Osazda ENERGY

Development of Low-Cost, Crack-Tolerant Advanced Metallization for Space Photovoltaics

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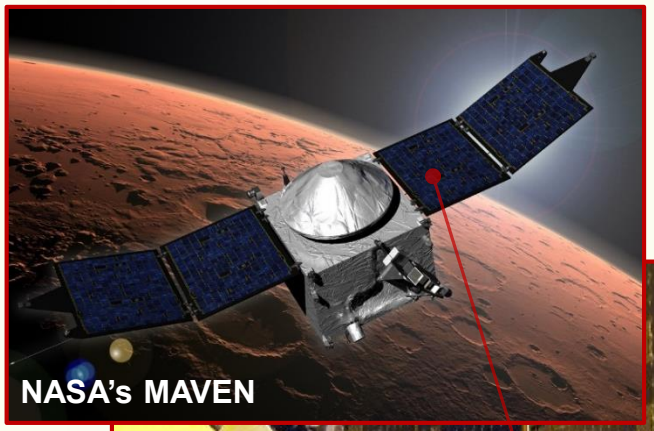
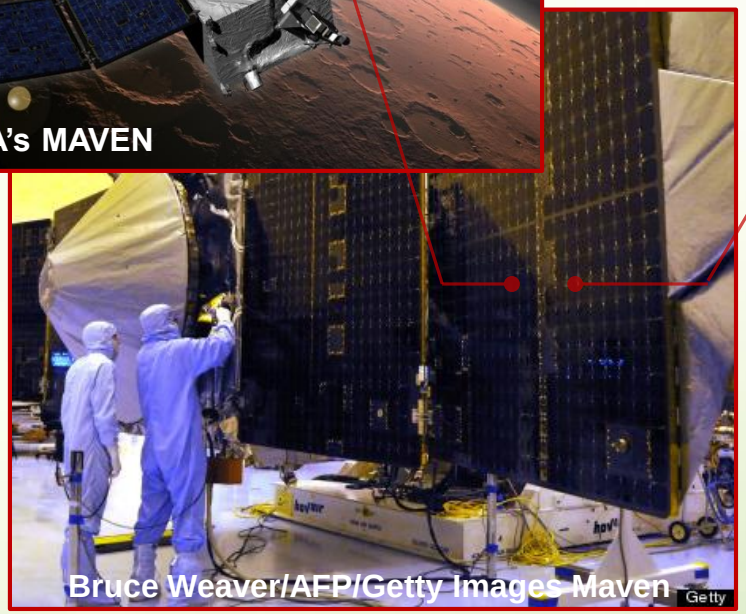
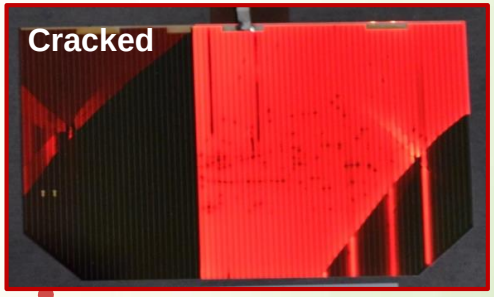
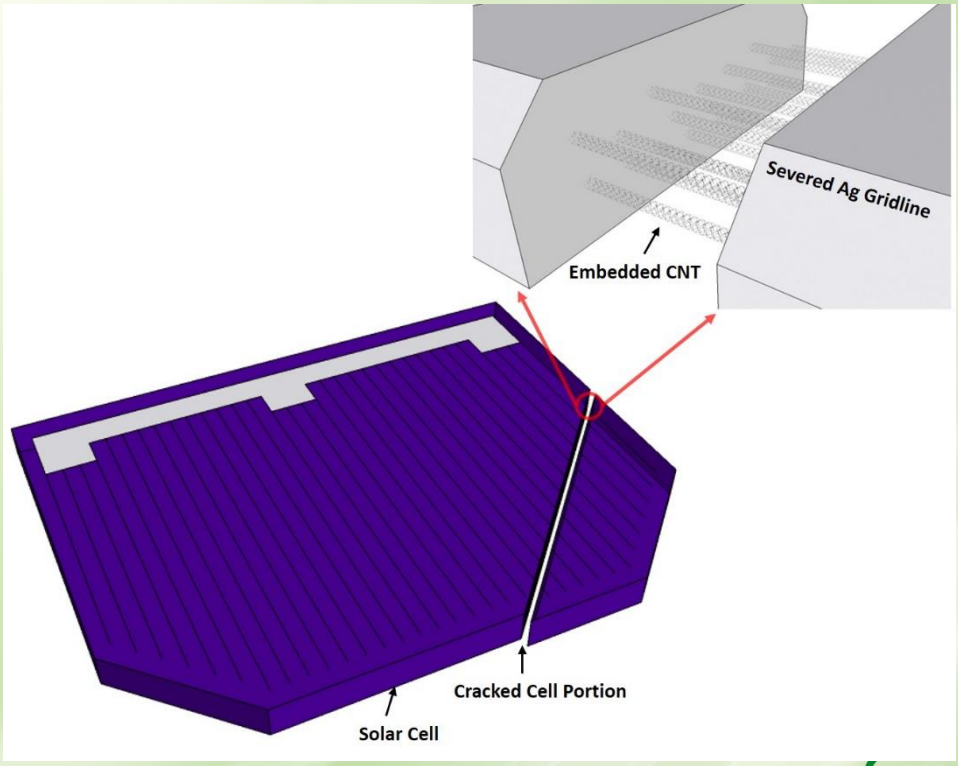
MOTIVATION





