# Printed $CuInSe_2$ Nanocrystal Photovoltaic Devices

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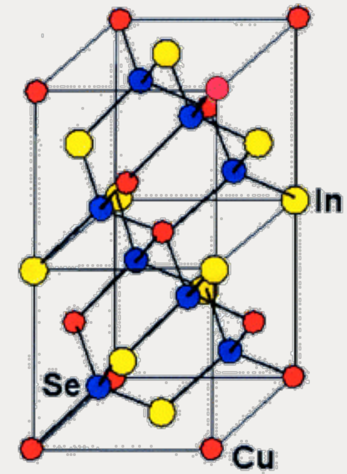
# ***Next Generation PV Devices***

- Solution processed
- Flexible and stretchable electronics
- Low cost, High efficiency

## ***$CuInSe_2$ (CIS)***

○ High efficiency & commercially viable
○ No toxic elements like Cd or Pb
× Require **High Temperatures** to form CIS (~550 $^{o}$C)

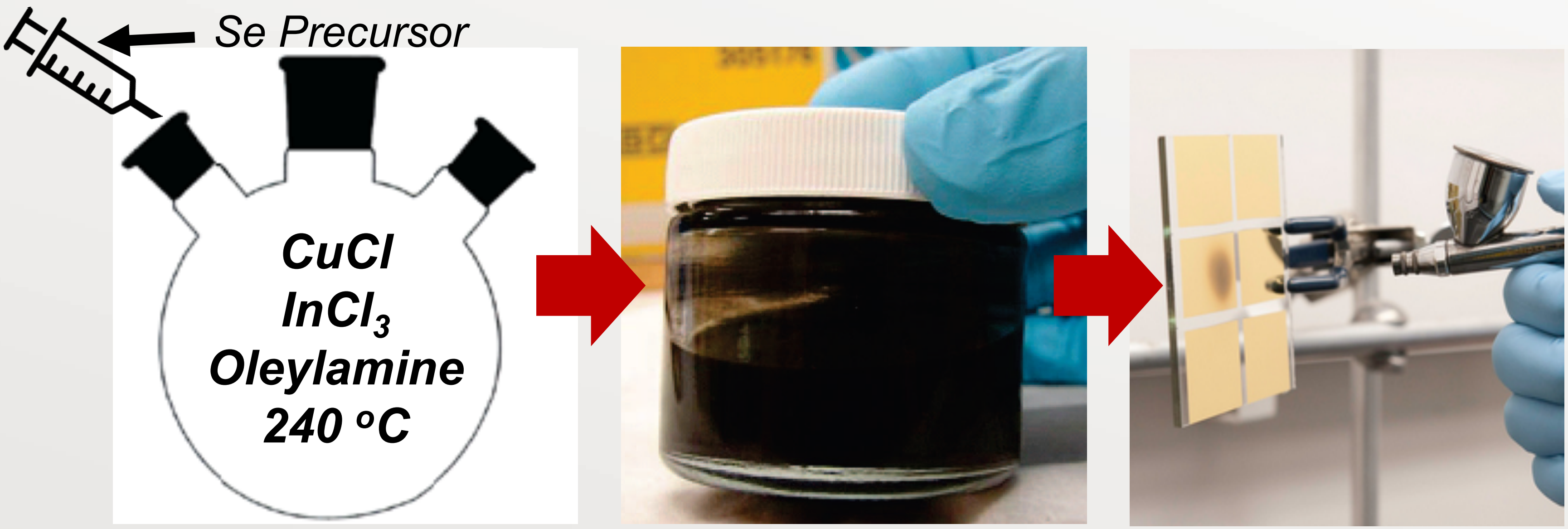



**CIS nanocrystals can solution processed at room temperature.**

# ***$CuInSe_2$ Nanocrystal Photovoltaics***

Mild Fabrication Processes

- Colloidal synthesis of chalcopyrite $CuInSe_2$ nanocrystals
- **Solution processed** inks
- Deposited in **ambient conditions** on substrates

