

# Fabrication of High Efficiency and Lightweight CdTe Solar Cells for Space Applications

Manoj K. Jamarkattel, Adam B. Phillips, Ebin Bastola, Aesha P. Patel, Sabin Neupane, Deng-Bing Li, Yanfa Yan, Randy J. Ellingson, and Michael J. Heben



Wright Center for Photovoltaics Innovation and Commercialization, Department of Physics and Astronomy,  
University of Toledo, Toledo, OH, 43606, USA



## Background

### Key requirements needed for space applications

- ❑ Low dollar/watt
- ❑ High EOL
- ❑ High Specific power

### What about CdTe based solar cells ?

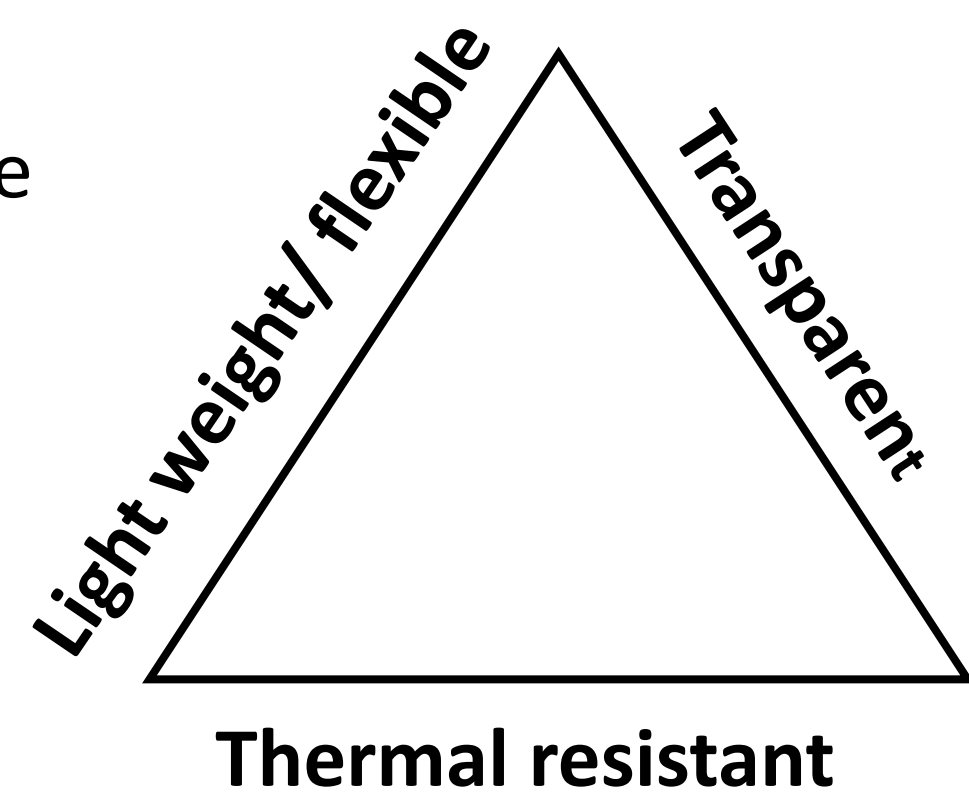
- Record efficiency of 22.1 % [1] has been reported for CdTe based solar cells under AM1.5 illumination
- Low deposition cost (Thin-film deposition technique) CdTe ✓
- Cheap source materials CdTe ✓
- Low radiation damage CdTe ✓
- Higher End of Life ( EOL) or stable device performance CdTe ✓
- Specific power density ?

### Substrate properties required for CdTe based solar cells to increase specific power density

- Higher efficiency CdTe solar cells are fabricated on superstrate configuration and require high temperature processing

