SAND2008-5243C

Environmental Sensitivity of a Radiation Sensitive Semiconducting Polymer

Tiffany M.S. Wilson,[1,2] Douglas A. Chinn,[3] and F. Patrick Doty[1]

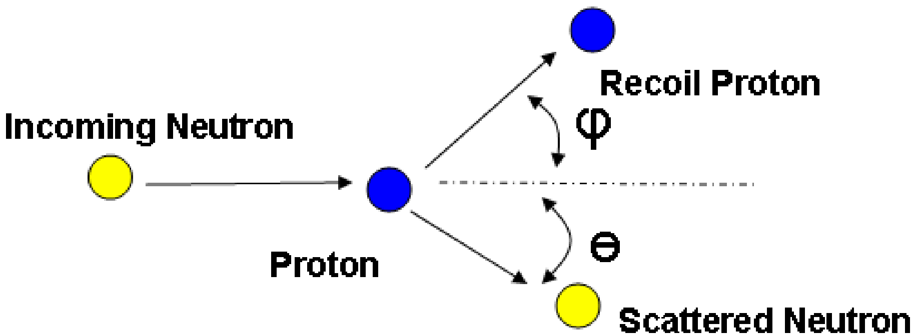
1. Sandia National Laboratories, Livermore, CA
2. The Ohio State University, Dept of Chemical and Biomolecular Engineering
3. Sandia National Laboratories, Albuquerque, NM

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Polymer Radiation Detection - Why?

- Semiconducting radiation detectors allow detection with no photomultiplier, as required with scintillators
- Polymer detector allows direct detection of fast neutrons (2 MeV), with no moderator
- Room temperature operation improves cost, size and convenience
- Low Z polymer provides minimal gamma interaction
- High H/C ratio for neutron sensitivity
- High Dielectric strength – Can operate at high field
- Low Dielectric constant – low capacitance
- High Resistivity – low leakage current

Polymer Radiation Sensors – How?

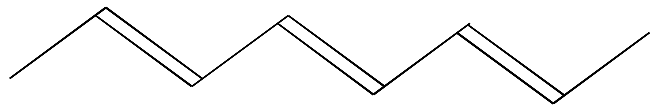


- Proton recoil reaction
- Proton excites mobile charged particles → detection
- Charges transported by imposed bias

- We Need
  - High mobility
  - High resistivity
  - Thickness (high H density per unit area)
  - Low trapping and recombination

- Controlled by
  - Chemistry
  - Processing
  - Additives
  - Environment

Conjugated Polymer Conduction



- Conductivity from insulator to metallic (after doping)
- π - π * energy gap Eg is typically 1.5 - 3 eV
- Upon photoexcitation of a polymer, a neutral exciton is formed
- Charge separation by electron transfer to an adjacent chain, resulting in positive and negative polarons on separate chains
- Charges can then be transported to electrodes with an imposed bias
- Recombination and trapping are can reduce charge collection
- Excitation by ionizing radiation likely proceeds along a similar pathway
- Typically hopping transport, field and temperature dependant

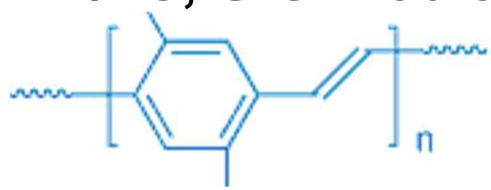
$$\mu_h(E,T) \propto \exp(-\Delta / kT) \cdot \exp(\beta \sqrt{E} / kT)$$

THE OHIO STATE UNIVERSITY

Sandia National Laboratories

Poly(p-phenylene vinylene), PPV

- **I have chosen to work with the family of PPVs**
- **PPVs have mobilities typically from ~10-5 - 10-2 cm2/Vs (Si~ 500 cm2/Vs; SiO2~30 cm2/Vs)**



- **Workable air stability – easier processing**
- **Properties dependant on many variables**
  - **Side chain symmetry**
  - **Solvent, concentration**
  - **Deposition method and conditions**
  - **Post-Deposition processing – vapor, anneal, stretch**
  - **Additives – nanoparticles and plasticizers**