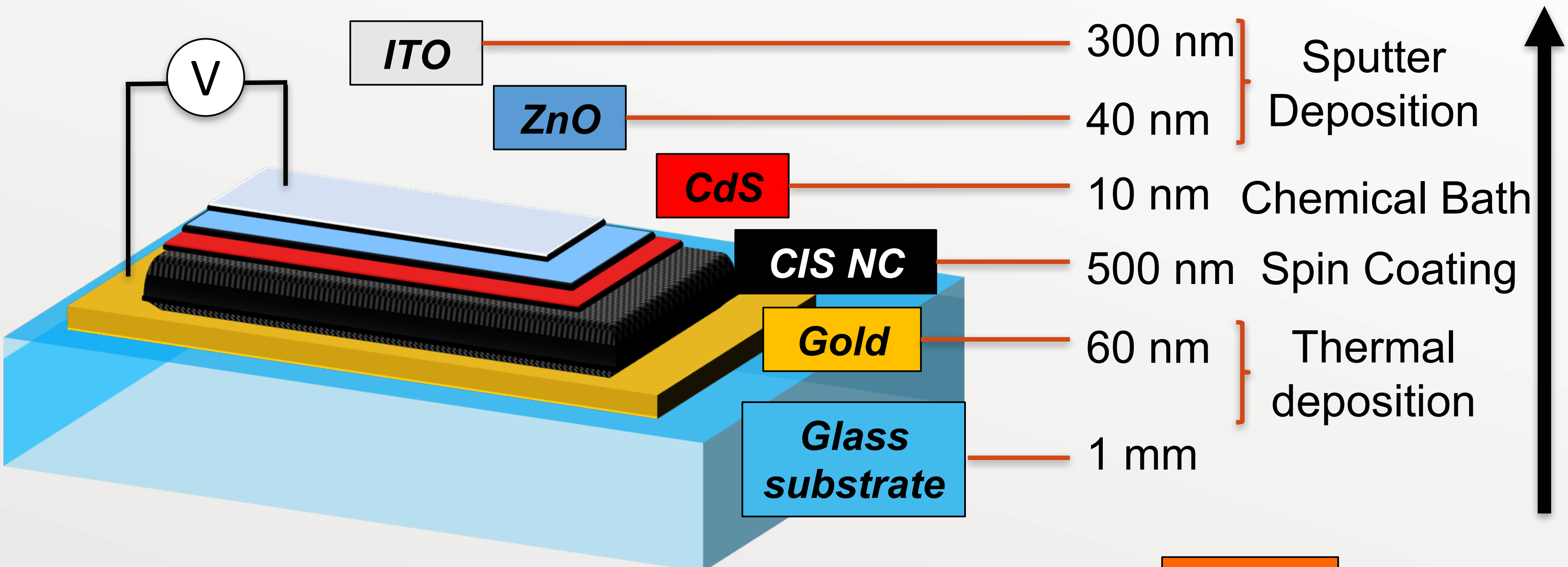



*Panthani et. al. J. Phys. Chem. Lett. 2013, 4, 2030.Panthani et. al J. Am. Chem. Soc., 2008, 130 (49), 16770*

The efficiency of CIS nanocrystal PV is still not high (~3 %).

