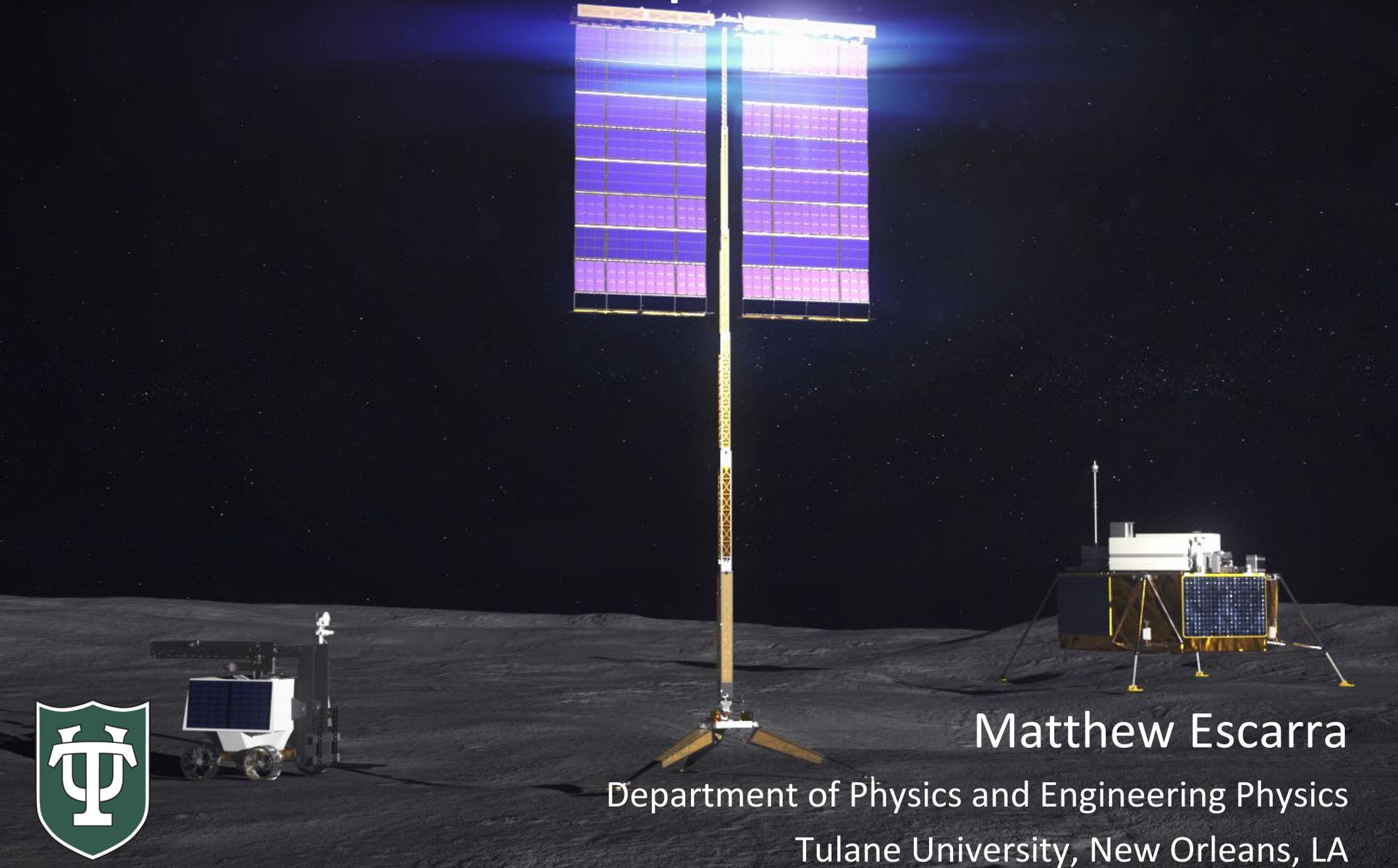


The Future of Space Solar Power



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- Cynthia Ebinger, Denys Bondar, Matt Escarra, and colleagues at Tulane's School of Science and Engineering
- One of five research task forces initiated in 2025 under new Dean Hridesh Rajan
- So far:
 - 8 REU summer students; 8 undergrads active in space research this fall
 - 28 undergrads working on the Student Spaceflight Experiment Program Competition
 - Numerous grad students and active grants, including six internally funded seed awards, ranging from new materials and devices for space applications to satellite remote sensing and lunar resource extraction
 - Building relationships within the private and public space industry in the region, alongside alumni and colleagues across the nation



Escarra Research Group

We do **computational design, material synthesis, micro and nanofabrication, and characterization** of novel optical materials, devices, and systems, with emphasis on **solar energy conversion and nanoscale photonics**



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NASA STMD Priorities



#2 out of 187: High Power Energy Generation on Moon and Mars Surfaces

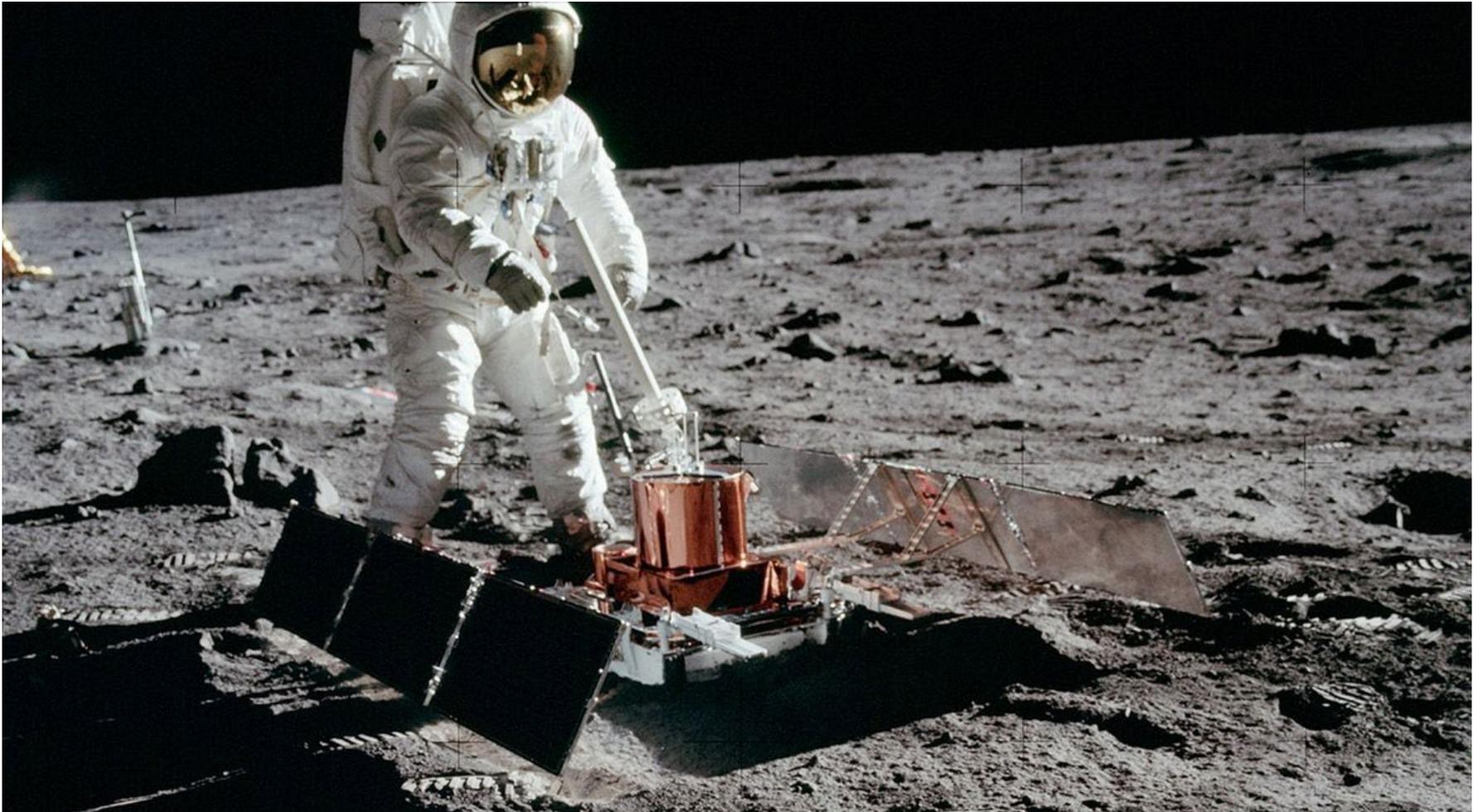
Two options: Nuclear Fission and Solar

Existing solar array systems do not provide sufficient **durability** or **scale** to support full scale ISRU production in the **Lunar Pole** thermal, dust, and radiation environment. Current **technology for deployment** of towers and reflectors is not optimized **to gather sunlight low on the horizon** as at the Lunar poles.