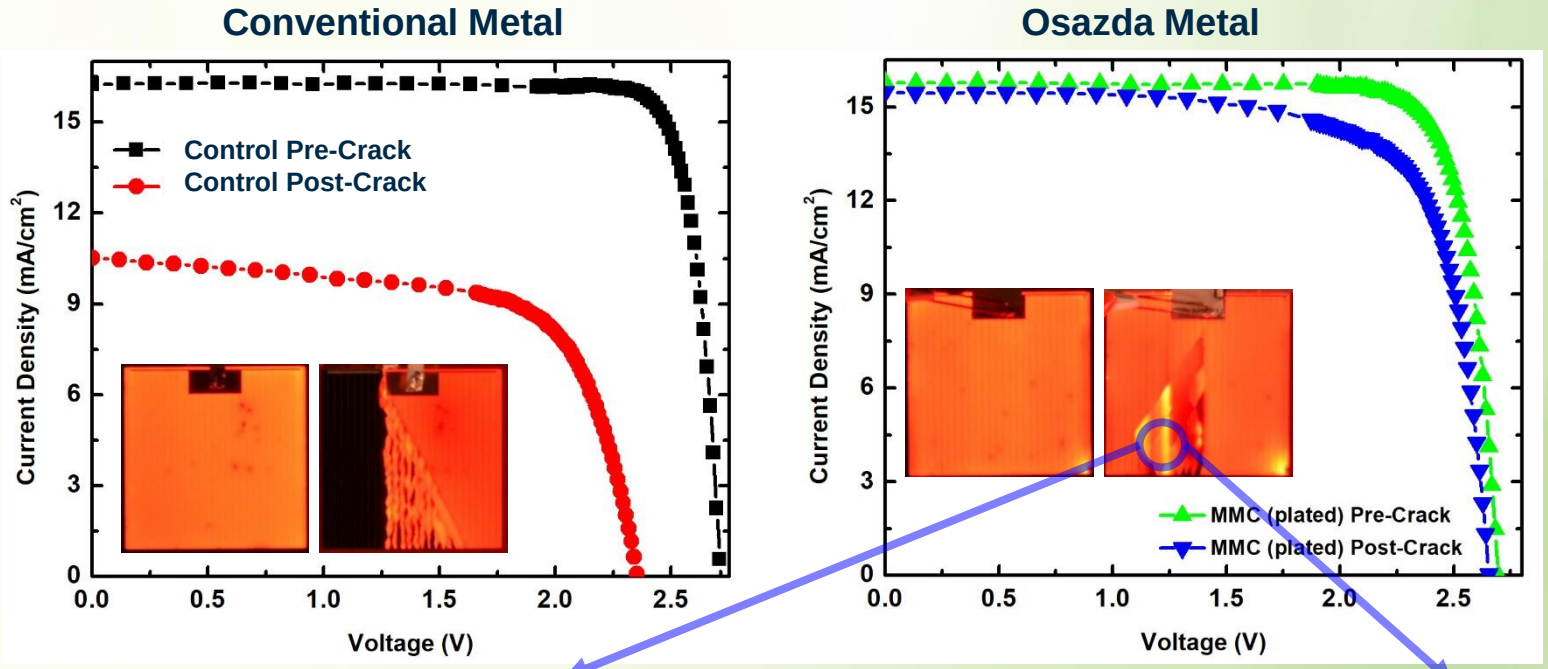




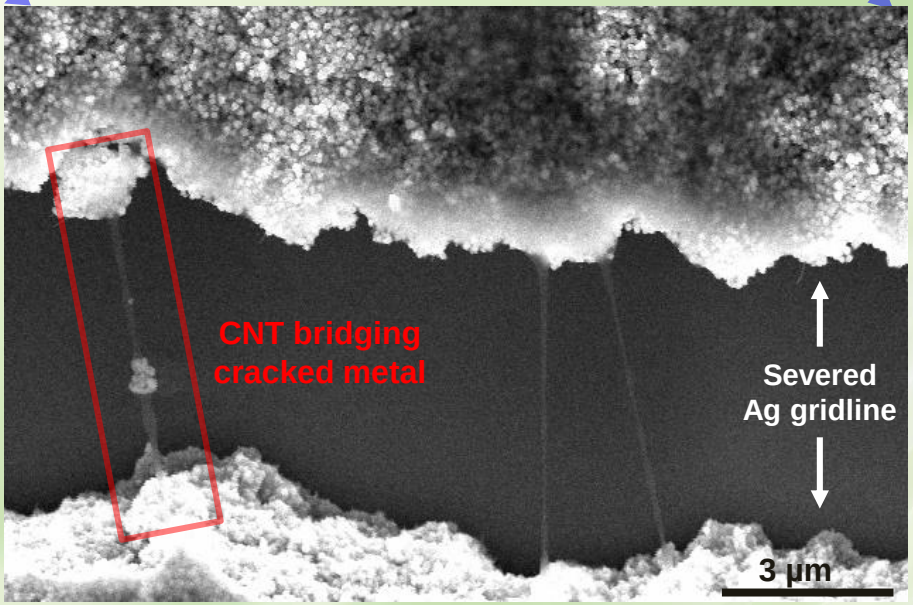
Osazda Energy Approach:

Develop crack-tolerant metal matrix composites (MMC) using Carbon Nanotubes as mechanical and electrical reinforcements to gridlines

OSAZDA ENERGY TECHNOLOGY



Incorporate nanomaterials into solar cell metallization to enable crack tolerant performance