We aim to investigate methods for improving the efficiency

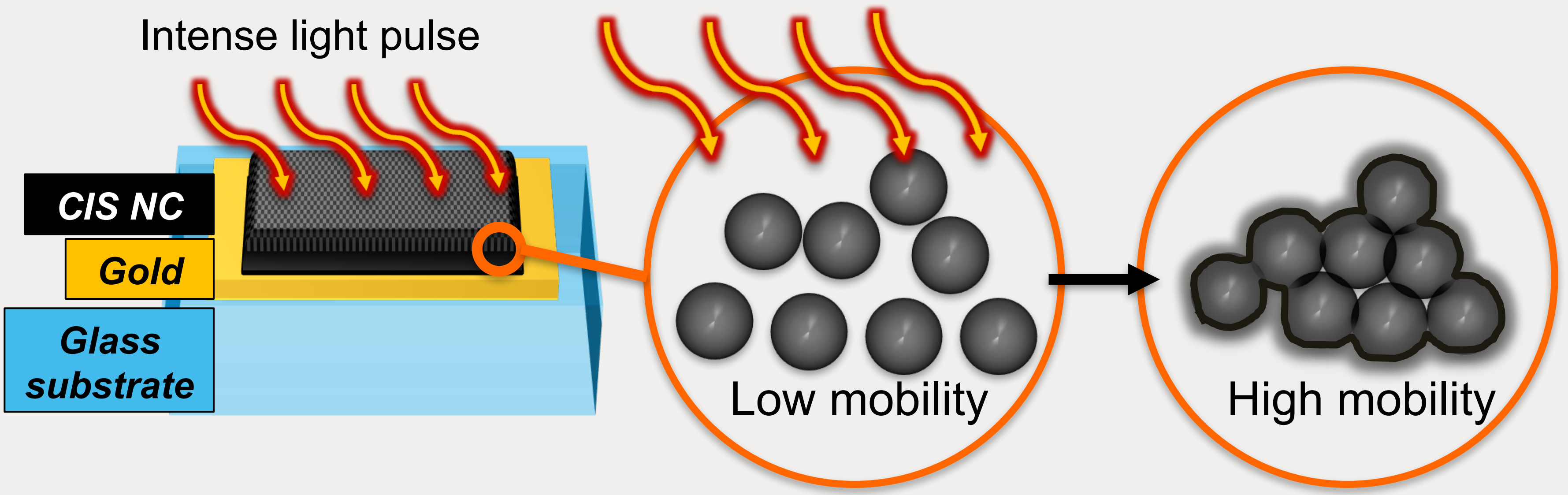
# $CuInSe_2$ Nanocrystal Photovoltaics




# Intense Light Pulse Sintering


## Requirements to minimize substrate heating

- Enable to remove ligands surround CIS
- Enable to sinter the CIS particles in the short time (~1 ms)



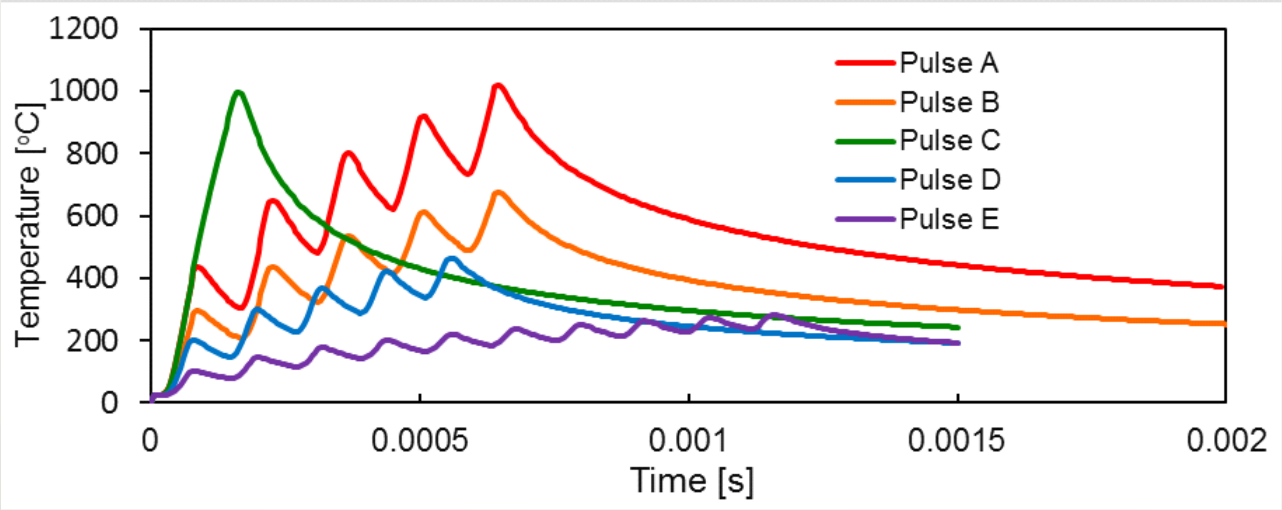

We can expect to improve CIS PV efficiency by intense light pulse

K. A. Schrode Mechanisms of Photonic Curing™: Processing High Temperature Films on Low Temperature Substrates NCC NanoLLC