Solar Power in Space Then

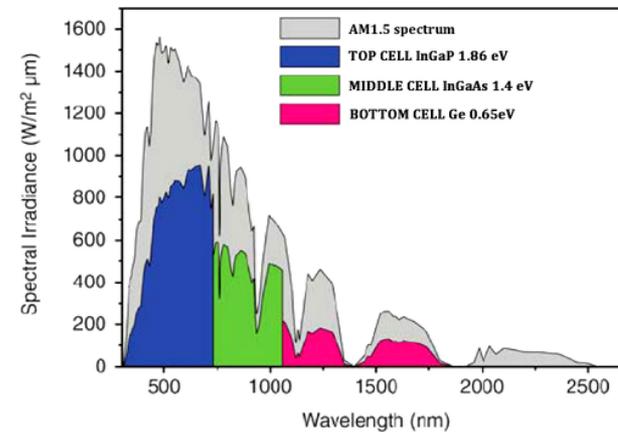
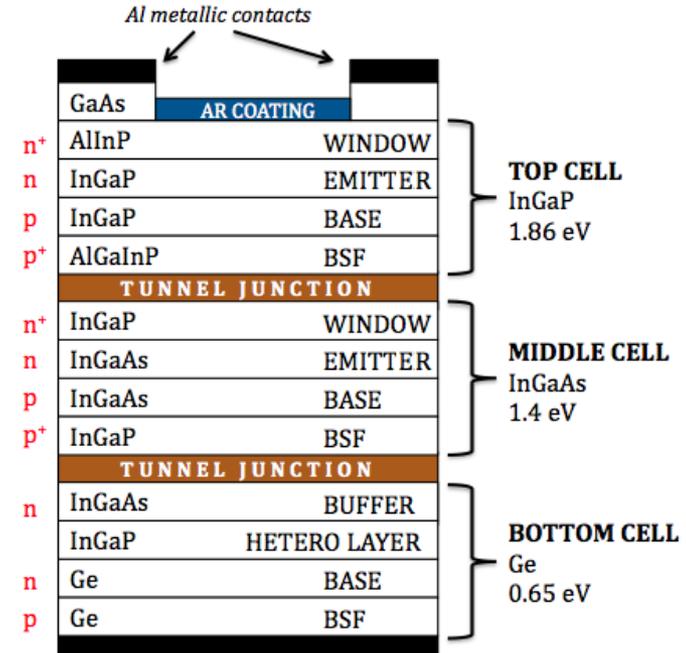
Apollo 11 (1969): Early silicon solar panels supported moonquake measurements





Solar Power in Space Now

ROSA on ISS (2017-2025)





Solar Power in Space Now

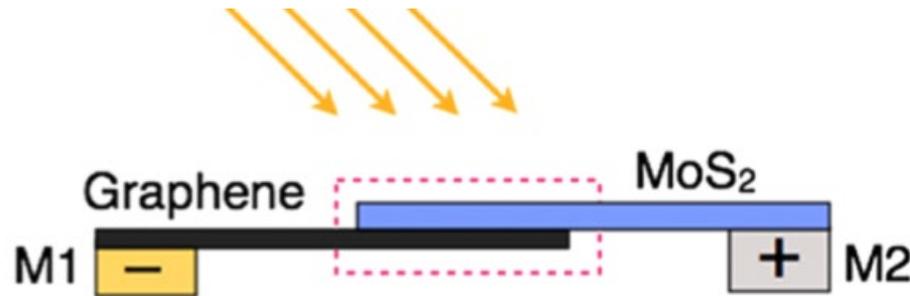


- ~8000 satellites (~2/3 of all satellites in space), heading towards >12,000
- ~1/3 of mass to orbit is solar
- ~5 year solar lifetime





Highest Specific Power PV Material



| material | thickness | efficiency | weight (g/m ²) | power density (kW/L) | power density (kW/kg) |
|-----------------------------------|------------------|---------------------------|----------------------------|----------------------|-----------------------|
| GaAs | 1 μm | $\sim 29\%$ ³⁸ | 5.3 | 290 | 54 |
| Si | 35 μm | 20.6% ³⁹ | 92.7 | 5.9 | 2.5 |
| graphene/MoS ₂ | 0.9 nm | 0.1–1.0% | 3.9×10^{-3} | 1000–10 000 | 250–2500 |
| WS ₂ /MoS ₂ | 1.2 nm | 0.4–1.5% | 7.9×10^{-3} | 3000–12 000 | 450–1800 |

- High absorption coefficient ($1.24 \times 10^6 \text{ m}^{-1}$)
- Direct bandgap
- Ultrathin form factor

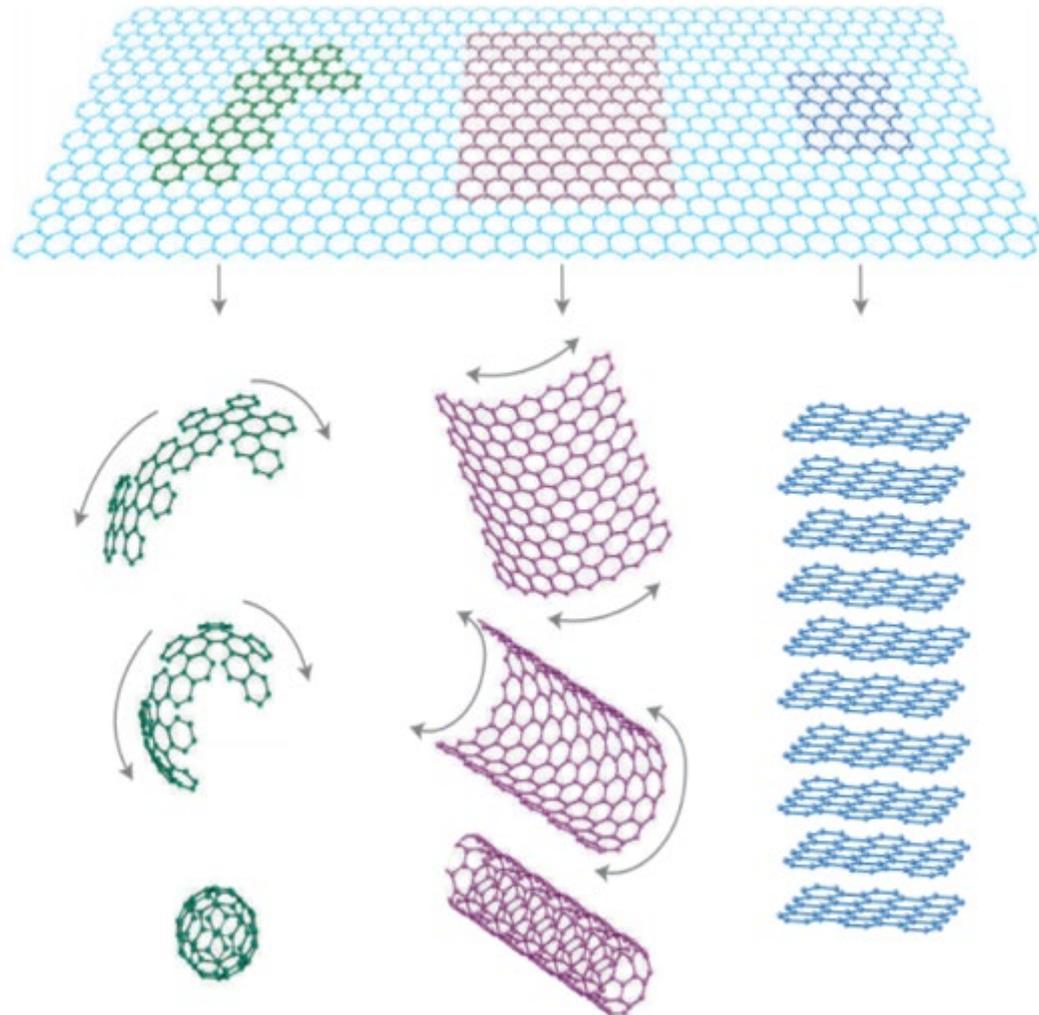
Mass-constrained power-production applications:

- Spacecraft PV
- Vehicle-Integrated PV
- Building-Integrated PV



What are Two-Dimensional Materials?