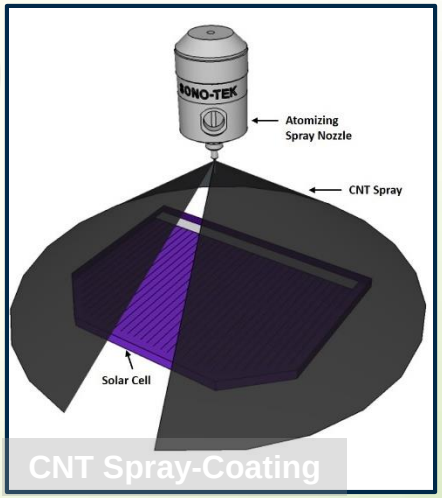
COMPOSITE LINE INTEGRATION

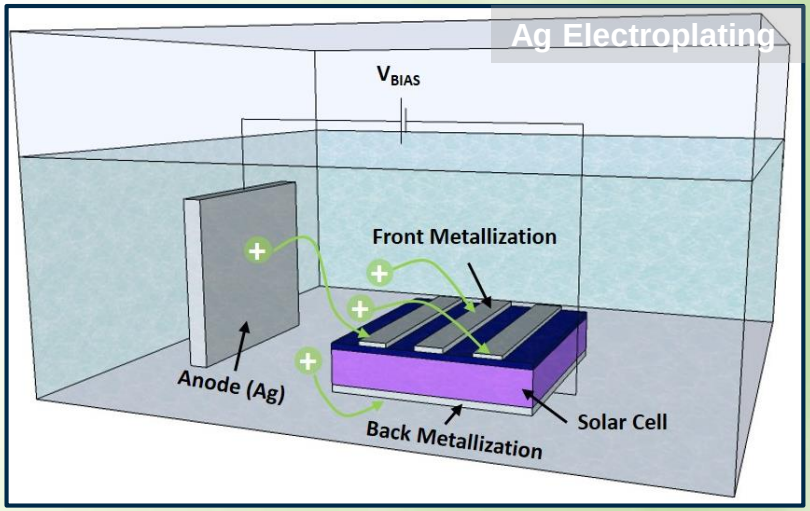
Layer-By-Layer Fabrication

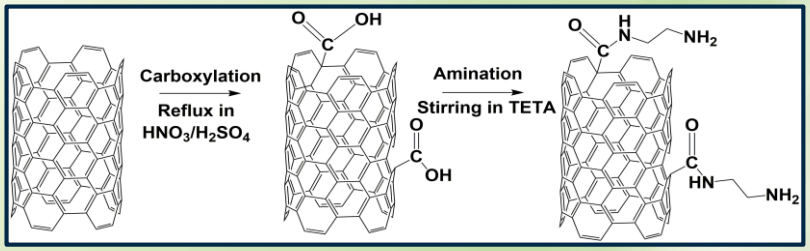
2 µm electroplated Silver

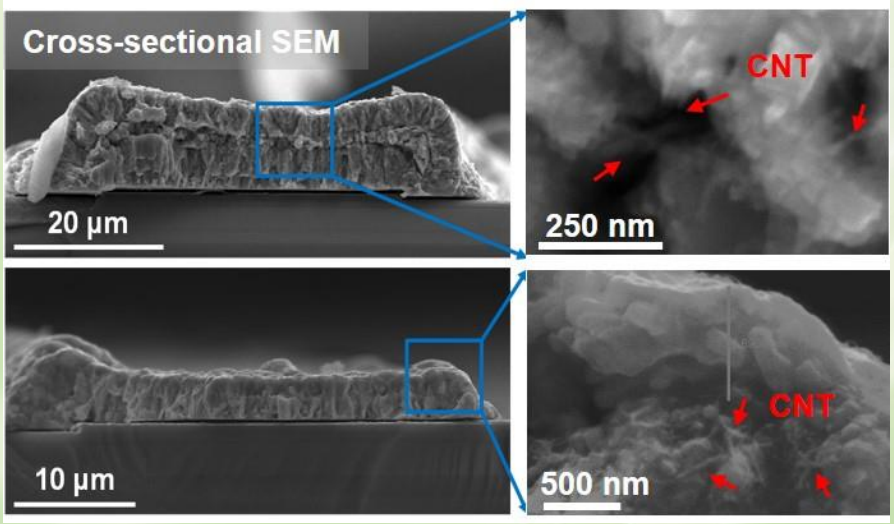
Spray coating thin CNT (functionalized) layer