# Devices Made with "Pulse A-E"

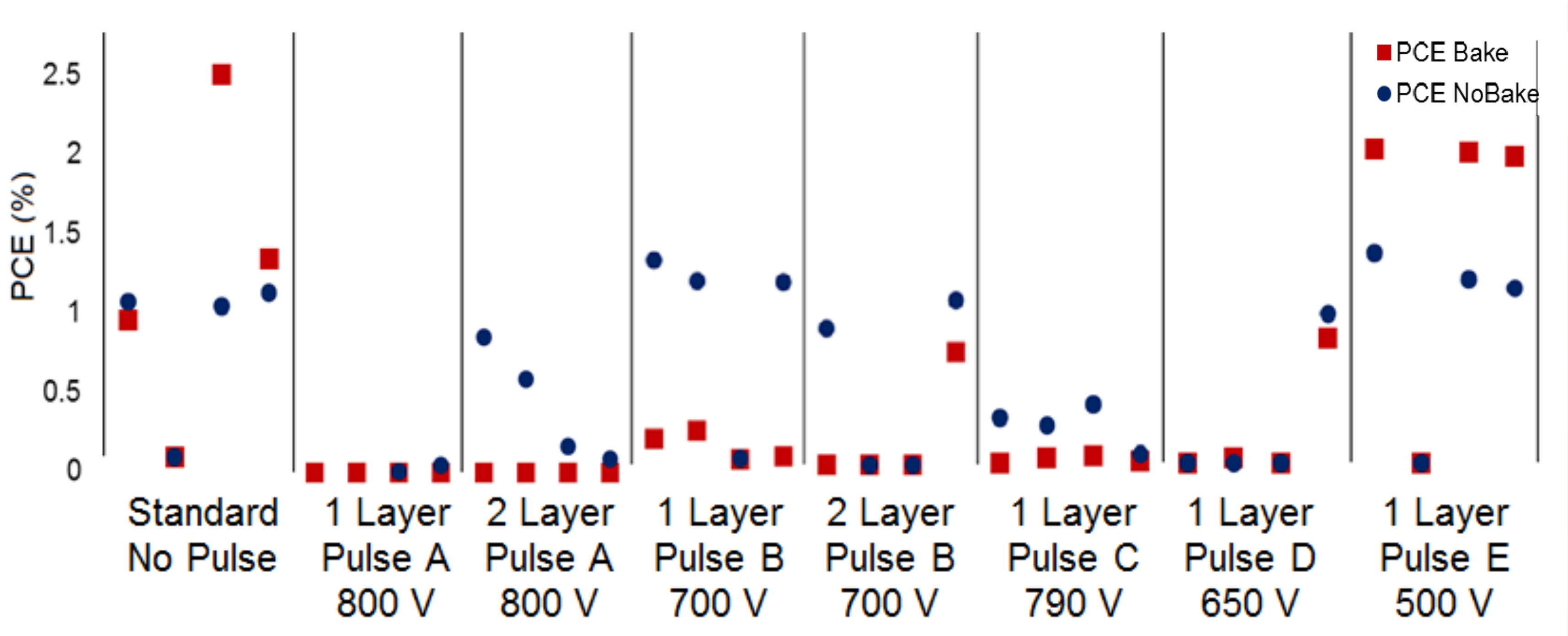
In this experiment we studied various light pulses.
The temperature at the surface of the CIS layer was simulated.

| Pulse Name | Bank Voltage (V) | Envelope Time (μs) | Number of Pulses | Cycle Duty | Energy Input (J/cm$^2$) |
|---|---|---|---|---|---|
| **Pulse A** | 800 | 700 | 5 | 50% | **3.848** |
| **Pulse B** | 700 | 700 | 5 | 50% | **2.739** |
| **Pulse C** | 790 | 150 | **1** | -- | **1.914 ± 0.032** |
| **Pulse D** | 650 | 600 | **5** | 50% | **1.958 ± 0.018** |
| **Pulse E** | 500 | 1200 | **10** | 50% | **1.925 ± 0.007** |