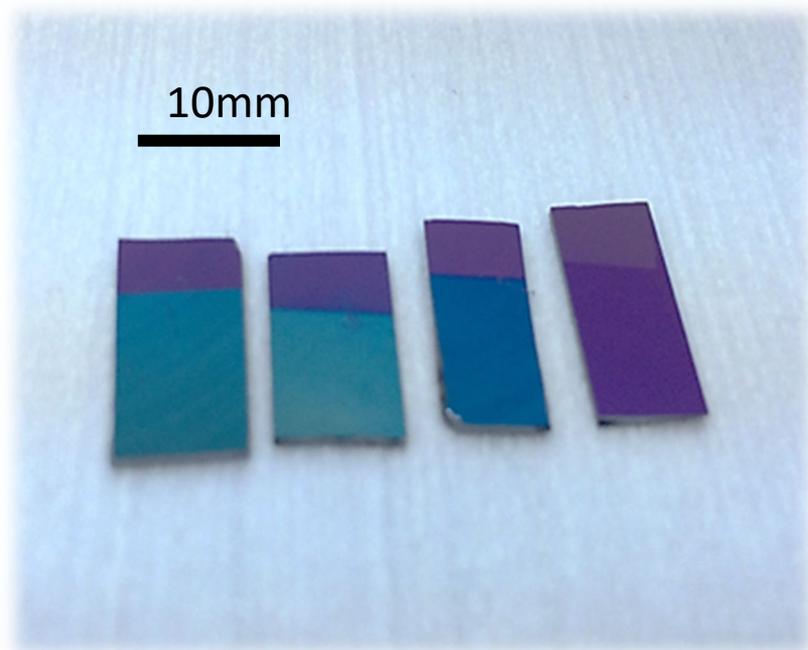
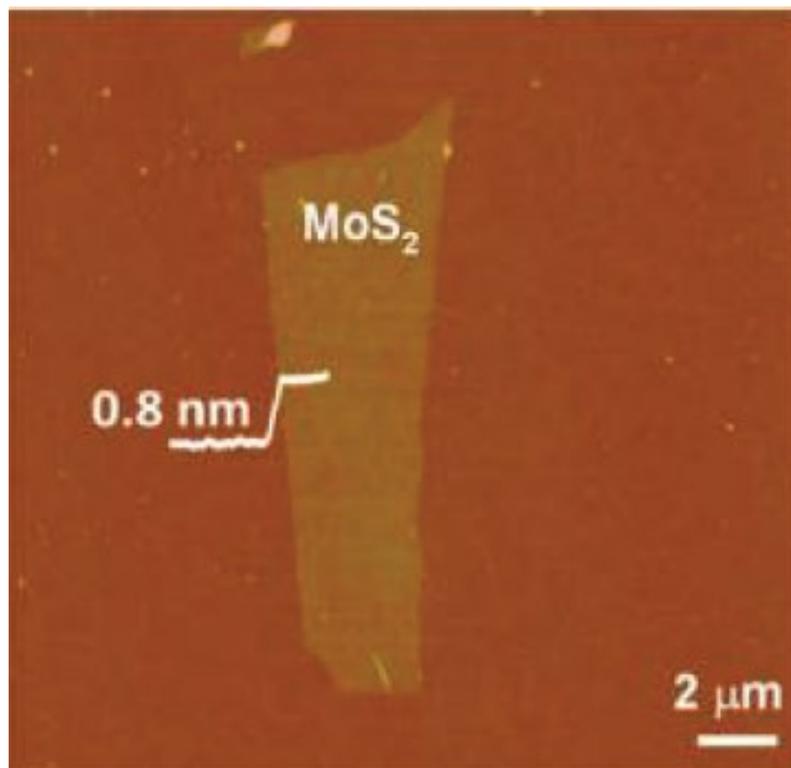
- Atomically flat (<5nm)
- Chemically Stable
- Flexible
- Quantum confinement in one dimension
- Example: Graphene, first reported in 2004





The Scale-Up Question:

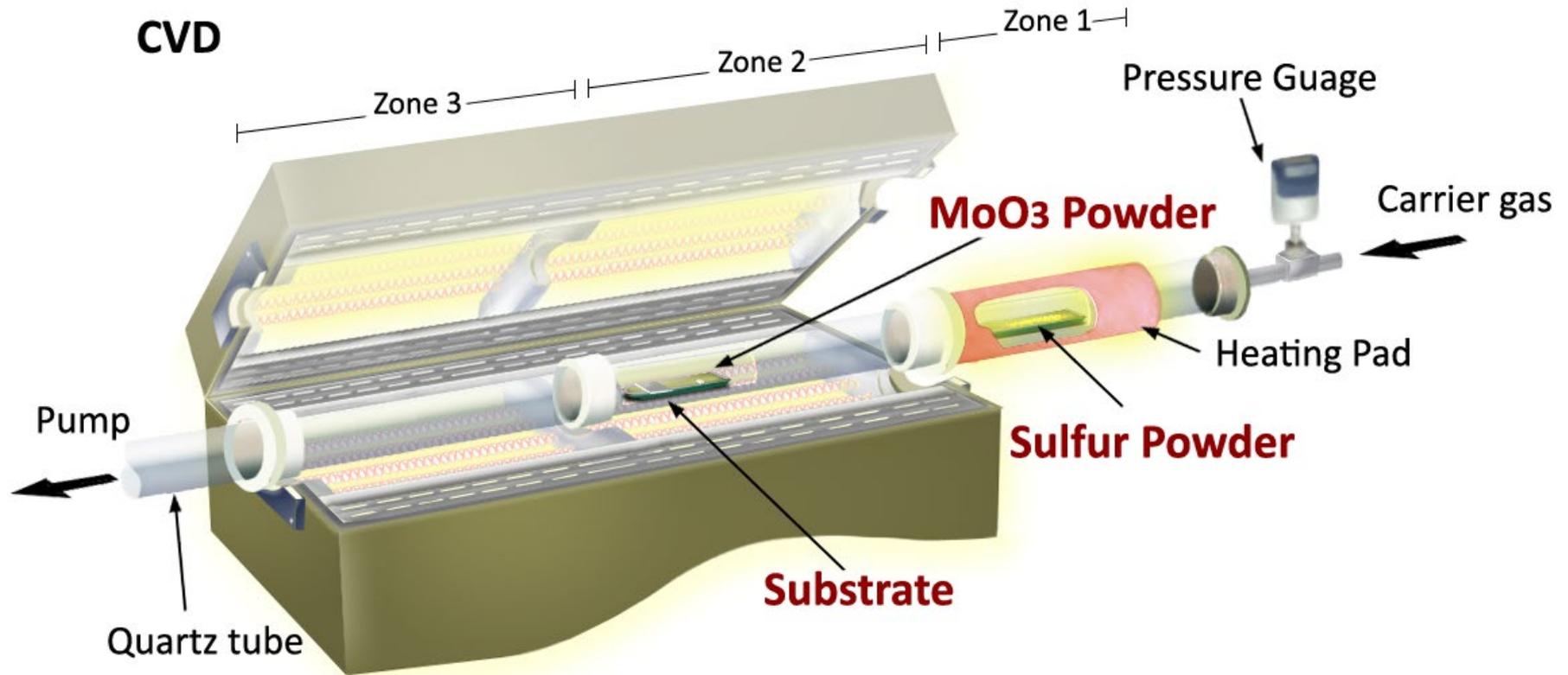
How can we go from exfoliated... to large-scale?



Yin et al, ACS Nano., Vol 6, No 1, 74-80 2012



Chemical Vapor Deposition (CVD): A Large-Scale Option



Also:

- Thermal Vapor Sulfurization (TVS) for thickness control

Robertson, et al., *2D Materials* (2017)

- Rapid Thermal Processing (RTP) for 2D films in minutes

Robertson, et al., *Appl. Phys. Lett.* (2019)



Quasi-epitaxial MoS₂ CVD on c-plane Al₂O₃ substrates

Goals:

- Larger domain sizes
- Uniform coverage
- Minimal vertical (2nd layer) growth

Growth parameters:

MoO₃ = 0.5, 1, 3 & 5 mg

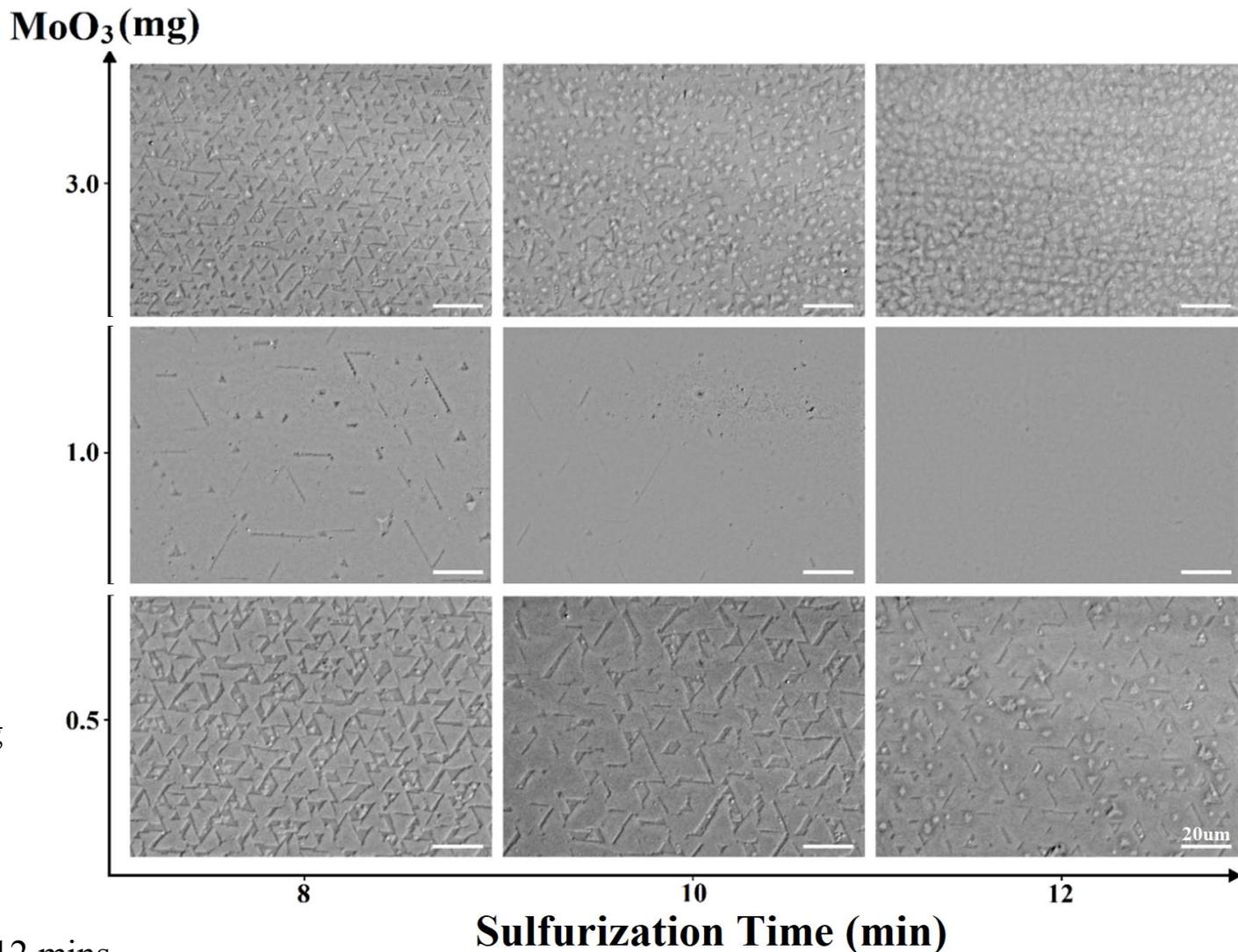
Sulfur = 230 mg

T₂, T₁ (°C) = 750, 120

Flow Rate = 180 sccm

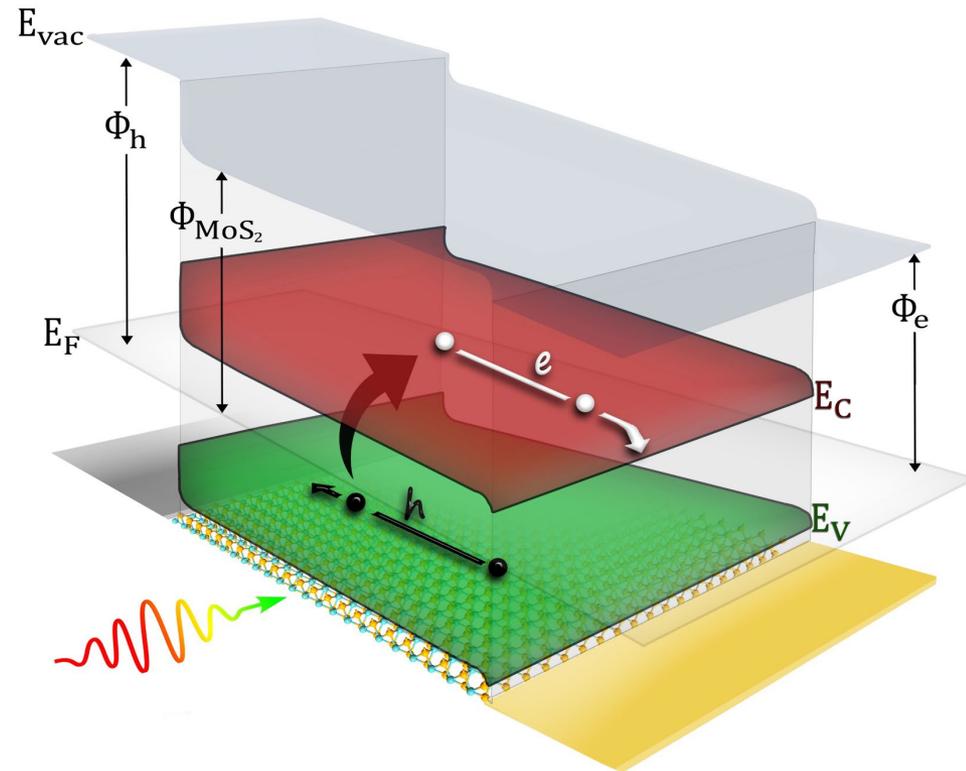
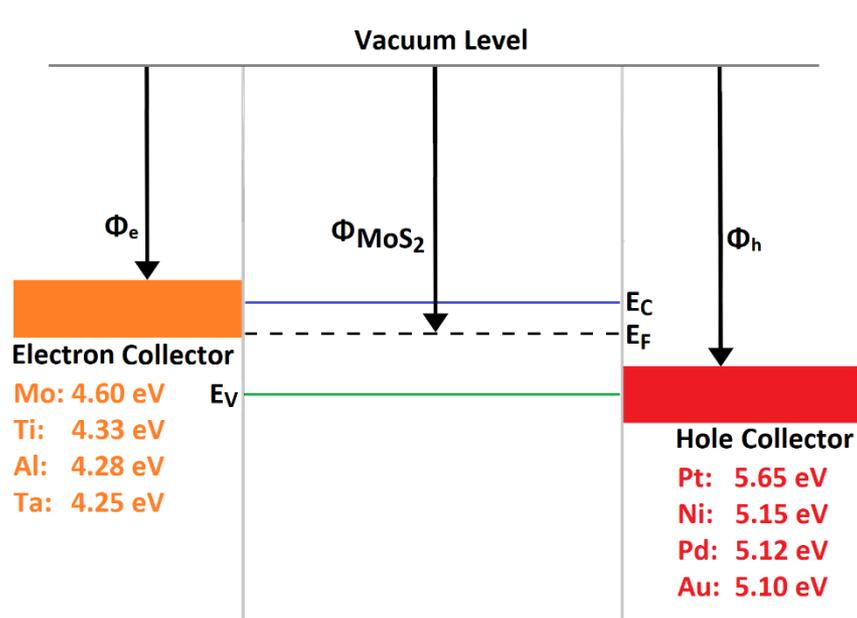
Pressure = 2.4 torr

Growth Time = 8, 10 & 12 mins





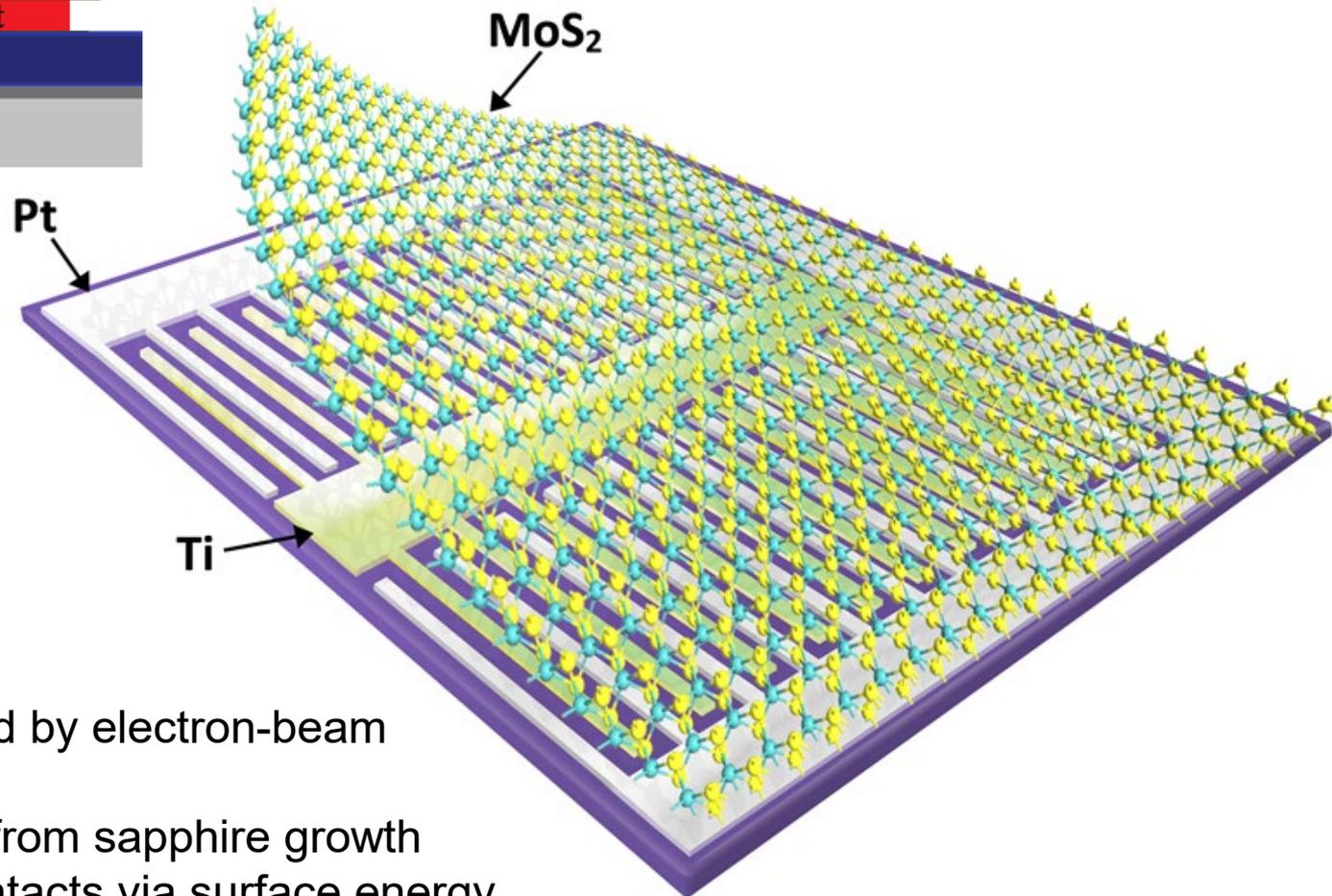
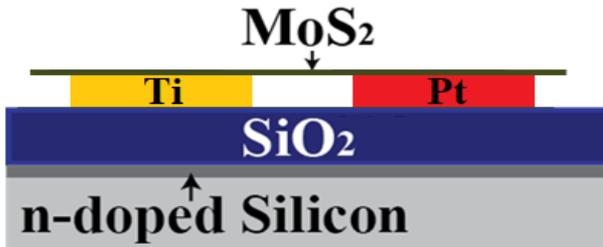
Lateral Schottky junction photovoltaics



| Metal | Pre-Sputtered Φ (eV) | Post-Sputtered Φ (eV) |
|-------|---------------------------|----------------------------|
| Ti | 3.77 | 4.19 |
| Pt | 4.61 | 5.35 |