### Some available substrates/problems

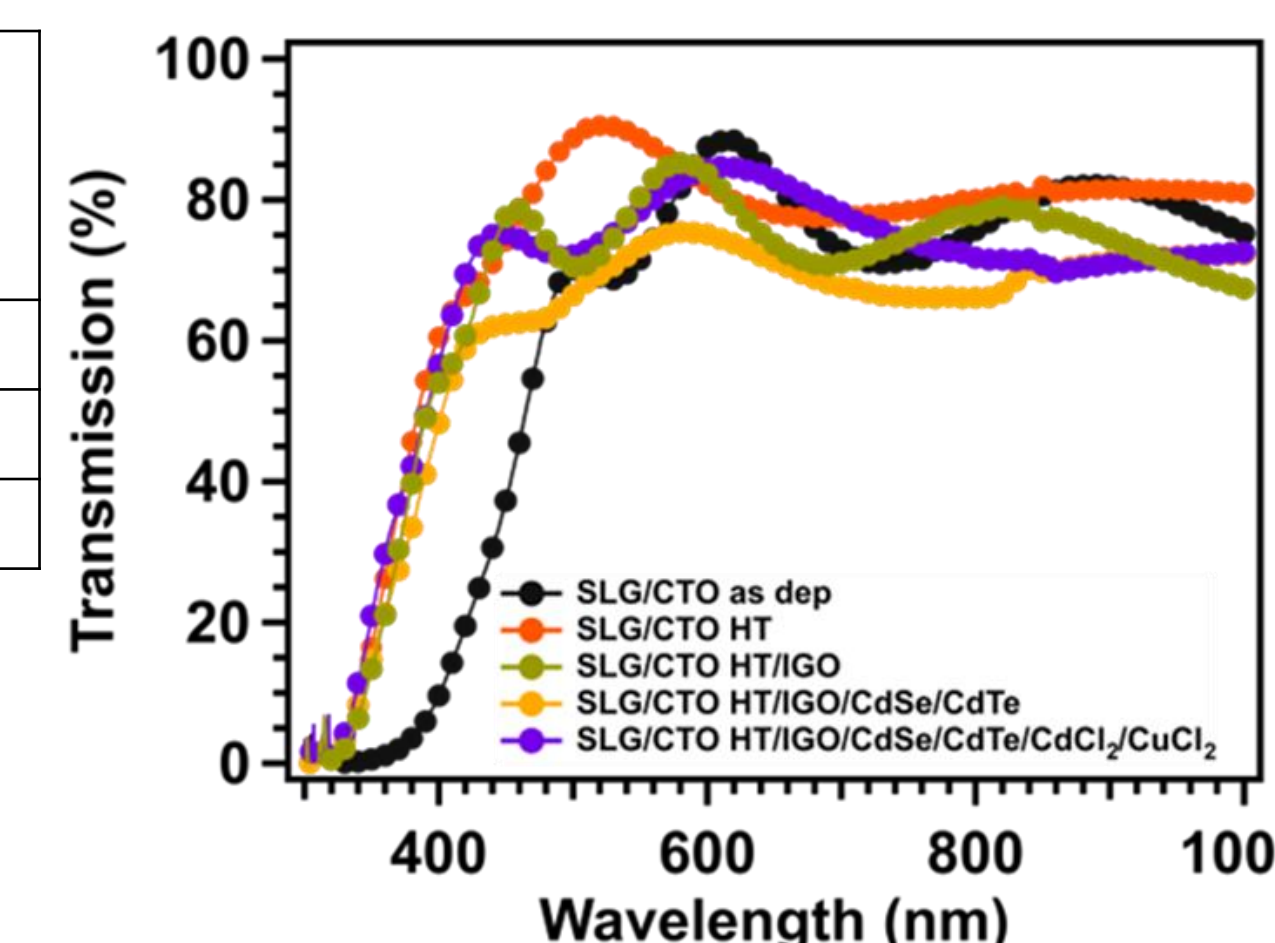
- 3YSZ Ceramic → High reflection, Non TCO coated
- Willow® glass → Non TCO coated