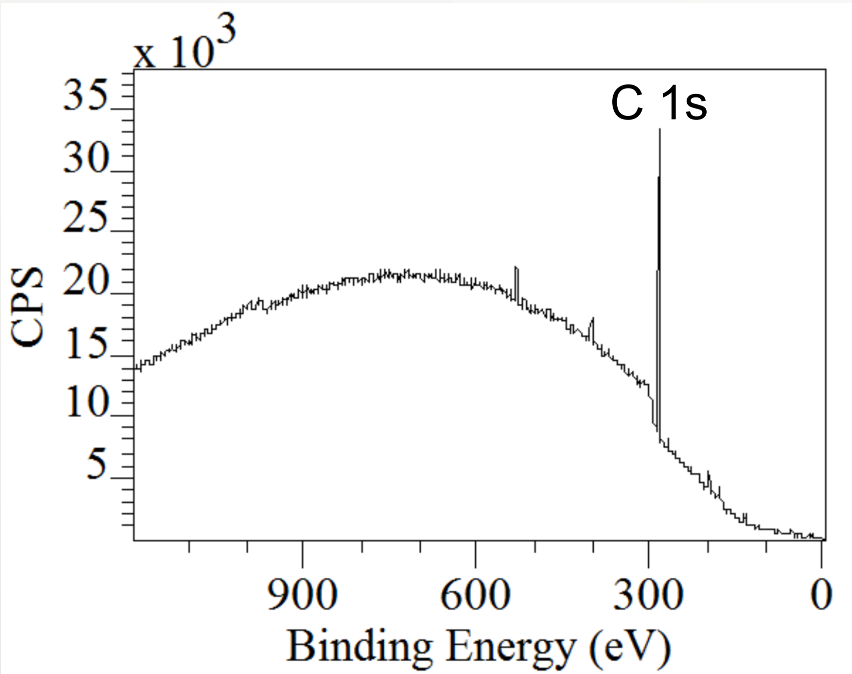
# Devices Made with "Pulse A-E"

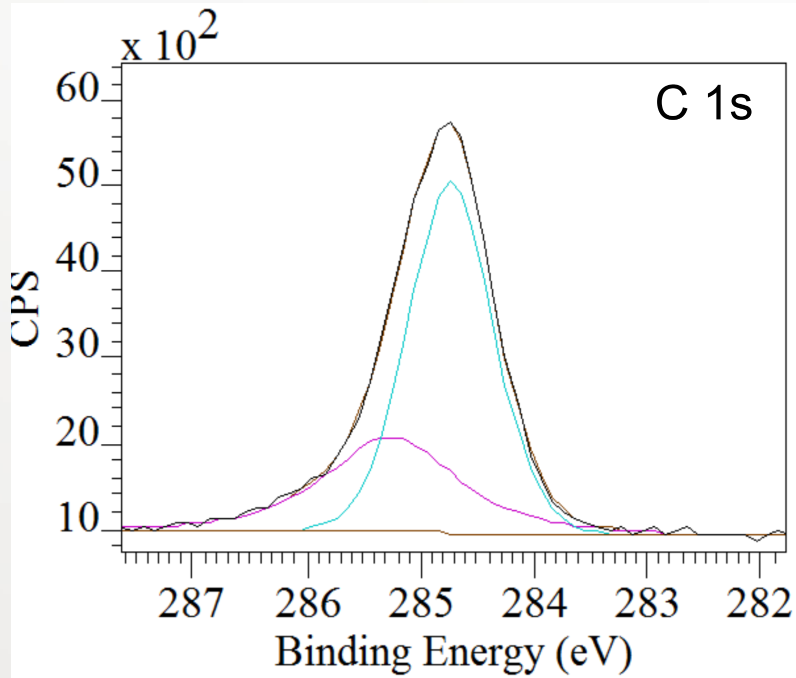
- Pulse A: Appears to short out the devices.
- Pulse B: Almost the same value as standard.
- Pulses C-E: Increasing the duration of pulses of the same energy improves performance.




High intensity Pulse (650-800 capacitor voltage) didn't give any improvement efficiency, likely due to thermal damage.