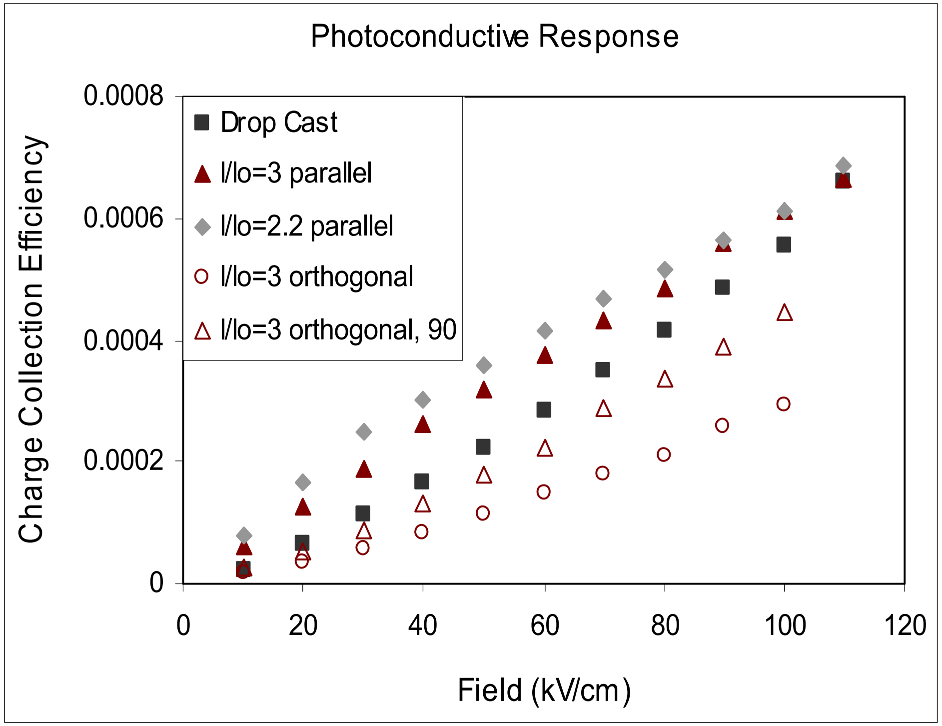
Geens, *Synthetic Metals* **2001**; Tanase, *Journal of Applied Physics* **2005**; van Breemen, *Advanced Functional Materials* **2005**