2 µm electroplated Silver



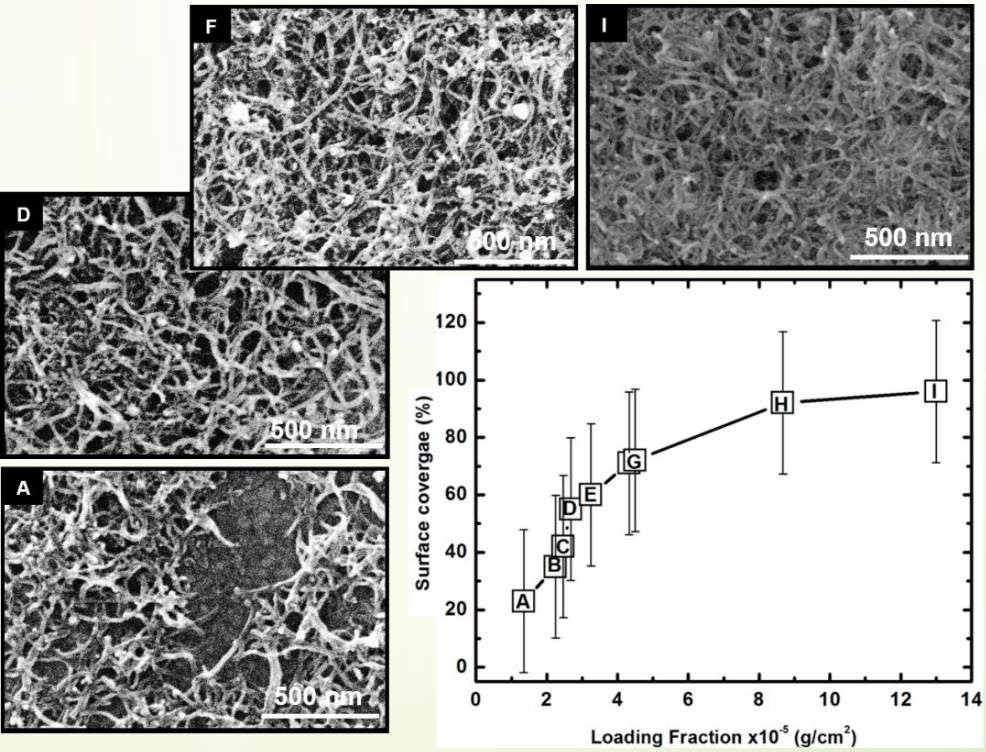




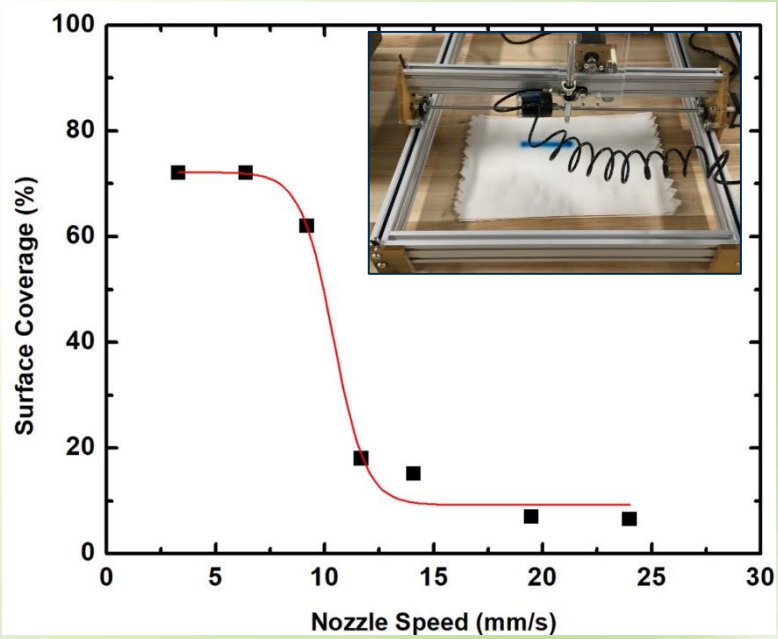


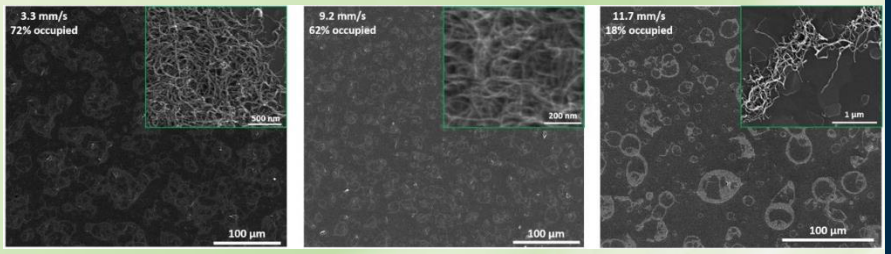
MATERIAL DEVELOPMENT – CNT DEPOSITION

Drop Casting



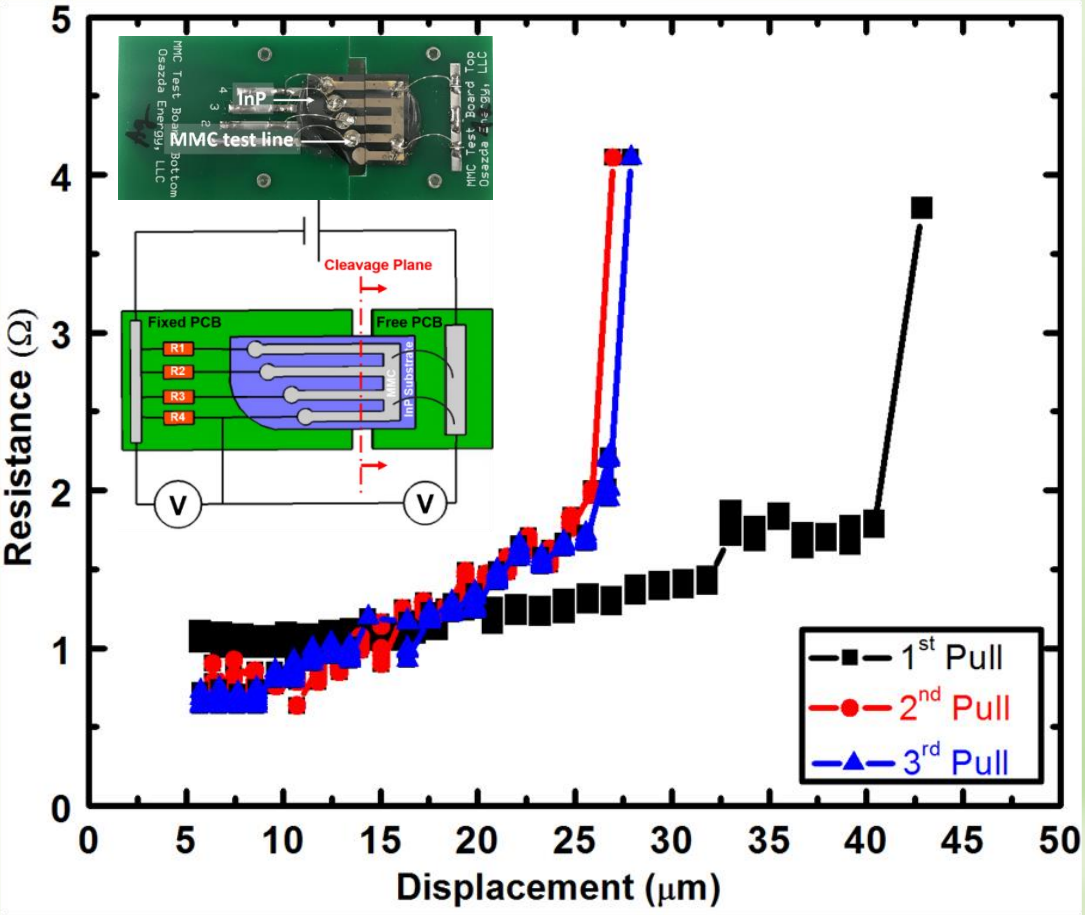
Spray-Coating





- Tailoring the degree of Ag interaction within CNT network by altering the CNT surface coverage
- CNT surface coverage as a function of concentration (drop casting) or stage pull speed (spray coating)
- Spray coating results in uneven coating (“blotchy” islands), lowering the probability of finding a continues CNT network along the exposed cross-sectional plane in the crack