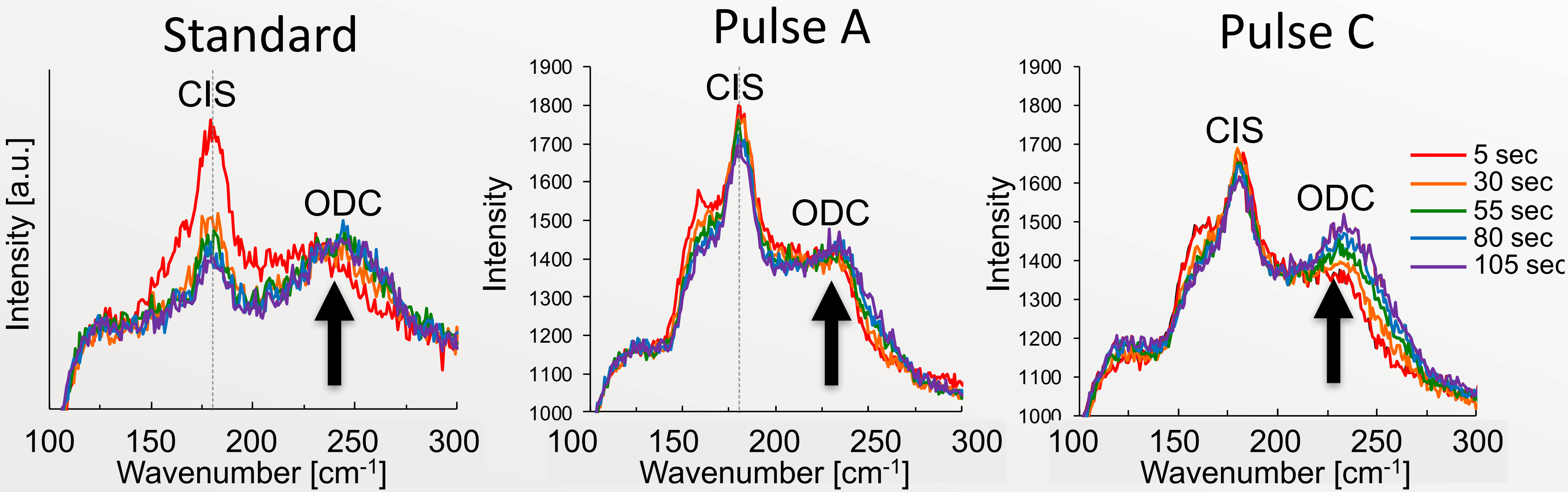
# X-ray Photoelectron Spectroscopy (XPS)



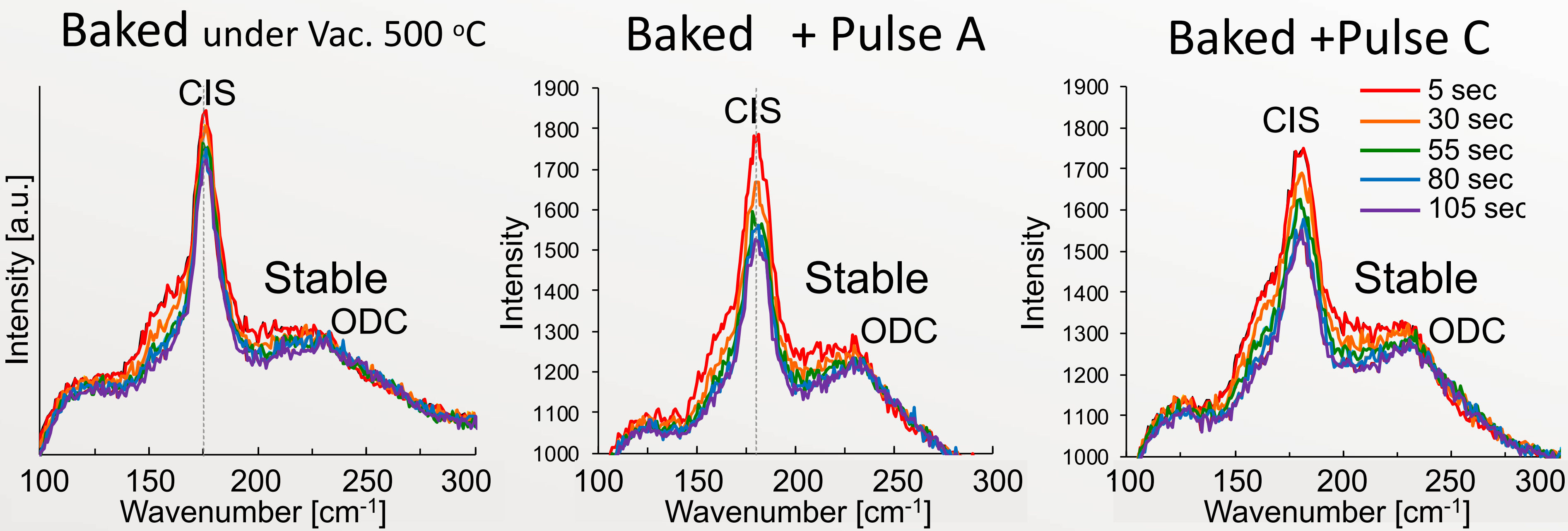

Carbon layer on the pulsed CIS nanocrystal surface, likely reducing the efficiency of the CIS PV devices

# Raman Spectroscopy




- After Pulse, the CIS peak at 180 $cm^{-1}$ is stable.
  → Pulse is useful for making a stable CIS crystal structure
- The peak coming from ligand or ordered defect compound (ODC) increased over laser exposure time.
  → Removing ligand and ODC will likely improve the efficiency.