Device Schematics



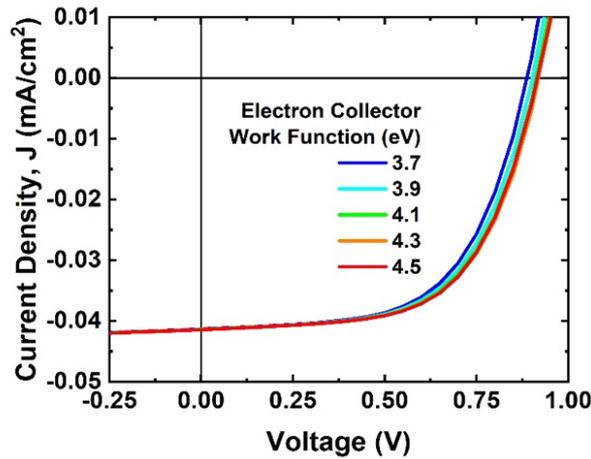
- Contacts patterned by electron-beam lithography
- MoS₂ transferred from sapphire growth substrate onto contacts via surface energy assisted transfer



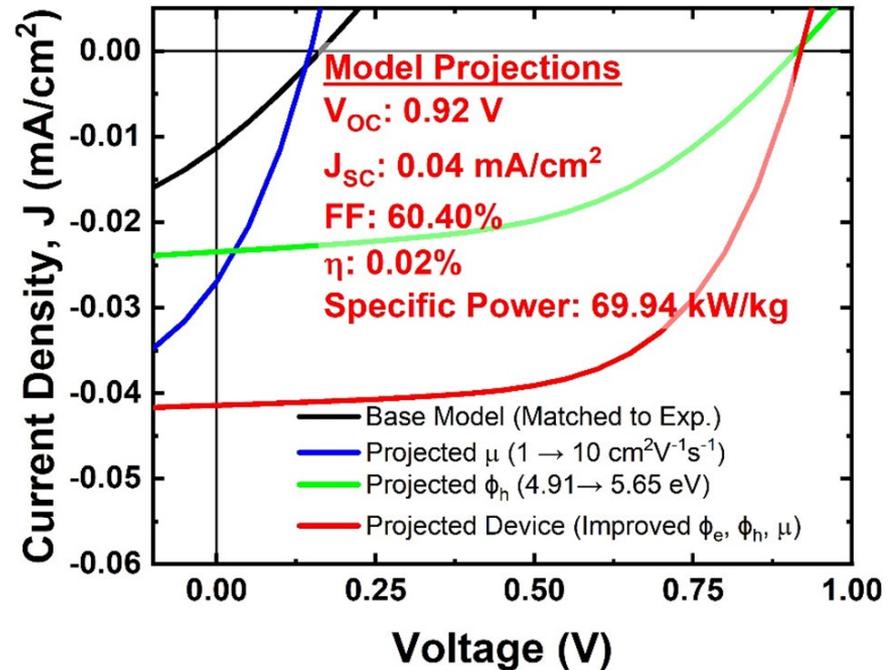
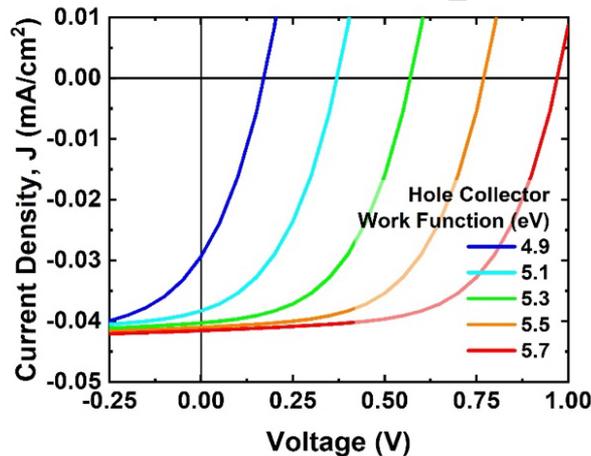
Semiconductor Device Model

COMSOL Multiphysics

Sweeping Φ_e



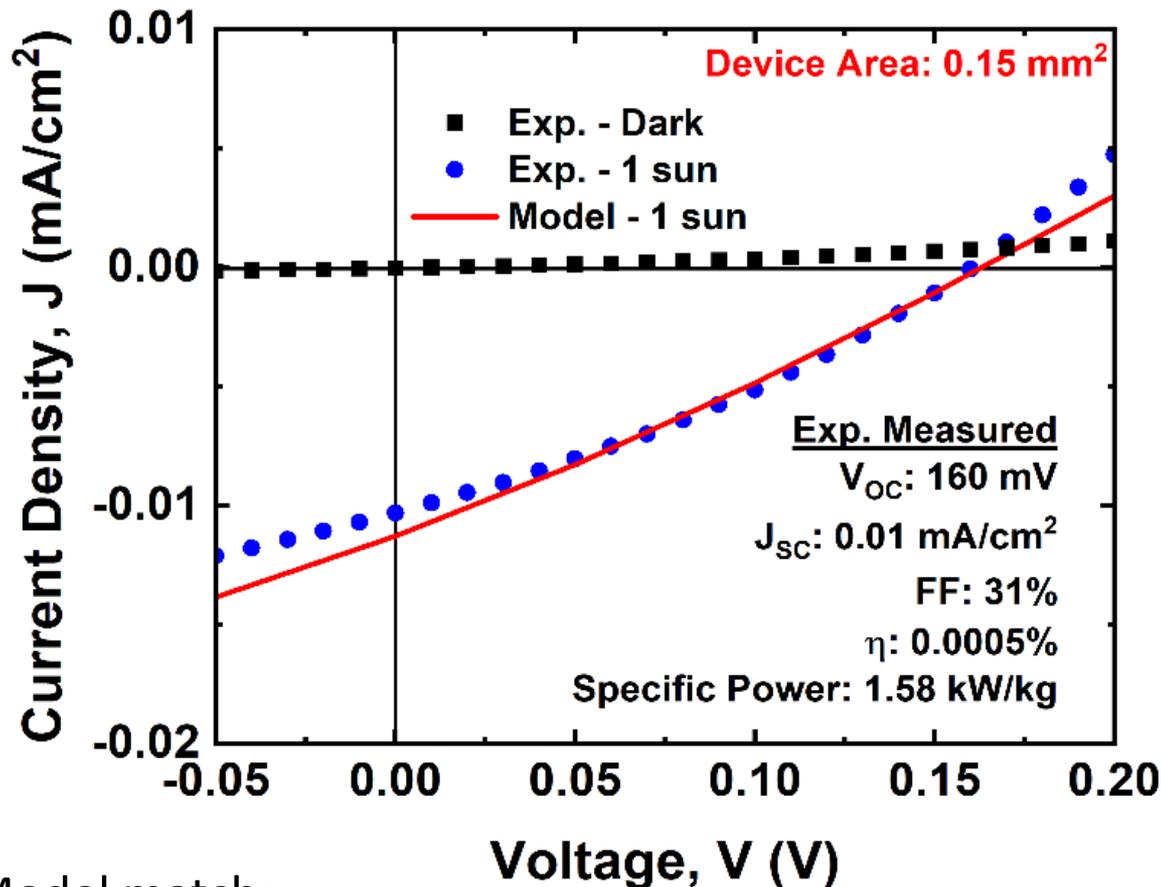
Sweeping Φ_h



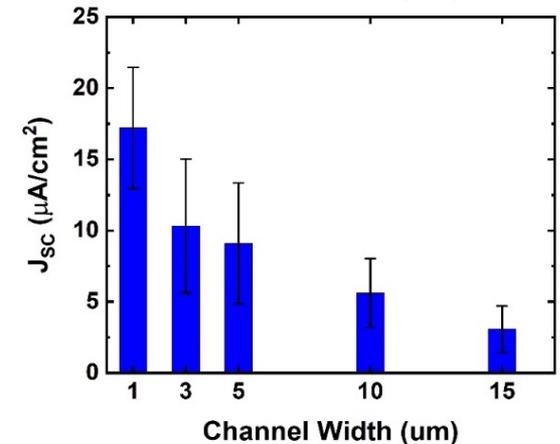
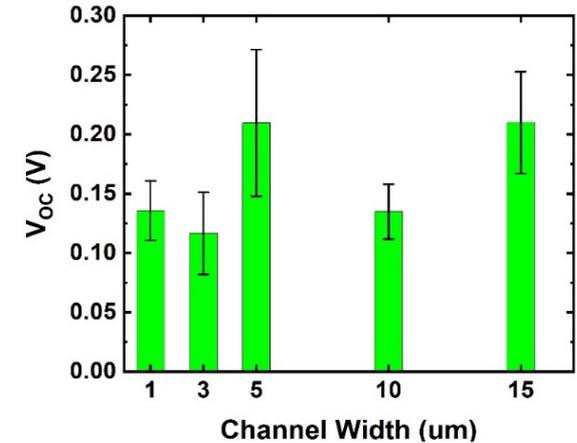
- V_{OC} has strong dependence on Φ_h .
- J_{SC} has strong dependence on μ
- 69.9 kW/kg specific power predicted
- Single layer only in this analysis



Device Performance



vs. channel dimensions



Model match:

- $\Phi_e = 3.8$ eV, $\Phi_h = 4.9$ eV,
- mobility = 1 cm²/(V·s)
- Lifetime = 1 μs