THE OHIO STATE UNIVERSITY

Sandia National Laboratories

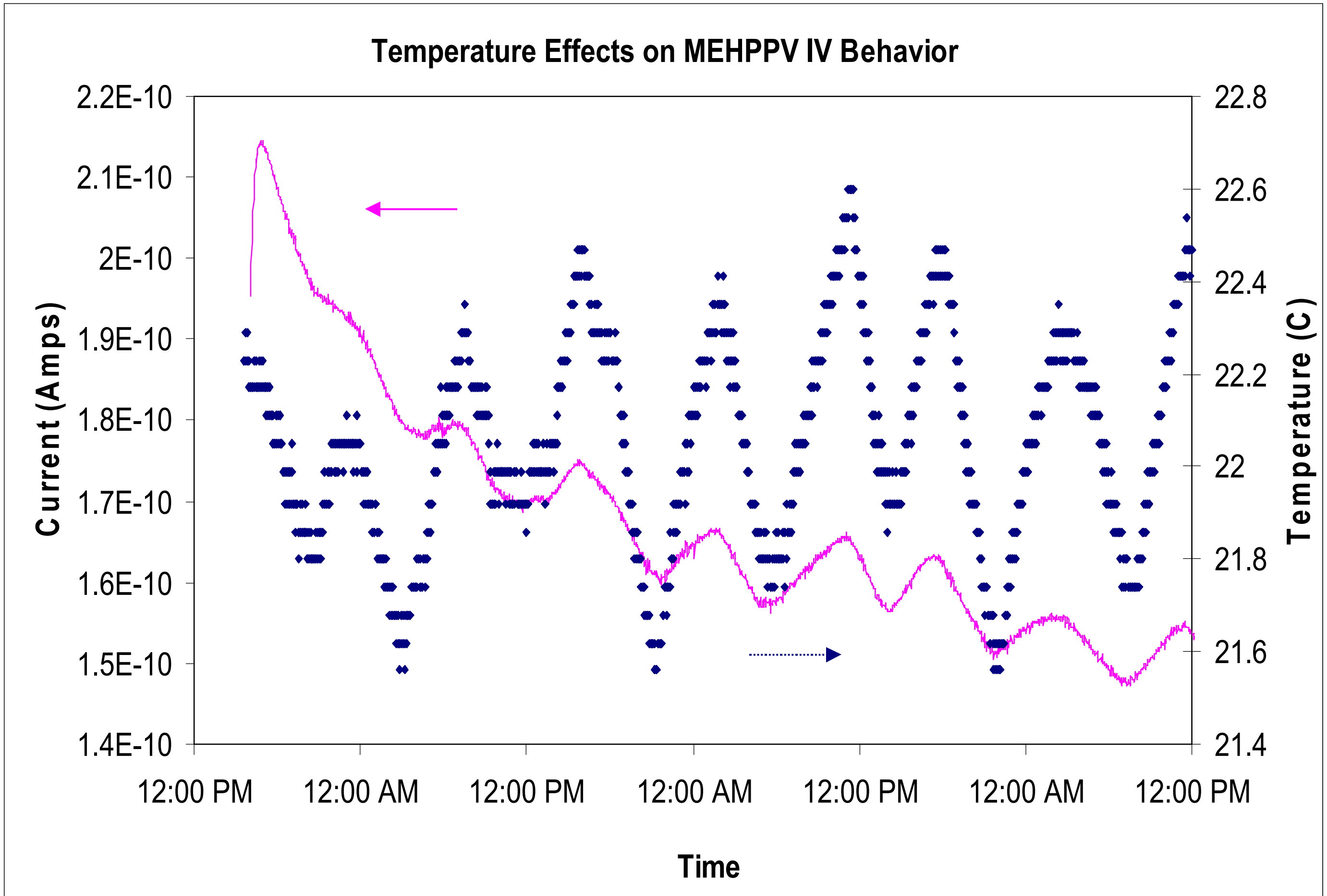
Previous Work

- **Demonstrated radiation sensitivity**
- **Showed increase in photoconductivity with certain processing variables**
- **Current work examines relevant environmental variables**



T. M. S. Wilson, F. P. Doty, D. A. Chinn, M. J. King and B. A. Simmons, "Order and Charge Collection Correlations in Organic Materials for Neutron Detection," in *Penetrating Radiation Systems and Applications VIII*. F. Patrick Doty, Hans Roehrig, Ed., p. 670710, SPIE, San Diego, CA (2007).

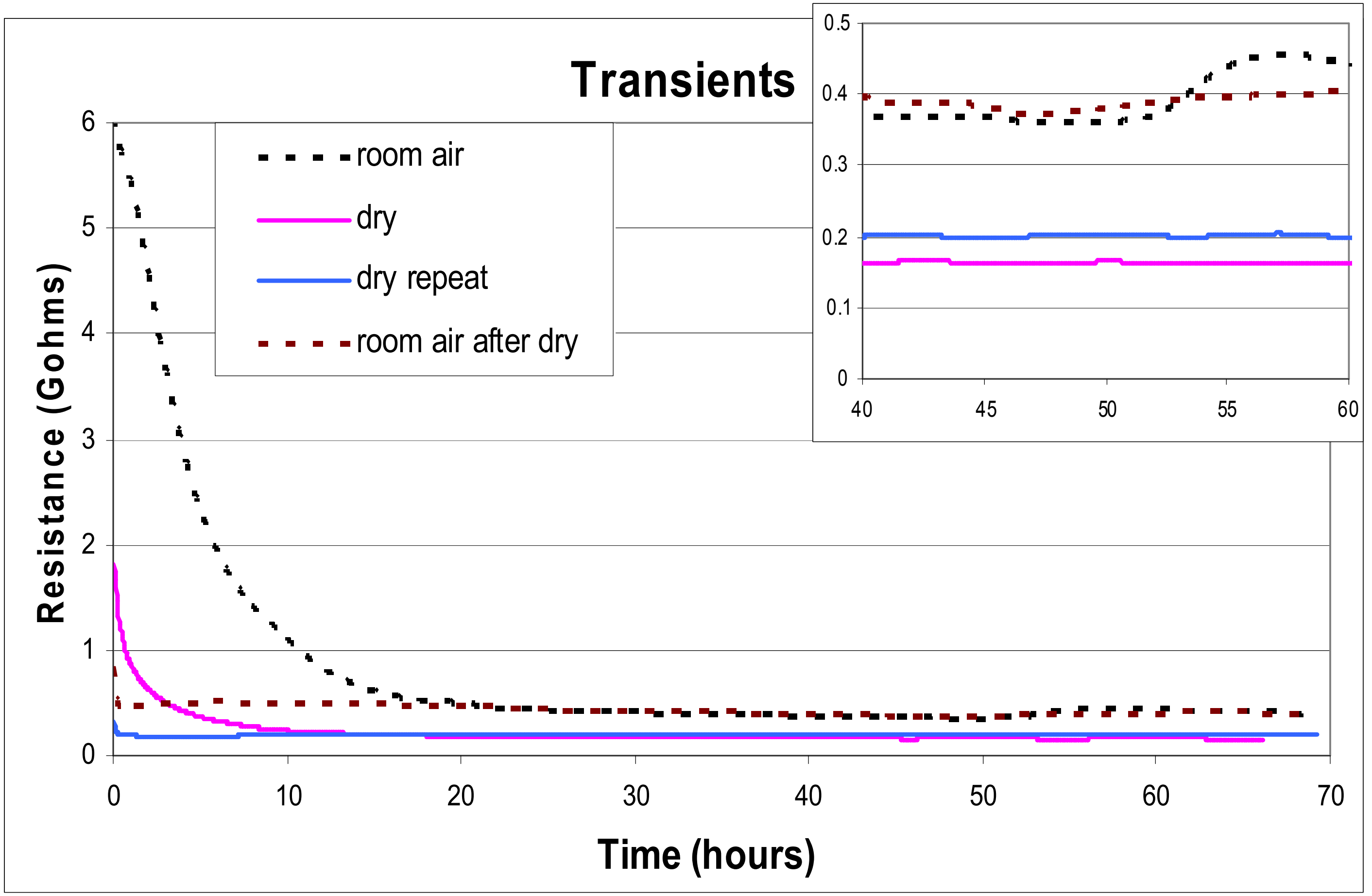
Temperature Dependence



- 1 °C variation in room temperature causes 10 pA change in current
- Temperature sensitivity expected, but not this extreme
- Possible complication
- Possible sensor application