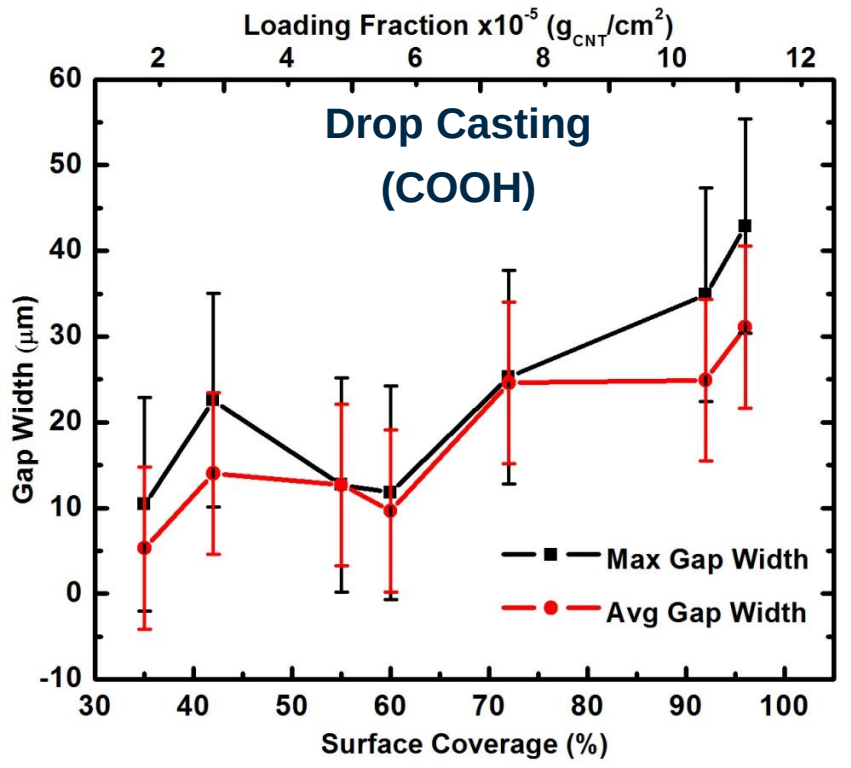
ELECTRICAL CHARACTERIZATION

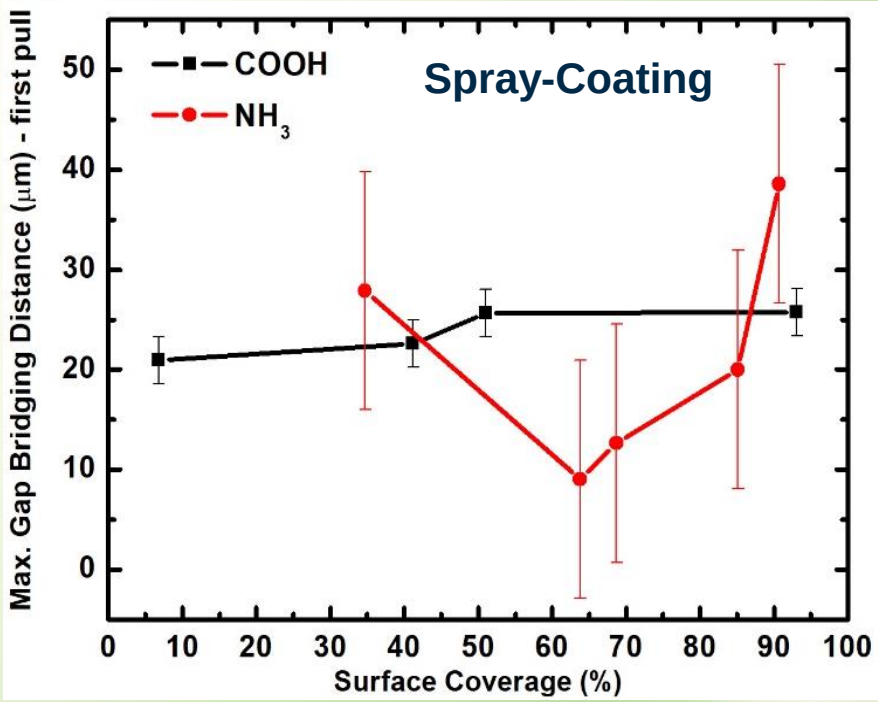


Abudayyeh, O. K. *et al*. IEEE J. Photovolt. **6** (2016)

- Gridlines pulled at micron increments and electrical resistance monitored across each gridline until complete failure
- MMC gridlines can reestablish connection “self-heal” and maintain connection for successive pulls

ELECTRICAL CHARACTERIZATION – PULL DATA

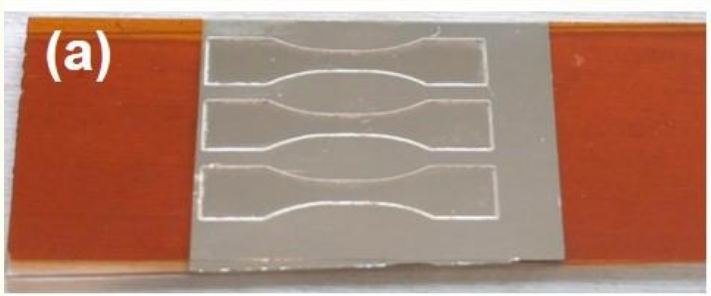


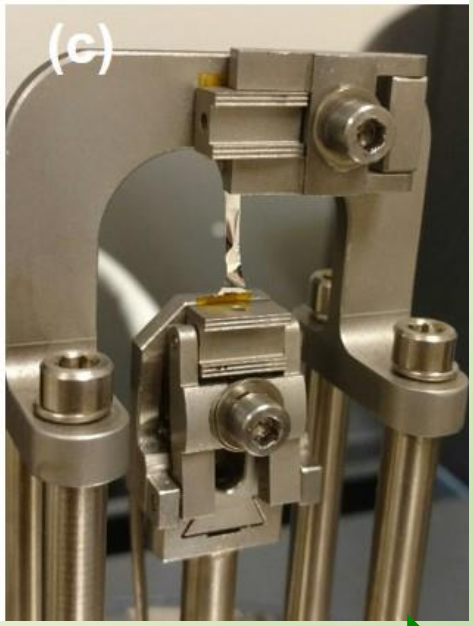


- Gridlines maintain connection across wider gaps as CNT loading (surface coverage) increases, while bare Ag control gridlines (not shown) loses connection immediately
- Due to non-uniform deposition during spray-coating, the samples prepared with carboxylated (COOH) CNTs bridge smaller gaps than drop-casted (COOH) samples
- Samples prepared with Amine-terminated (NH_3) CNTs bridge wider gaps compared to carboxylated ones (CNT-NH_3 does not desorb during electroplating Ag^+)

MECHANICAL CHARACTERIZATION

Dynamic Mechanical Analysis (DMA)





Shadow Mask

(a) Kapton tape applied to glass slide and three dog-bone structures are laser cut