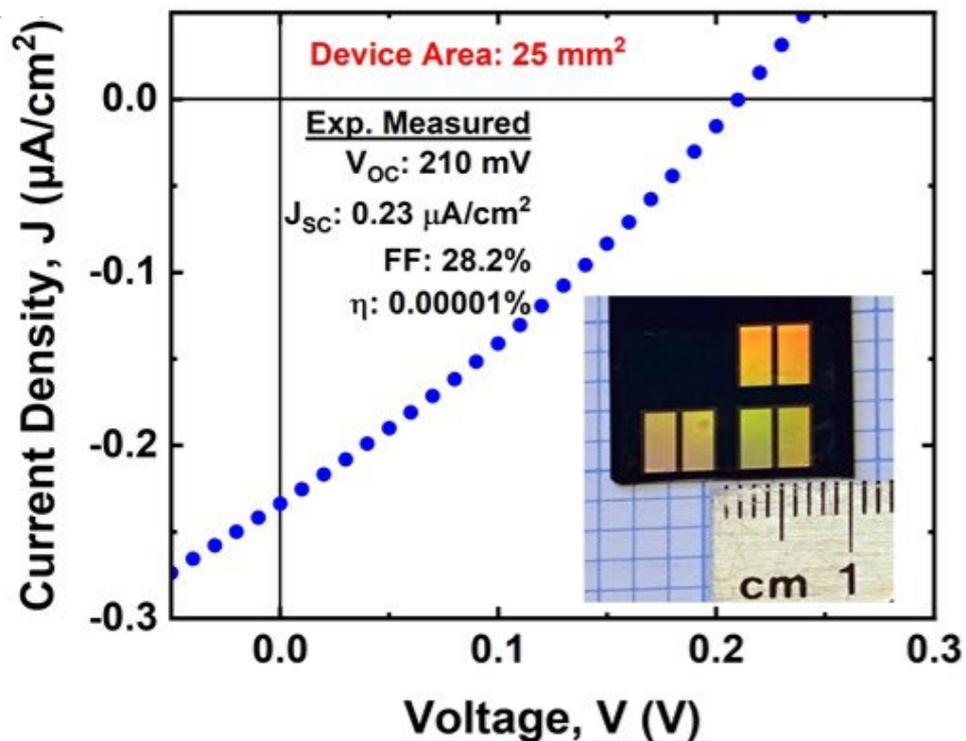
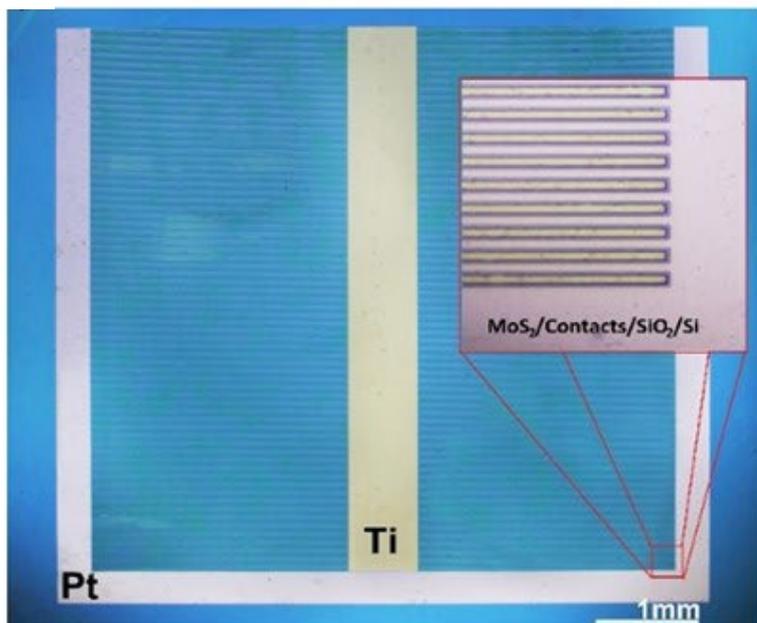
Diffusion length:

~1 μm – monolayer

~2 μm – two stacked layers



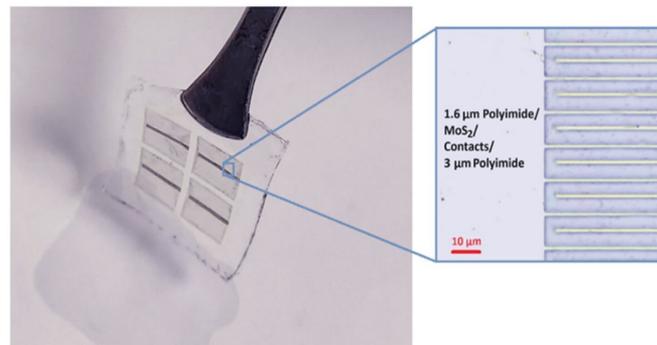
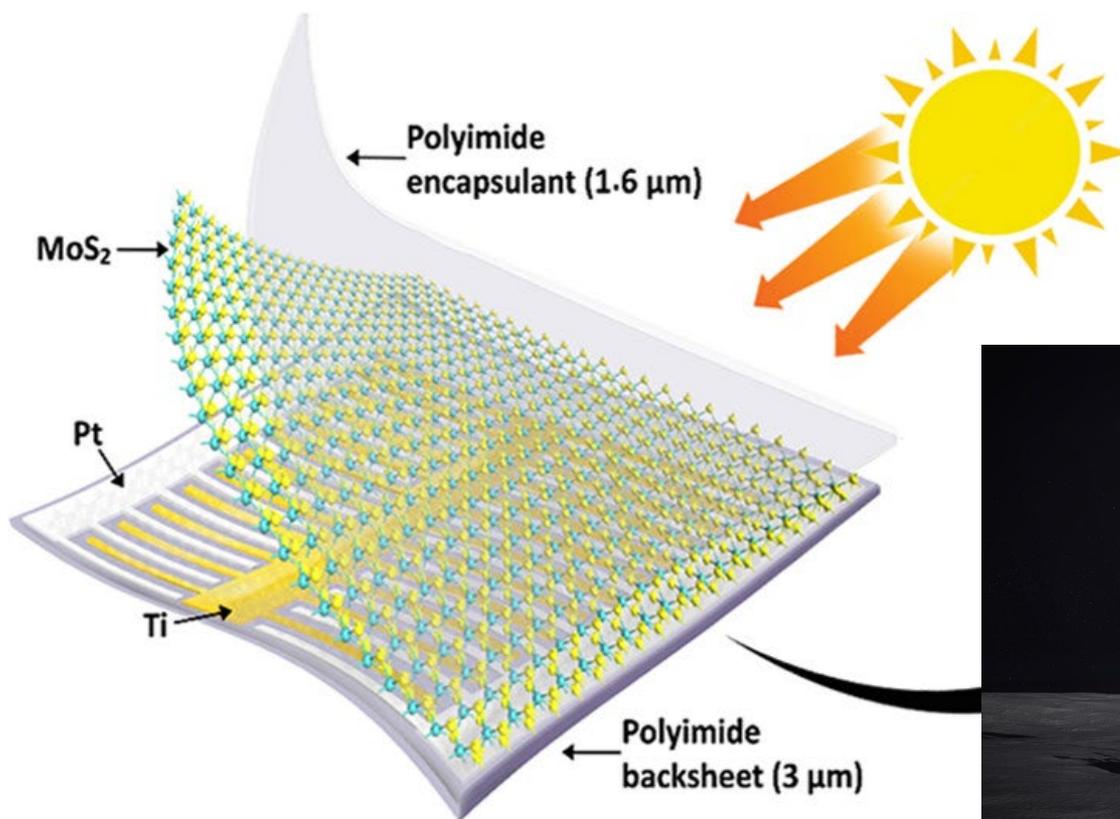
Large-Area Devices



0.65 nm x 5 mm x 5 mm photovoltaic cells!