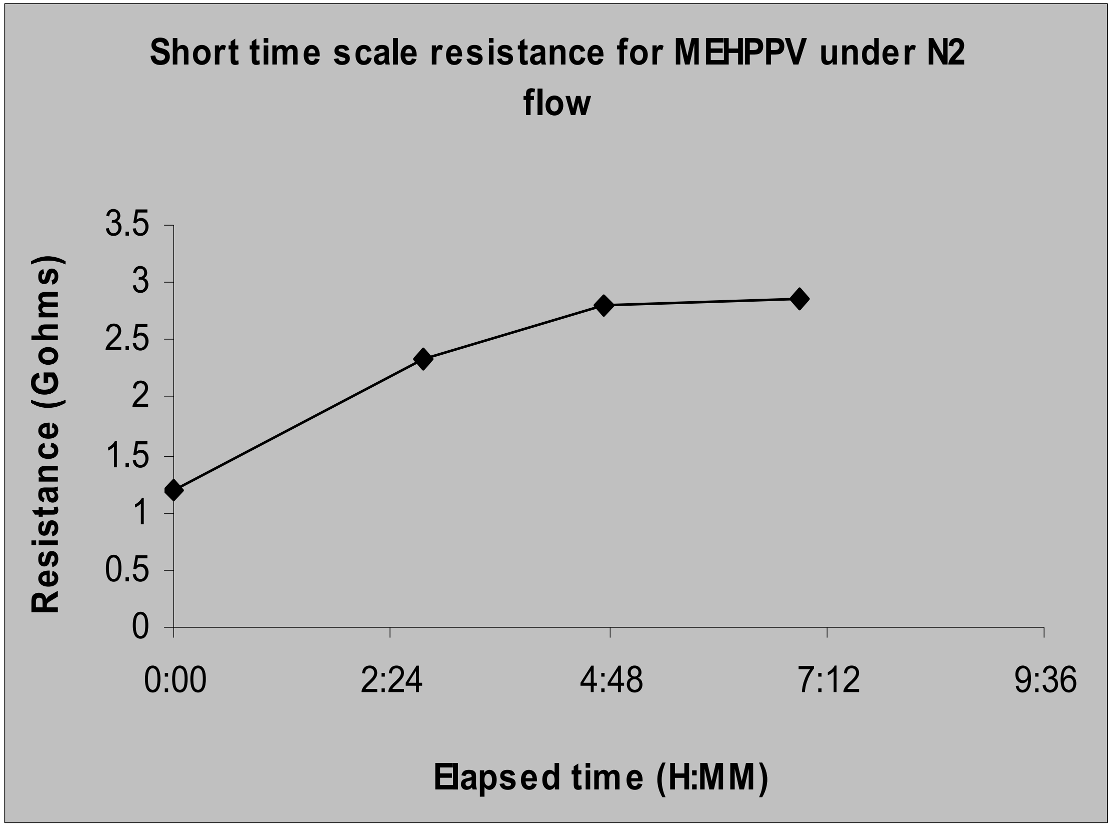
Moisture

- Air v dry air
- Sample in dry air shows roughly 1/2 the resistivity of the sample in room air after equilibration (0.2 GΩ in dry air vs 0.4 GΩ in room air)
- Completely reversible