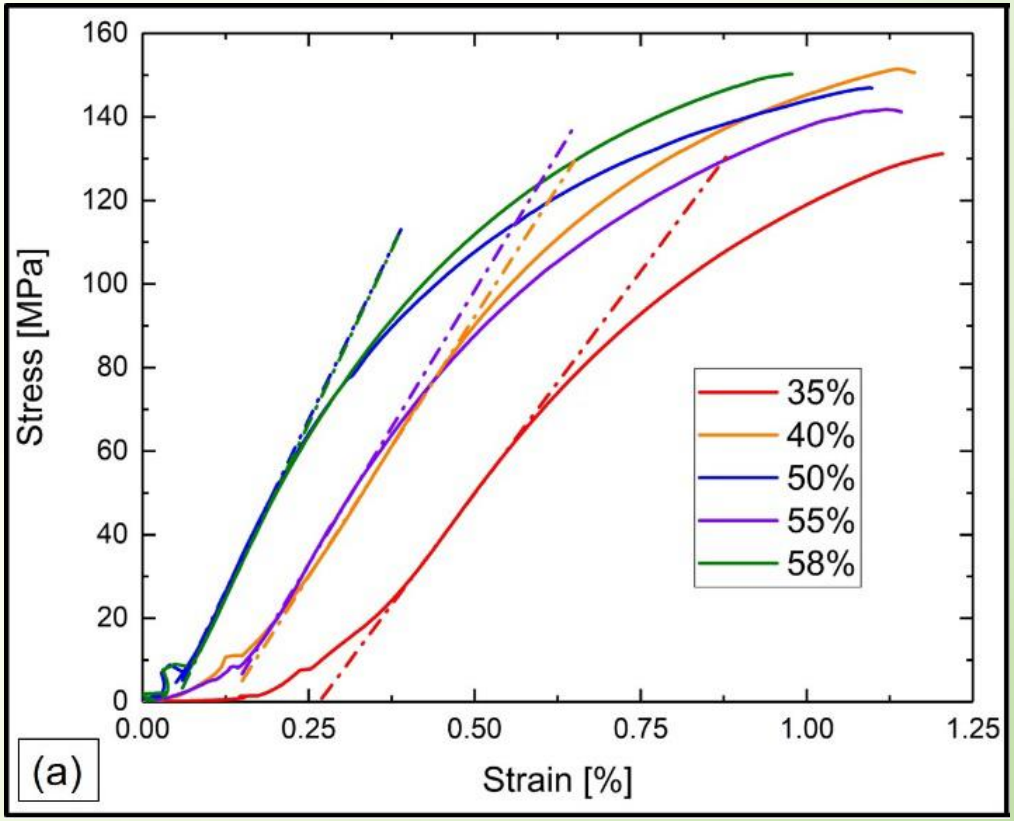
Ag/CNT/Ag deposition

(b) LBL deposition of composite lines at different CNT loading fractions

DMA thin film

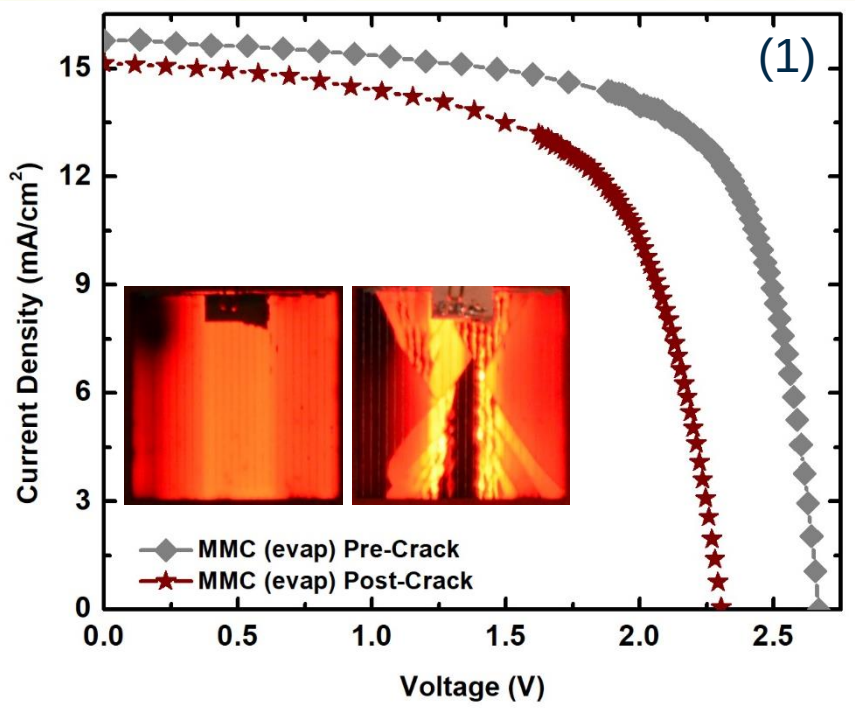
(c) Composite lines lifted off glass substrate and freestanding films are mechanically analyzed

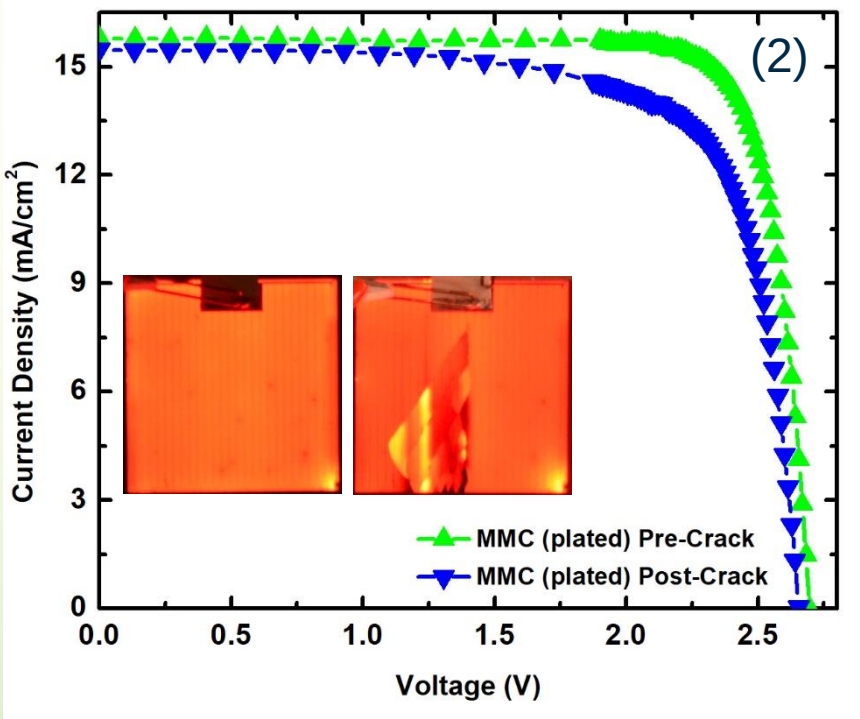
MECHANICAL CHARACTERIZATION – DMA DATA



- Young's modulus (slope of linear region) increases as the CNT surface coverage increases
- The incorporation of CNTs within Ag/CNT/Ag stack enhances the mechanical strength of metal lines (33 GPa MMC line with 58% CNT surface coverage)
- Bare Ag lines (not shown) Young's modulus 22 GPa (evaporated Ag) and 10 GPa (electroplated Ag)