# Raman Spectroscopy




- The peaks coming from ODC is stable over laser exposure time.
- We can see peak shift from 180-174 $cm^{-1}$ meaning cation ordering.

→ We can expect the higher efficiency of CIS nanocrystal PV devices baked and Pulsed.

# Summary

- ✓ High intensity Pulse (650-800 capacitor voltage) didn’t give any improvement in efficiency like due to the carbon layer or defect formation

- ✓ We can expect that the efficiency of CIS PVs can be improved by baking in vacuum condition to remove some defects and ligands

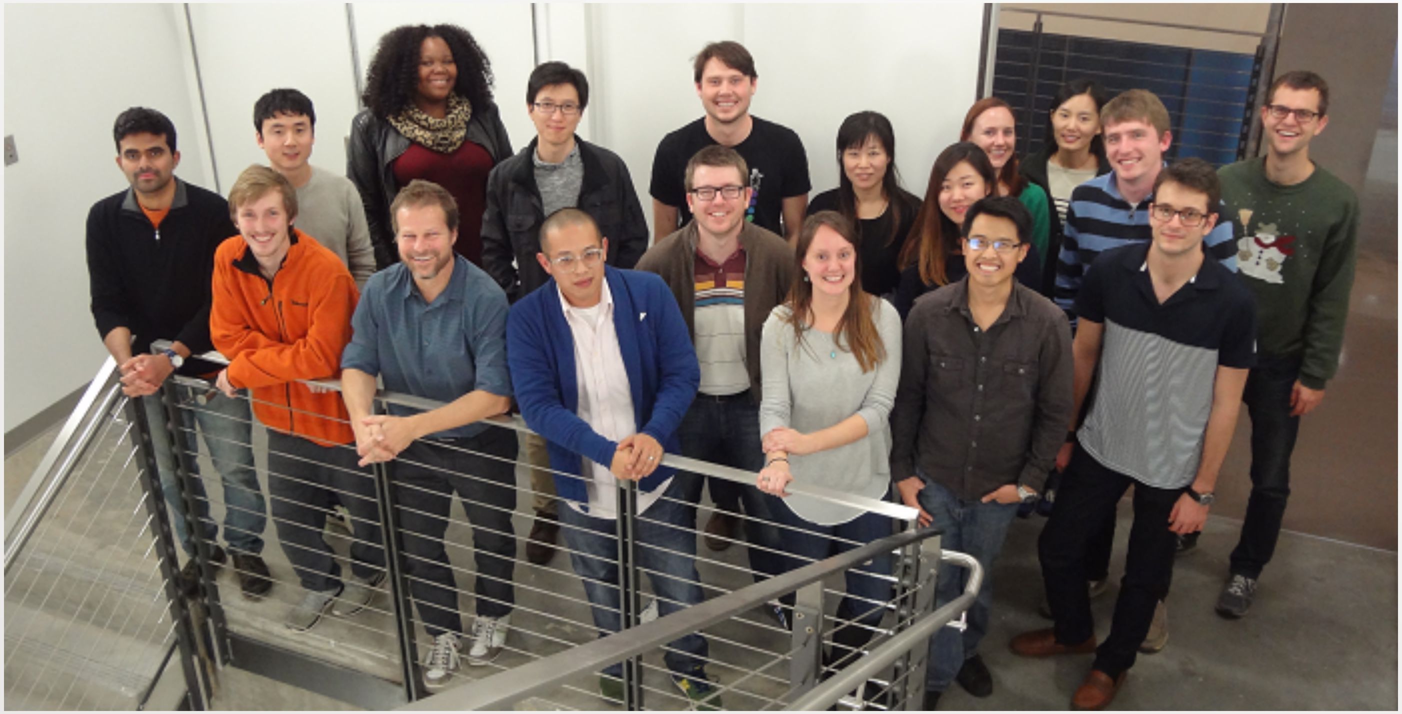
# Future work

- ✓ Prevent the formation of a carbon layer by baking in vacuum condition

- ✓ Fabrication and testing the baked and Pulsed CIS nanocrystal PVs devices

# Acknowledgement

Mentor: Dan Houck PI: Brian A. Korgel



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