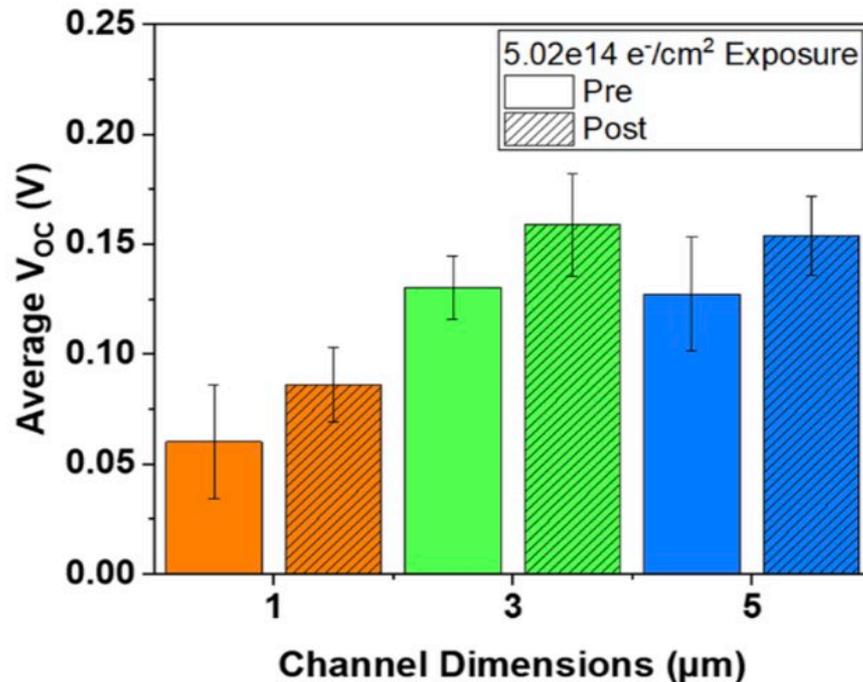
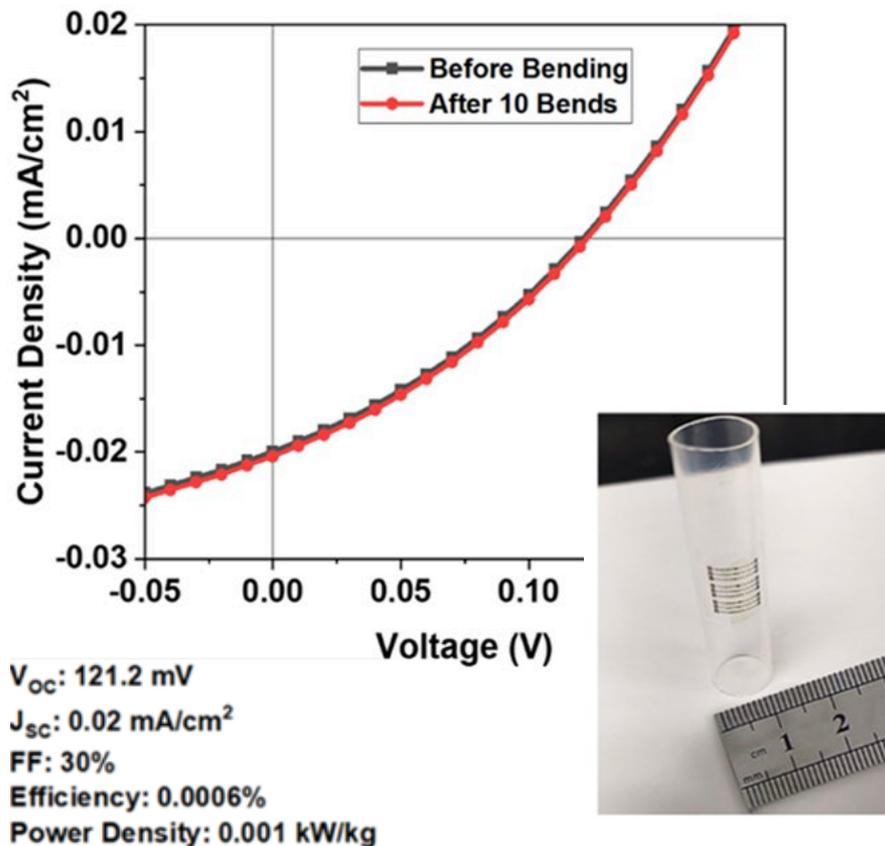


High-Specific Power Flexible 2D Solar Cells





Flexible 2D PV Performance

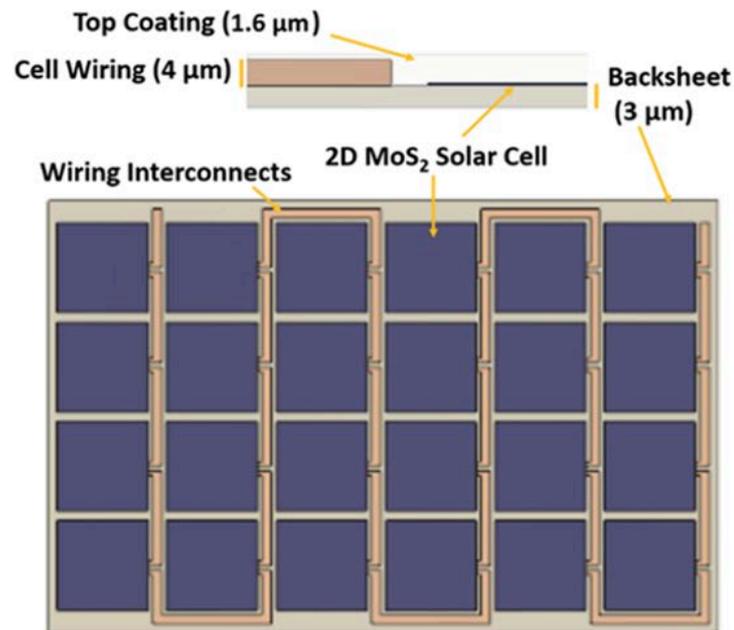
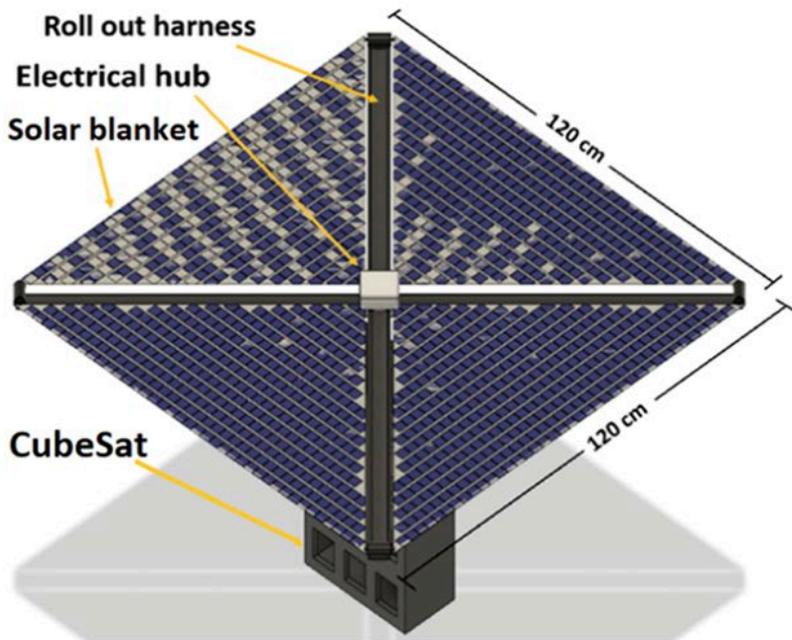


Bending tests (5 mm bending radius)

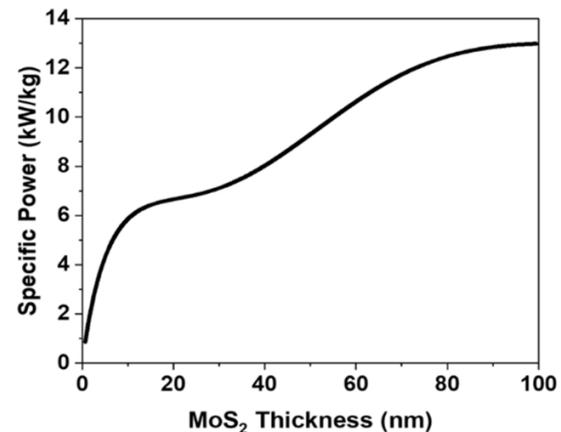
High energy electron radiation exposure



Space solar power blankets

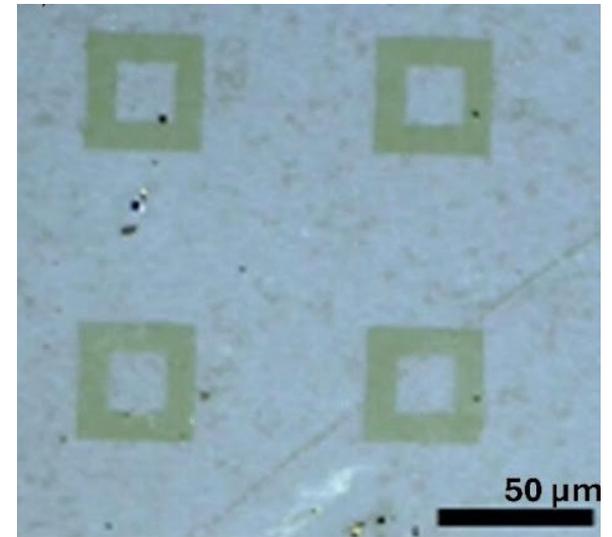
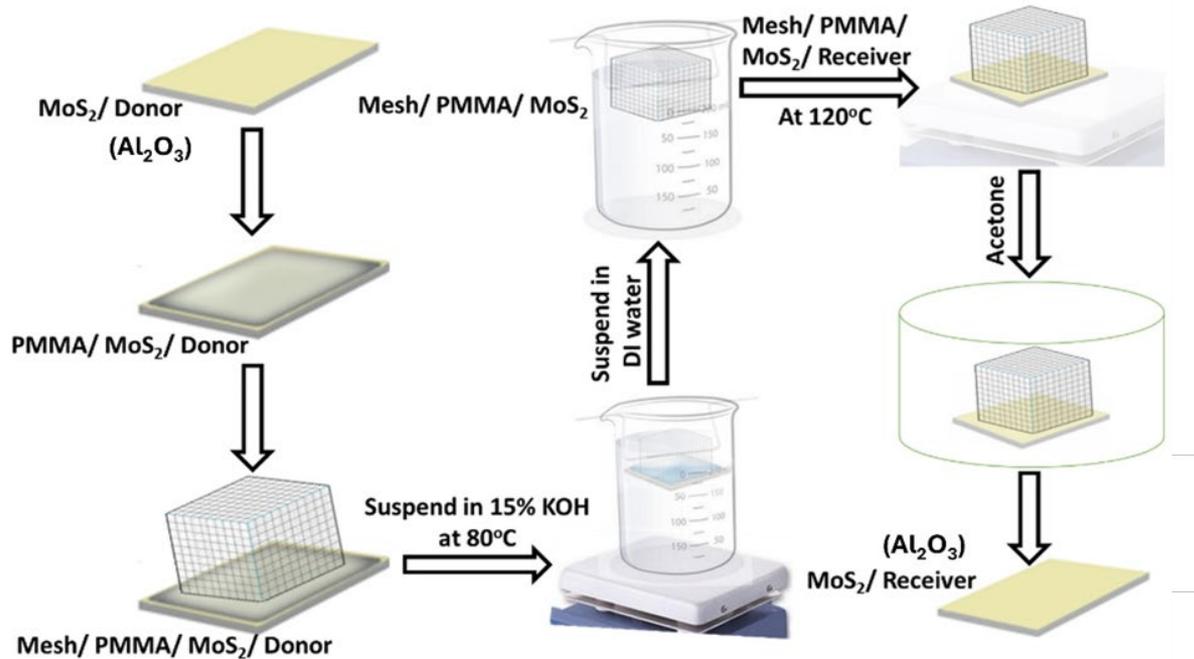