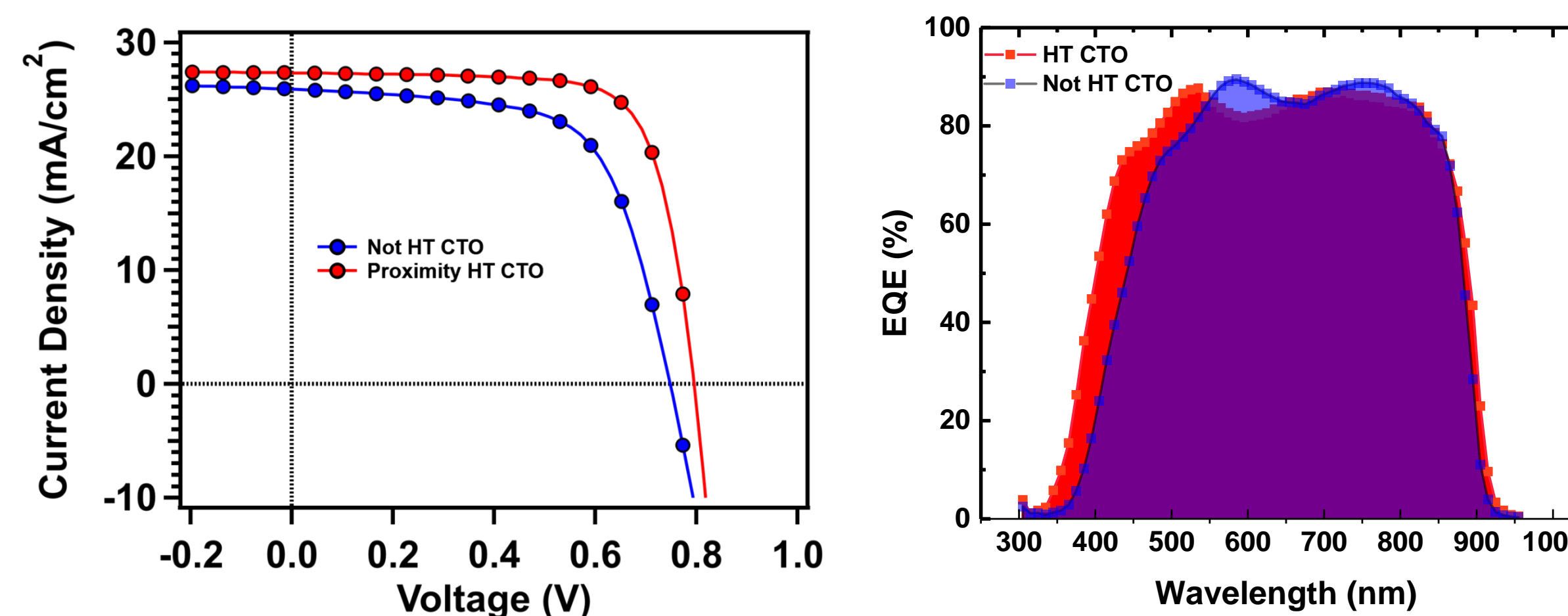
## Results and Discussions

### Electrical and optical properties of CTO films

CTO films fabrication condition	Sheet resistance (Ω/□)	Cd:Sn ratio
SLG/CTO	4953 ± 739	2:1
SLG/CTO/Heat Treatment (HT)	101 ± 22	1:1
SLG/CTO/proximity HT	11.3 ± 2.8	2:1
SLG/CTO/proximity HT/IGO	15.1 ± 6.4	
SLG/proximity HT CTO/IGO/CdSe/CdTe (lift-off)	21.5 ± 2.7	
SLG/proximity HT CTO/IGO/CdSe/CdTe/CdCl <sub>2</sub> /CuCl <sub>2</sub> (lift-off)	23.2 ± 1.9	



