirements for design, qualification, fabrication, test and delivery of solar arrays for missions to Venus surface
- Designed solar cell assembly (the "puck") which serves similar function as coverglassed-interconnected-cell (CIC) assembly in conventional solar arrays, but with the added high-pressure and corrosion resistance
- The puck is a sealed environmental container for the solar cell, outfitted with an optically transparent window
- Relied whenever possible on materials and processes whose Venus-surface survivability had already been documented in the literature
  - in some cases verified suitability by thermo-mechanical stress analysis
- Designed prototype solar array coupon, that will be fabricated in FY21
  - nine pucks in a series string, laid out on environmentally robust substrate




Prototype solar cell assembly ("puck") design



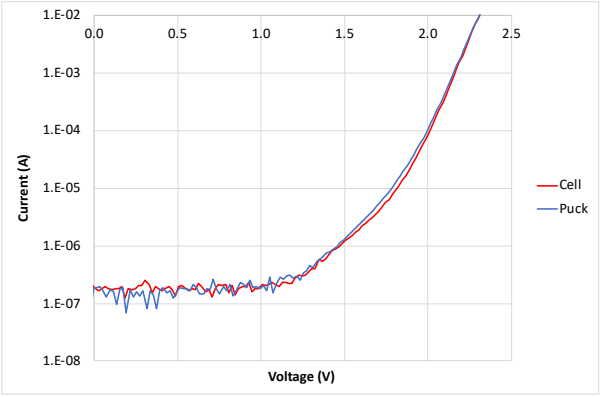

Prototype solar array coupon design

# Results

*Accomplishments versus goals (2 of 2):*

- Developed fabrication-ready drawings, selected vendors, procured parts for building a quantity of 10 prototype "puck" assemblies
- The solar cells (1.4cm$^2$ each) were fabricated by MicroLink using processes already developed on the HOTTech project
- Demonstrated initial portion of prototype puck assembly
  - built two assemblies: solar cells + all puck components except window flange
- Assembly process resulted in no measurable degradation of solar cell performance
  - no change in dark-IV curve, electroluminescence image pre- vs post-assembly
- Exposed the two partial assemblies to Venus surface temperature
  - dwell time 1 hour at 465C; in vacuum furnace of Thermoelectrics laboratory
  - post-bake inspection, data acquisition and analysis now in progress
- Planned for early FY21:
  - completing solar cell and optical-window installation in all puck assemblies
  - high-temperature and high-pressure testing of fully assembled pucks

Assembled puck (all components except window)




Dark-IV comparison: bare cell vs. puck assembly

# Results

*Significance*

- This task has met the majority of its objectives for FY20
- Completed requirements definition and prototype design; made good progress towards protype assembly demonstration

*Next steps*

- In FY21, the team will focus on completing the puck assembly demonstration, and on fabricating/testing the prototype coupon
- Upon successful completion of this task, the technology will be well positioned to obtain funding for TRL-5 development

# Publications and References

[1] D. V. Titov et al., "Radiation in the atmosphere of Venus", in Exploring Venus as a Terrestrial Planet, vol. 176, pp. 121-138, American Geophysical Union 2007, DOI:10.1029/176GM08.

[2] F. W. Taylor et al., "Venus: the atmosphere, climate, surface, interior and near-space environment of an Earth-like planet", Space Science Reviews 214:35 2018, DOI:10.1007/s11214-018-0467-8.

[3] D. Glass et al., "High temperature batteries for Venus surface missions", ECS PRiME 2020, accepted.

[4] J. Grandidier et al., "Photovoltaic operation in the lower atmosphere and at the surface of Venus", Prog. Photovolt. Res. Appl. 28-545, 2020, DOI: 10.1002/pip.3214.

[5] L. Del Castillo et al., "Extreme environment electronic packaging for Venus and Mars landed missions", Proc. 4th International Planetary Probe Workshop, 2006.

[6] L. Del Castillo et al., "Extreme temperature sensing system for Venus surface missions", Proc. IEEE Aerospace Conference 2008, DOI: 10.1109/AERO.2008.4526492.

[7] D. Lukco et al., "Chemical analysis of materials exposed to Venus temperature and surface atmosphere", Earth and Space Science 5-270, 2018, DOI: 10.1029/2017EA000355.

[8] G. C. C. Costa et al., "Chemical and microstructural changes in metallic and ceramic materials exposed to Venusian surface conditions", report no. NASA/TM-2017-219437.