| performance metrics | 2D array | Si PERC panel |
|----------------------------------|----------|---------------|
| cost/area (\$/m ²) | \$863.14 | \$21,238.94 |
| weight/area (kg/m ²) | 0.0105 | 10.64 |
| power/area (W/m ²) | 70.58 | 276.77 |
| specific power (W/kg) | 6697.74 | 26.02 |
| cost/watt (\$/W) | \$12.64 | \$104.83 |

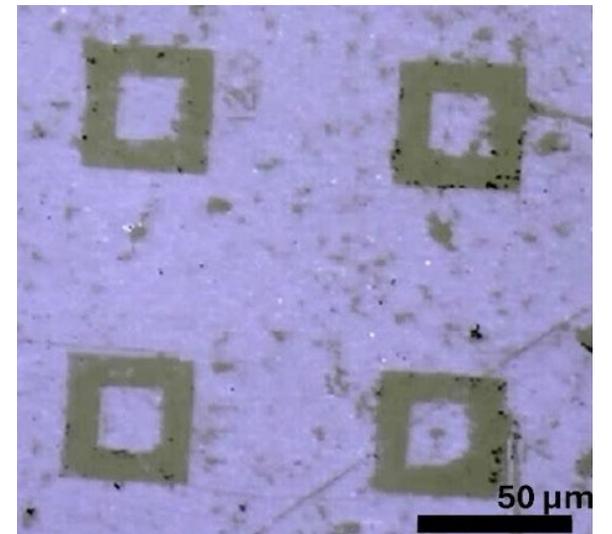




2D Layer Transfer and Stacking



Patterned film on donor

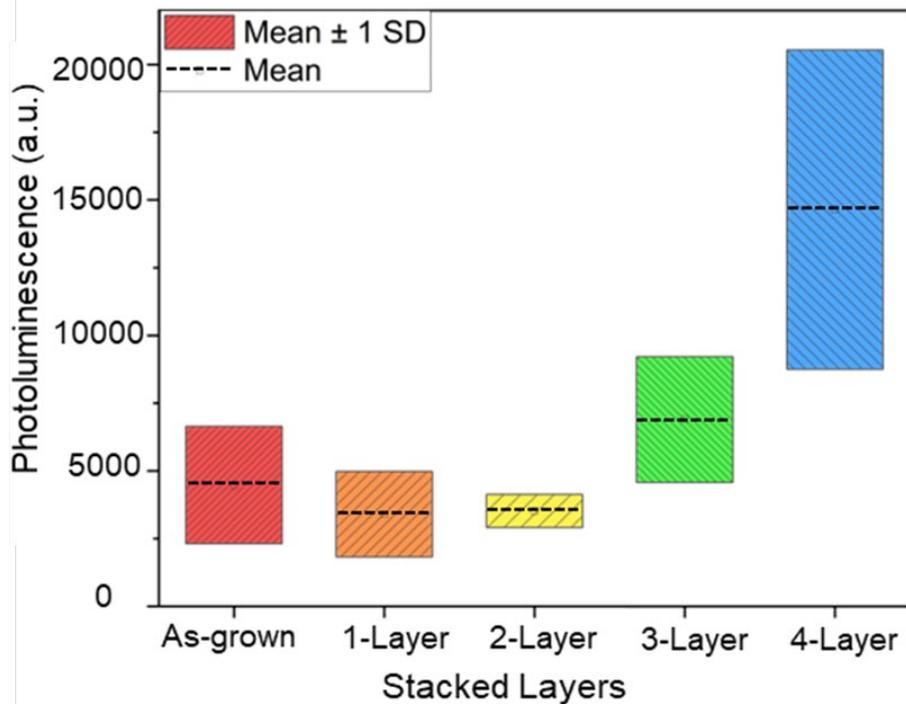


Patterned film on receiver

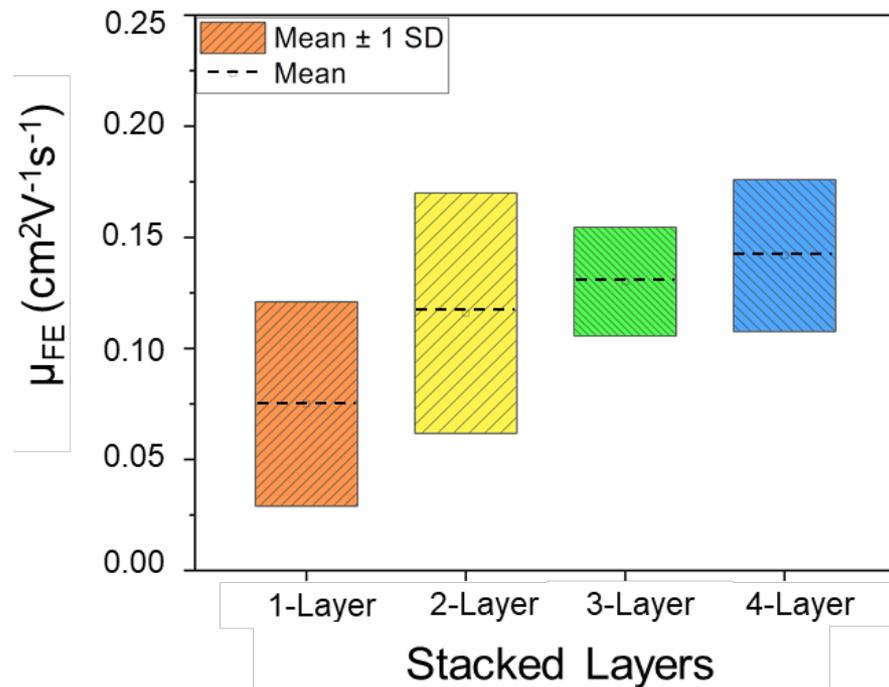


Stacking Performance

Optical properties



Electronic properties

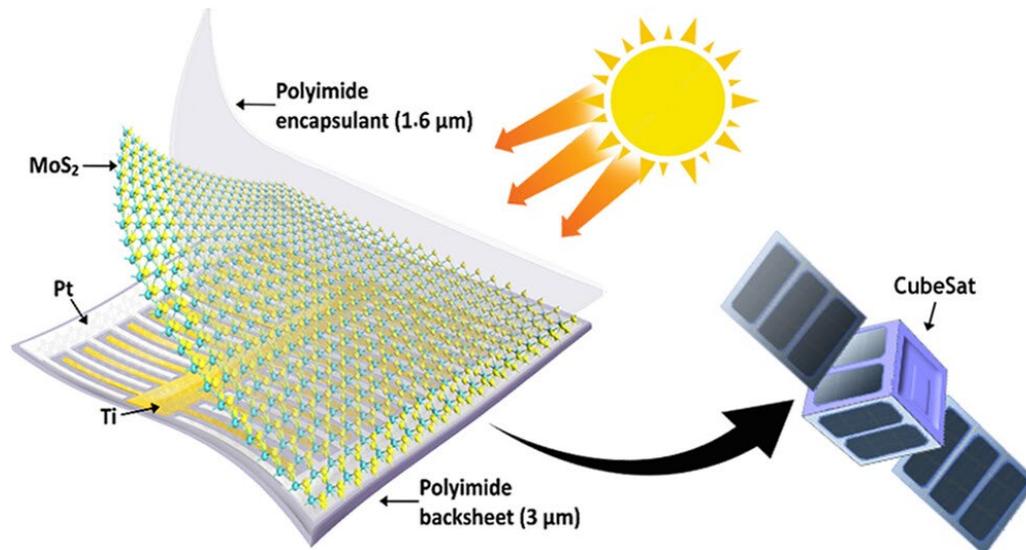
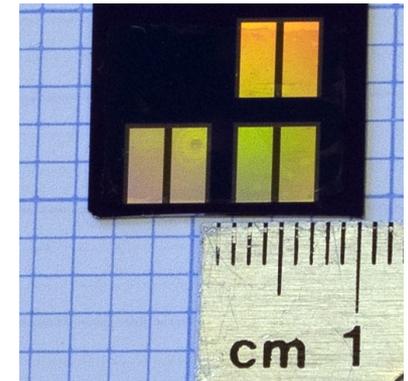


Stacking improves performance!



2D Solar Cells for Space

- Achieved **wafer scale growth of 2D MoS₂**, with a variety of techniques
- Fabricated **25 mm² photovoltaic devices**
- Specific power of flexible 2D solar cells projected to **exceed existing space solar power**
- **Layer stacking** shows path to enhanced performance





Contact Info

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Thank you!