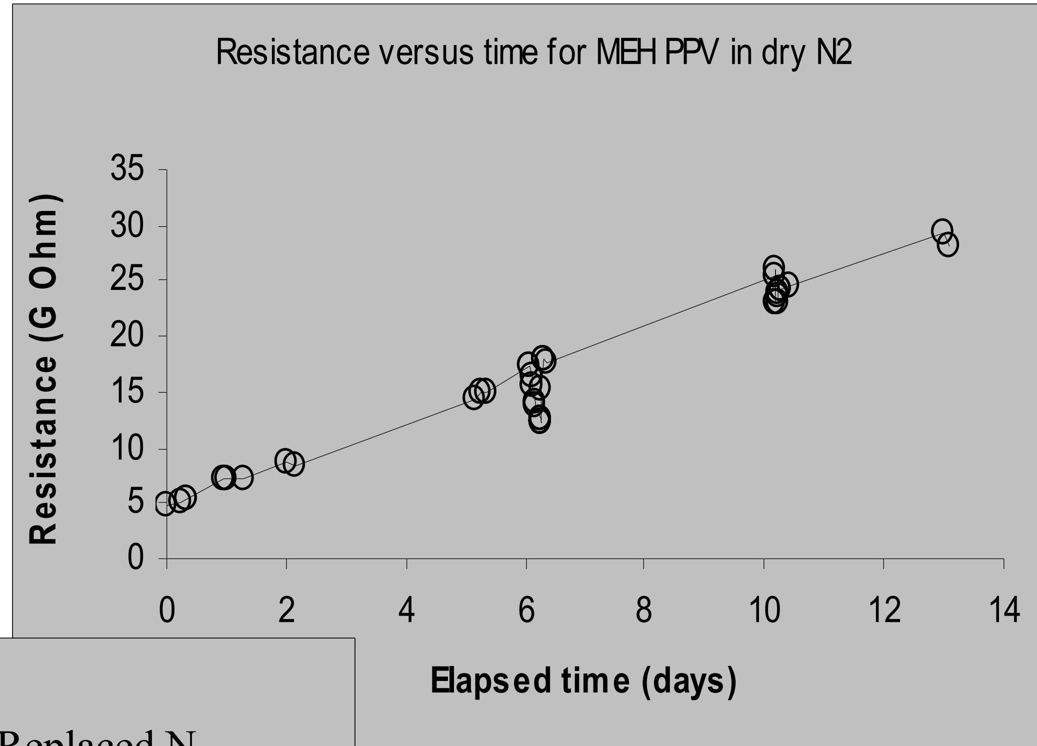
Nitrogen Purge

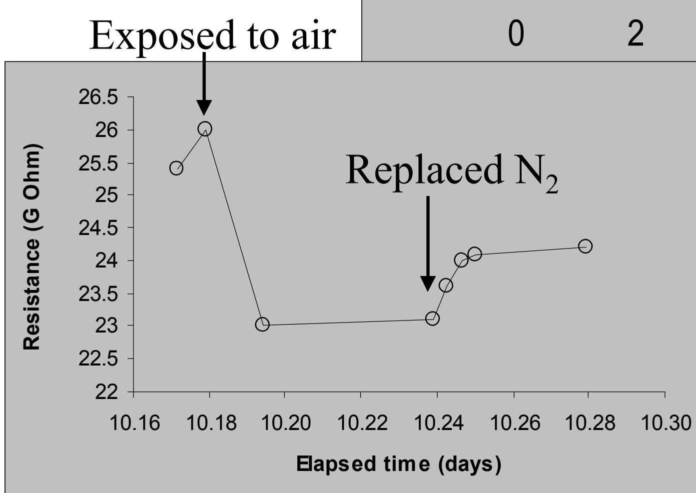
- Began purge with dry nitrogen and monitored resistance across interdigitated electrode over time
- Resistance quickly doubled in a matter of a few hours under purge