### Device Performance

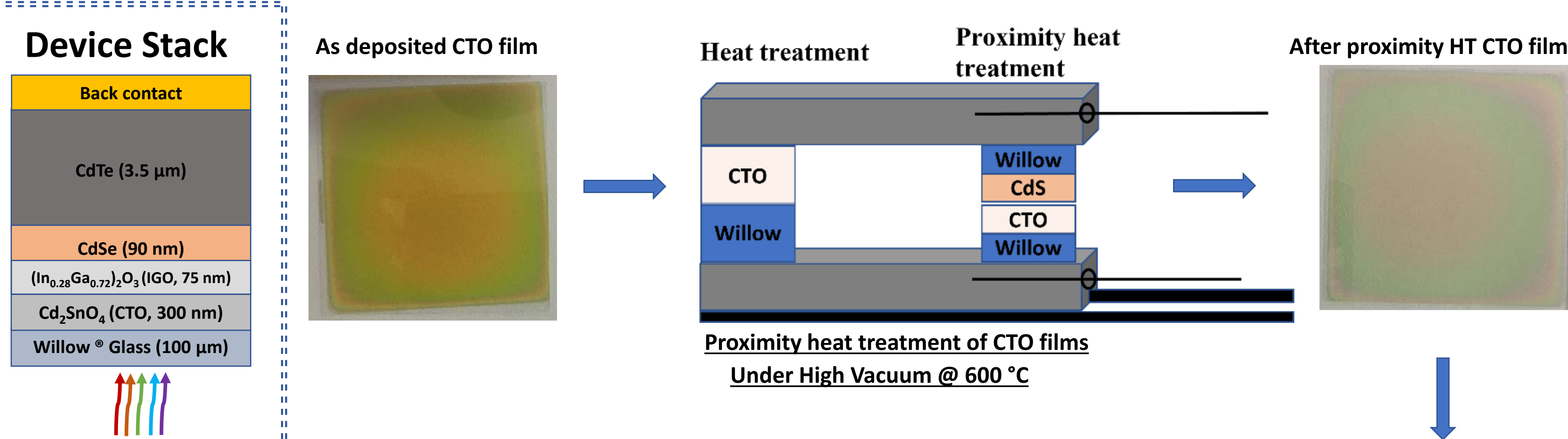


## Takeaways

- CTO could be a stable TCO layer to fabricate CdTe based solar cells.
- Above 16% efficiency with specific power density above ~700 W/kg was achieved for CdTe solar cells fabricated on lightweight Willow® Glass substrate.
- With higher specific power density and low fabrication cost, CdTe based solar cells show potential for space applications.

## Experimental Details

### Device stacks and fabrication methods



Illumination	Device stacks	Voc (mV)	Jsc (mAcm <sup>-2</sup> )	FF (%)	PCE (%)
AM1.5	MgF <sub>2</sub> /Willow/not HT CTO/IGO/CdSe/CdTe/CdCl <sub>2</sub> /CuCl <sub>2</sub> /Au	748	26.0	64.6	12.5
AM1.5	MgF <sub>2</sub> /Willow/proximity HT CTO/IGO/CdSe/CdTe/CdCl <sub>2</sub> /CuCl <sub>2</sub> /Au	798	27.3	74.1	16.1