CELL FRACTURE TEST

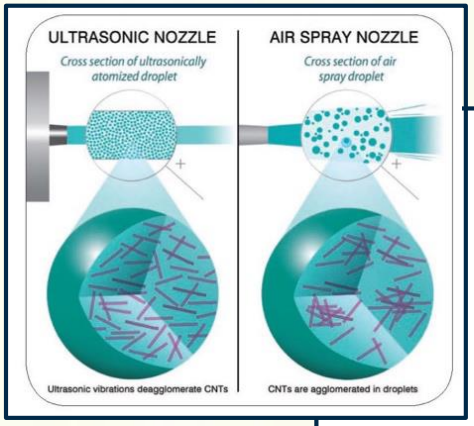


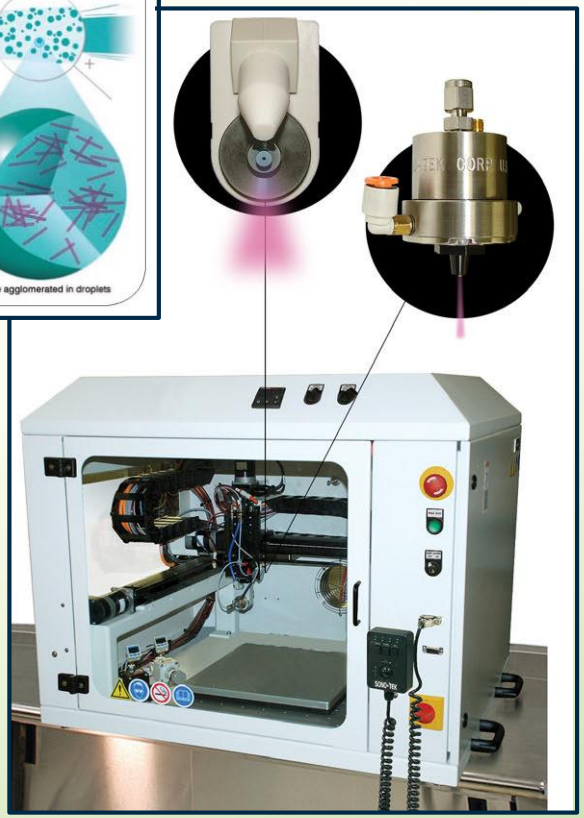


- Ag/CNT/Ag lines integrated on solar cells using two Ag metallization methods (1) electron-beam evaporation (left), (2) electroplating (right)
- Composite-enhanced cells prepared using electroplating are more crack tolerant than ones fabricated with evap. Ag
- Better interactions between CNT and electroplated Ag than CNT and evap Ag, despite lower metal ductility E_{plated} (10 Gpa) < E_{evap} (22 GPA)

NEXT PHASE DEVELOPMENT

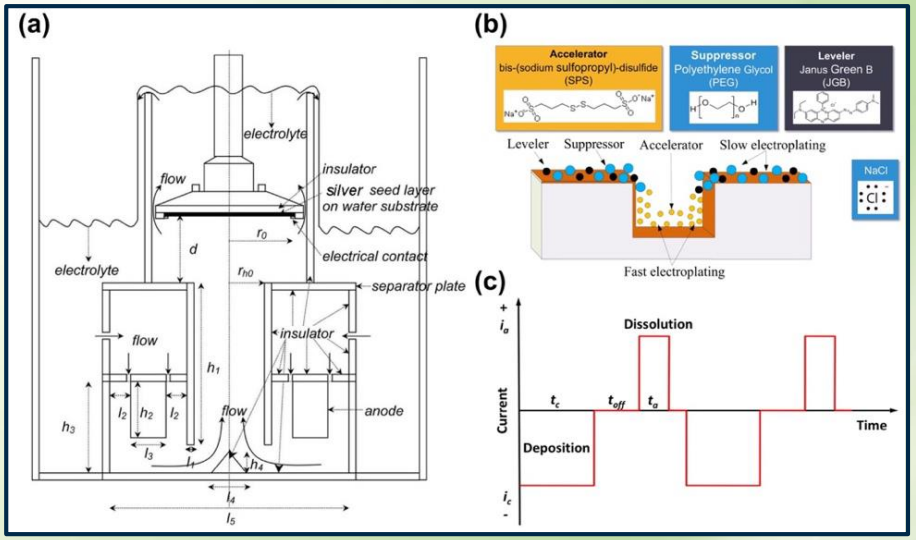
ExactaCoat (SONO TEK Co.)





Commercial CNT Coater achieving uniform CNT depositions for precise control over CNT surface coverage

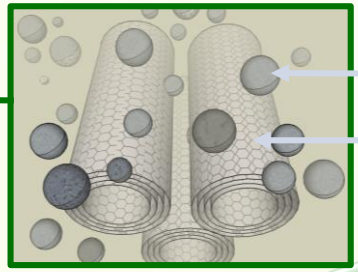
FARADAYIC® ElectroPlating Apparatus



(a) Wafer-scale of Ag electroplating through rotating disc bath, (b) chemical additives in plating solution to improve uniformity and edge definition, (c) reverse pulse DC plating to minimize H_2 generation

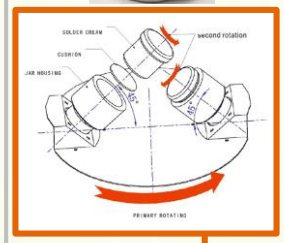
OTHER OSAZDA ACTIVITIES

DOE DuraMat (12 months) program to develop technology for terrestrial application, in collaboration with Georgia Institute of Technology and the National Renewable Energy Laboratory