Effects of Air/Oxygen

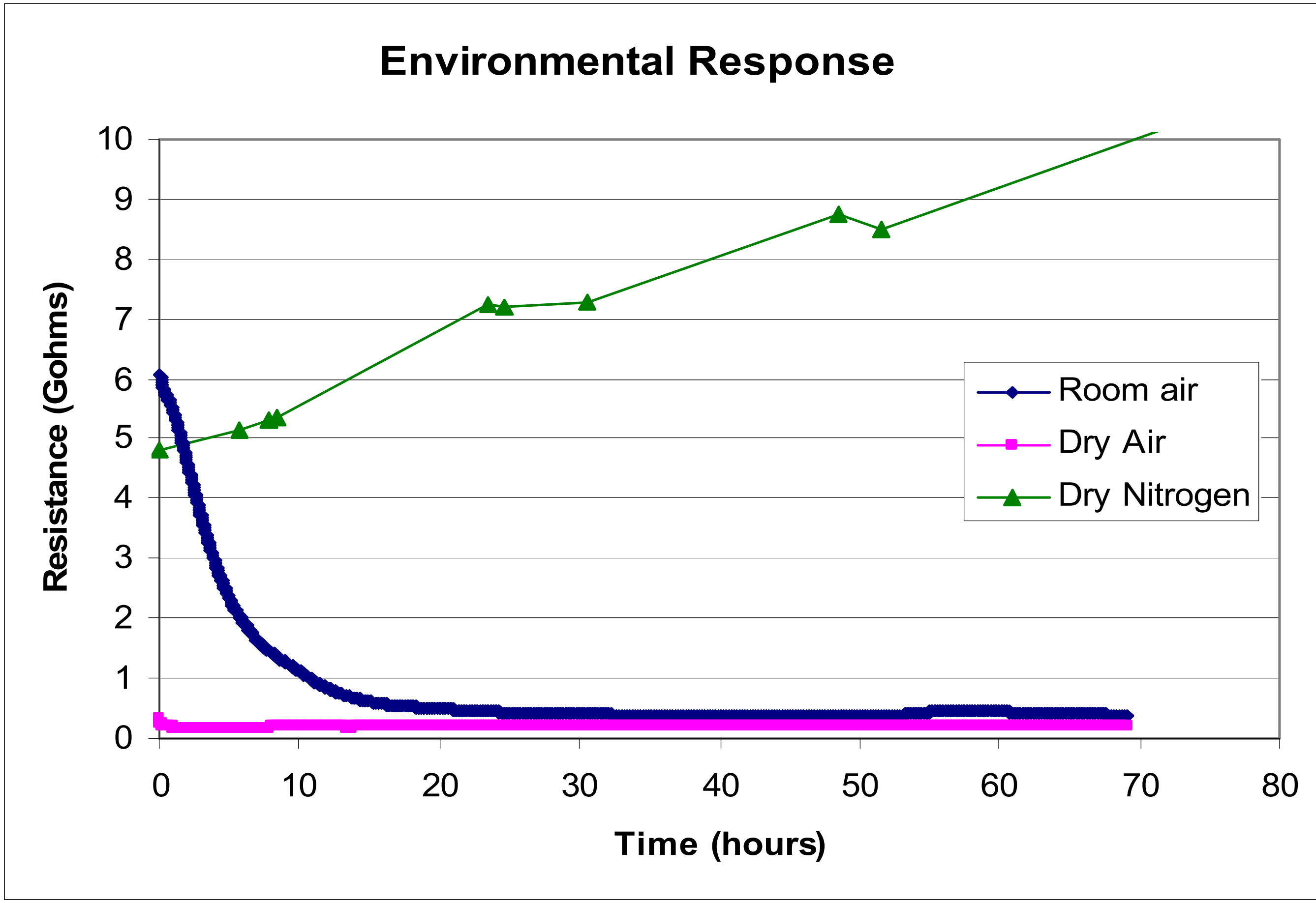
- Not simple diffusion effects
- Resistance decrease upon removal of N2 purge and air exposure is very fast (.18 Gohm/ min)
- Resistance increase under purge is much slower (.05 Gohm/ min)