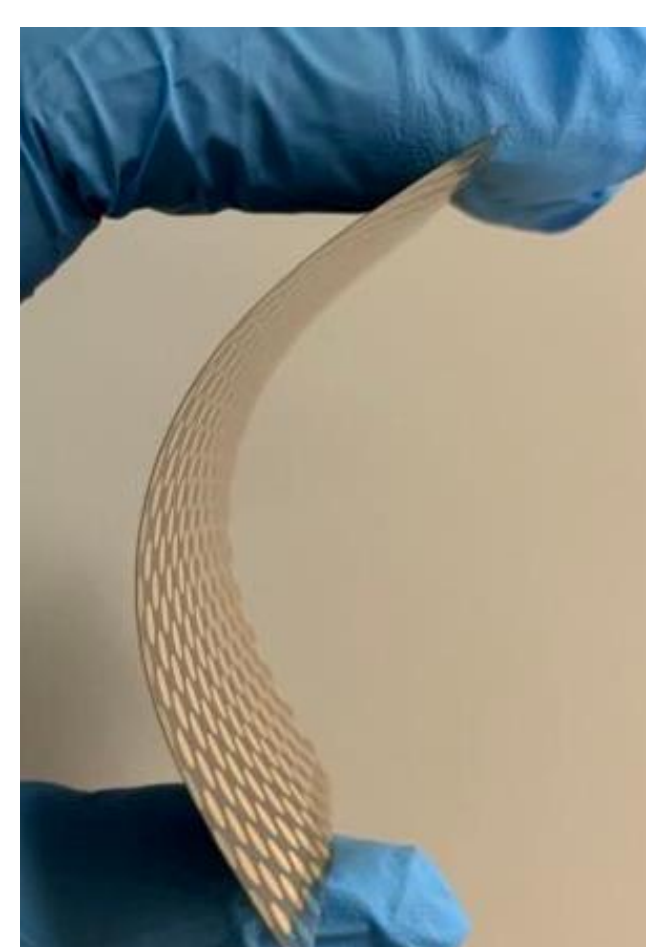
Specific Power density ~ 700 W/kg

## References

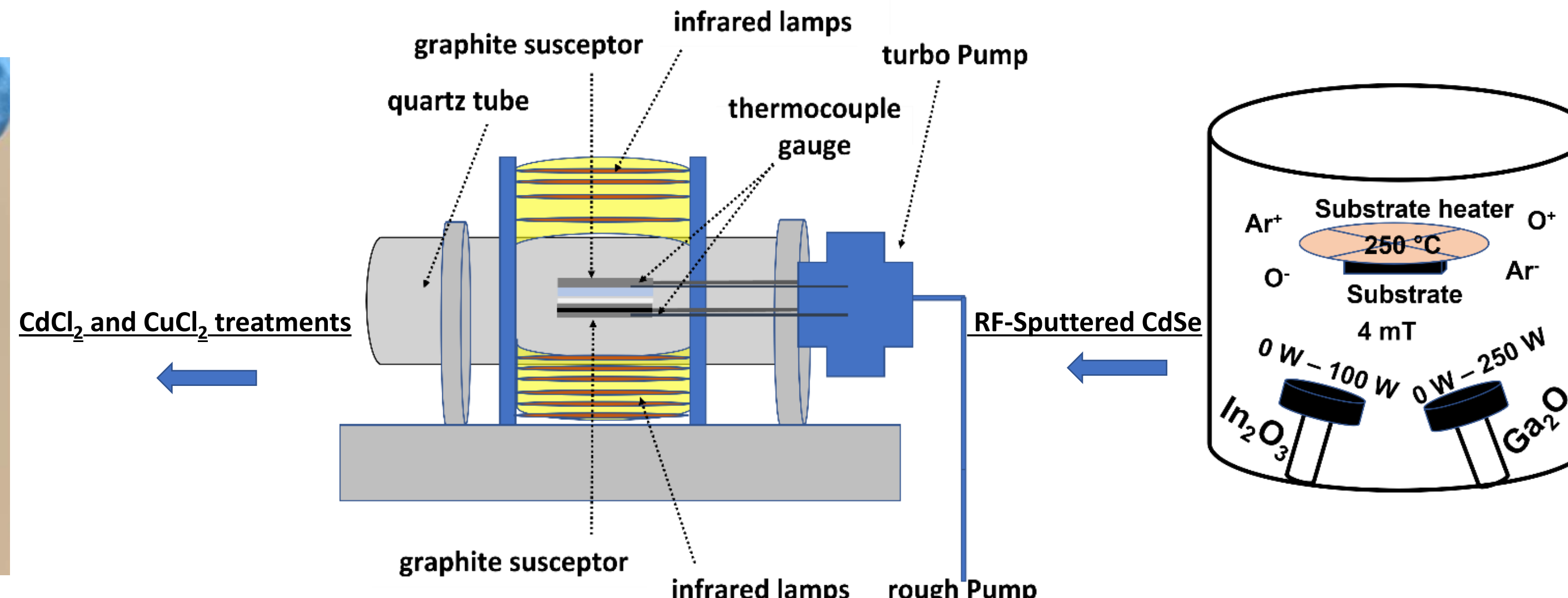
1. M. Green, E. Dunlop, J. Hohl-Ebinger, M. Yoshita, N. Kopidakis, and X. Hao, "Solar cell efficiency tables (version 57)," Progress in Photovoltaics: Research and Applications, vol. 29, no. 1, pp. 3-15, 2020.
1. Jamarkattel, Manoj K., et al. "Indium Gallium Oxide Emitters for High-Efficiency CdTe-Based Solar Cells." ACS Applied Energy Materials 5.5 (2022): 5484-5489.

## Acknowledgments

This material is based on research sponsored by Air Force Research Laboratory under agreements FA9453-19-C-1002 and FA9453-21-C-0056, and by the U.S. DOE's Office of Energy Efficiency and Renewable Energy (EERE) under the Solar Energy Technologies Office (SETO), through Agreement DE-EE0008974 and through the Alliance for Sustainable Energy, LLC, Managing and Operating Contractor for the National Renewable Energy Laboratory for the U.S. Department of Energy, under Award Number 37989. The U.S. Government is authorized to reproduce and distribute reprints for Governmental purposes notwithstanding any copyright notation thereon. The views expressed are those of the authors and do not reflect the official guidance or position of the United States Government, the Department of Defense or of the United States Air Force. The appearance of external hyperlinks does not constitute endorsement by the United States Department of Defense (DoD) of the linked websites, or the information, products, or services contained therein. The DoD does not exercise any editorial, security, or other control over the information you may find at these locations. Approved for public release; distribution is unlimited. Public Affairs release approval # 2023-0087. Authors would like to thank Dr. Sean Garner and Corning Inc. for providing the Corning® Willow® glass.



Completed device with Au electrode



CSS: High quality CdTe deposition

RF co-sputtered IGO [2]