Ag Particles

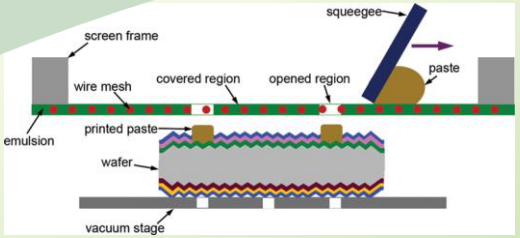
MWCNTs



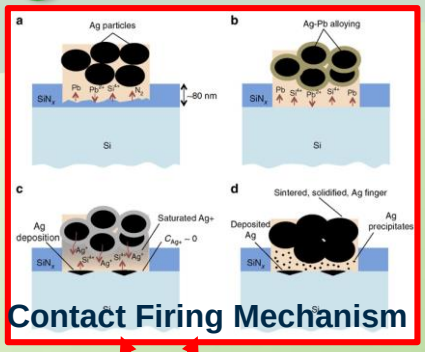
Ink Formulation

Silver Paste Dual Mixer

Screen Printing[1]



Cell Integration & Firing[2]

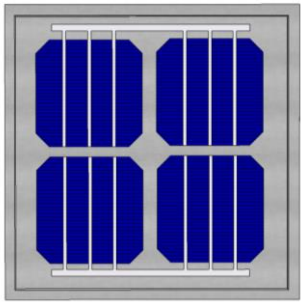


Contact Firing Mechanism

Crystalline Si cells printed with MMC contacts

Mini-Module Integration

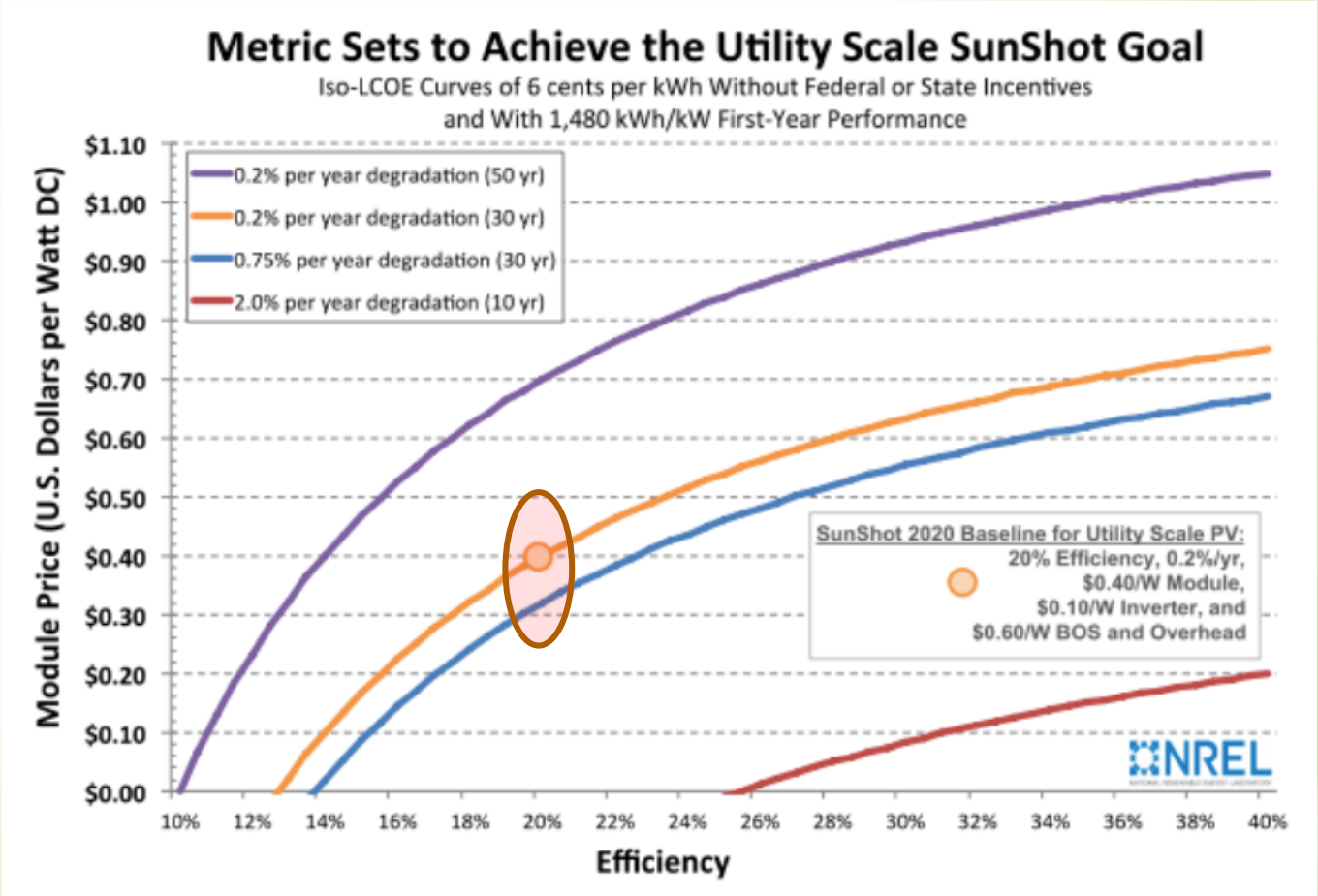
Cells in Series



Mini-Module Testing

[1]Tao, Y. Printed Electronics – Current Trends and Applications. Ch. 4, (2016).
[2]Fields, J. D. et al. Nat. Commun. **7**, 11143 (2016).

VALUE



If Osazda technology can reduce the degradation rate from 0.75%/yr to 0.2%/yr, it would be worth ~ $0.09/W in module price or $8.5B/yr (assuming 95 GW/yr installation)

BOTTOM LINE

- Cell cracking is a significant challenge for space and terrestrial PV market
- Osazda has demonstrated a cost effective approach to modifying SOP materials to address cracking issues
- Composite lines can maintain electrical connection while fractured and exhibit a “self-healing” behavior while composite-enhanced cells show significantly less degradation due to cracking
- Osazda is developing a low-cost CNT additive that can incorporated into commercial silver inks seamlessly addressing the cracking challenge

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NEW MEXICO ANGELS

NEW MEXICO START-UP FACTORY