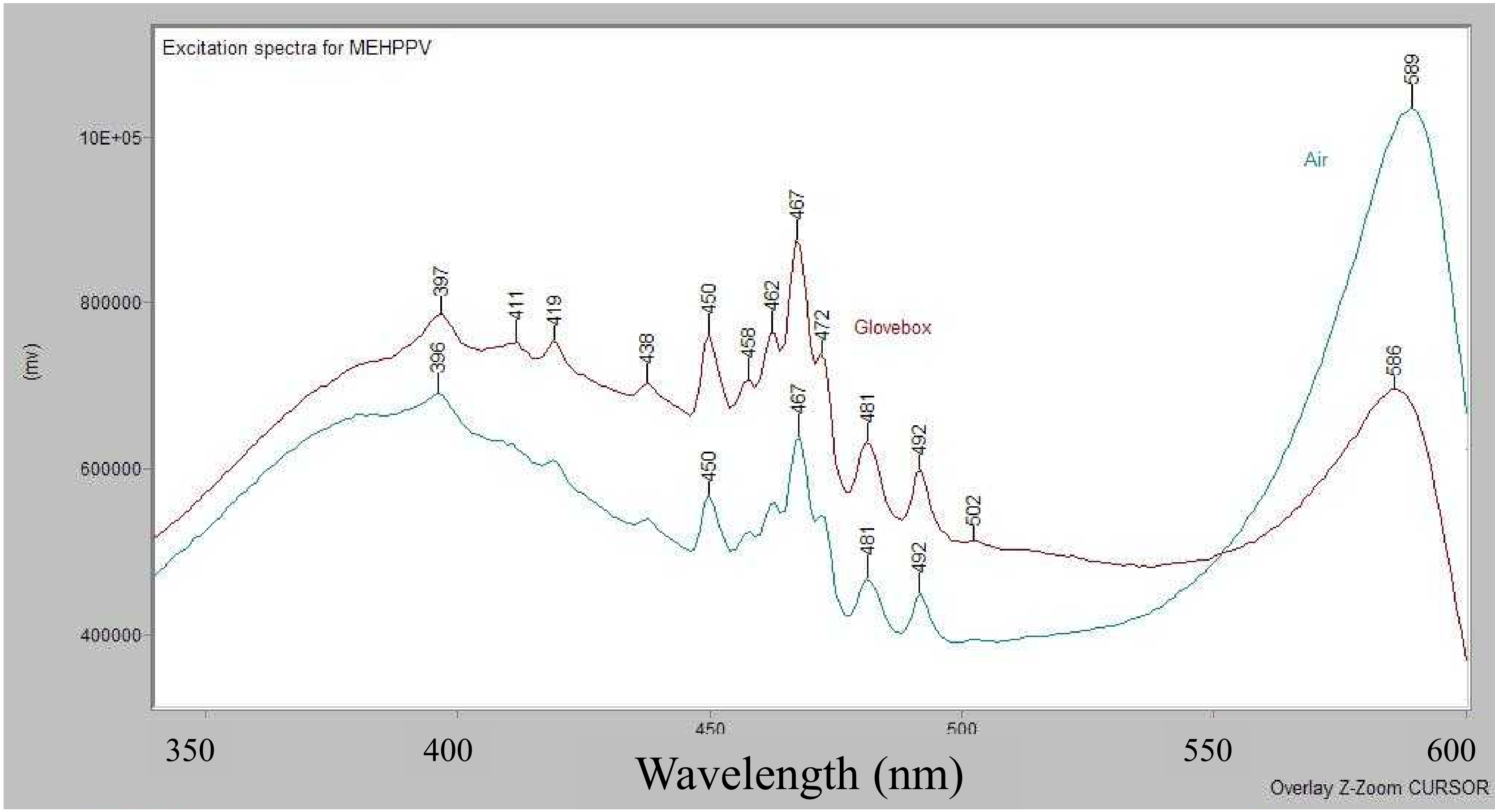


Environment Summary

- Complex Interactions
- Humidity
- Oxygen
- Other factors possible

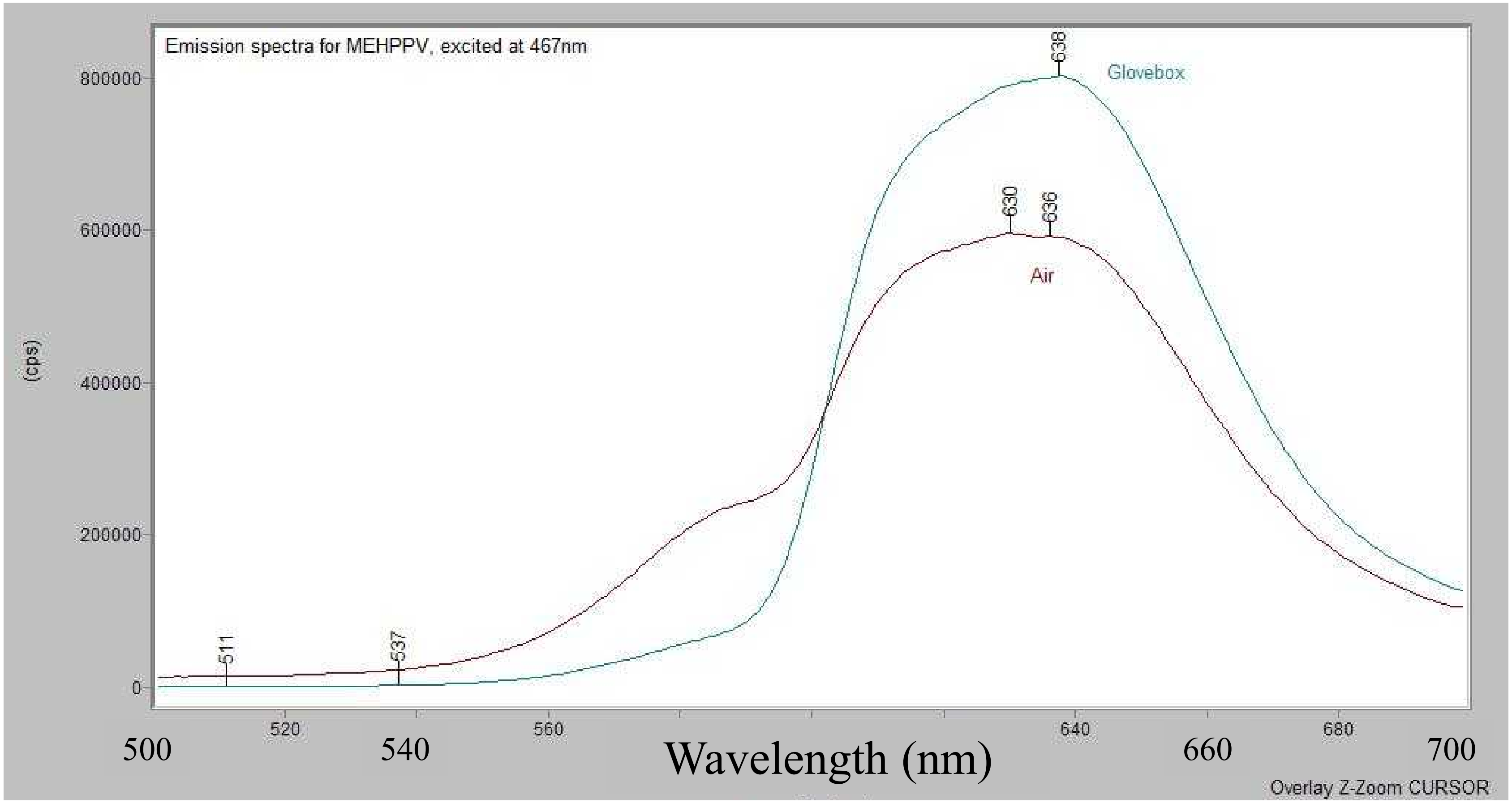


Excitation/Emission



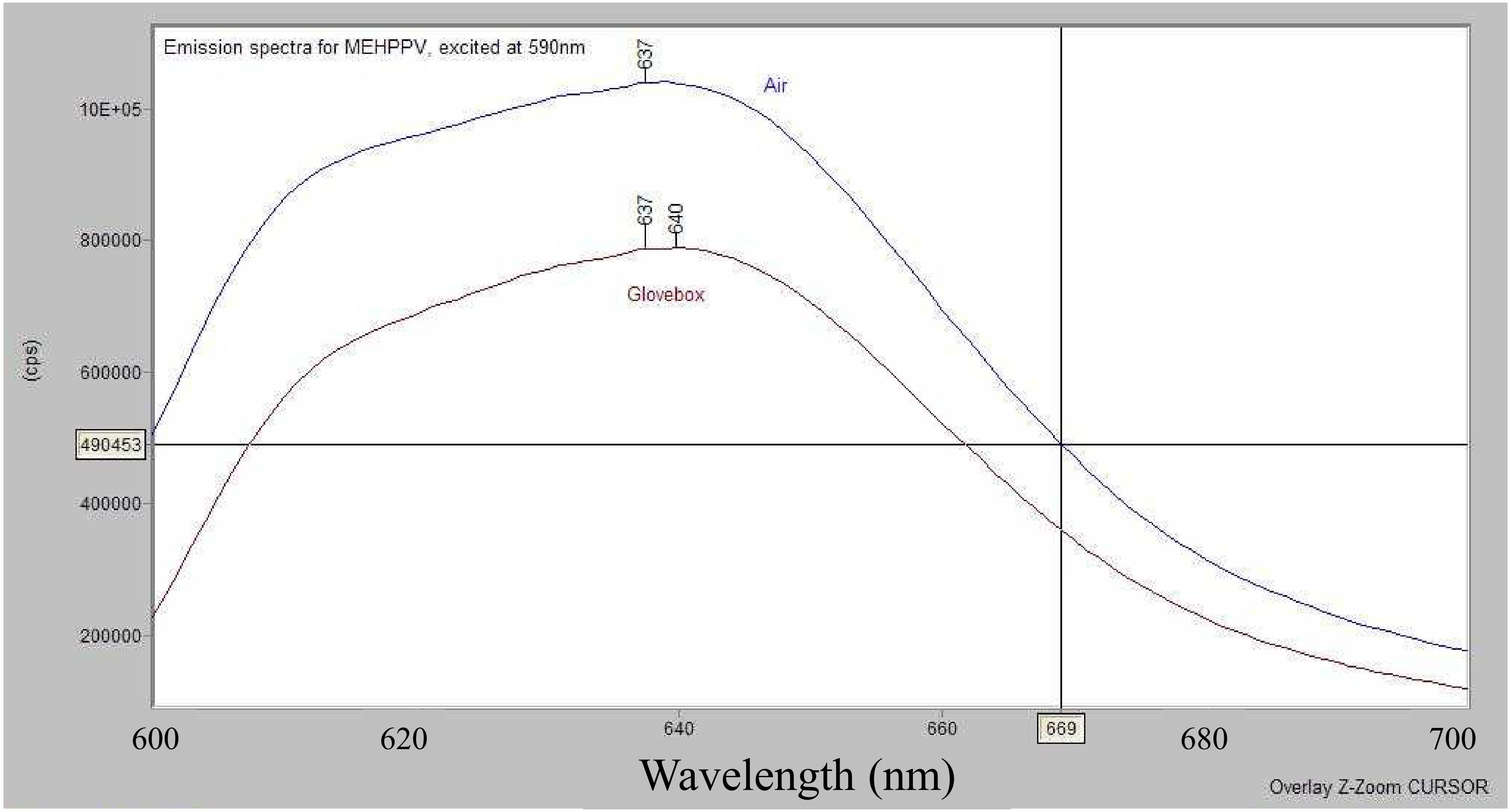
Excitation spectra

Excitation/Emission



Emission spectra, excited at 467 nm

Excitation/Emission



Emission spectra, excited at 590 nm

Conclusions

- Previous work showed the possibility of using conjugated polymers as ionizing radiation detectors, and showed improvements in sensitivity with processing parameters and additives
- This works shows possible complications due to environmental sensitivity
- Environment needs to be considered for other experimental work using these materials
- Environmental sensitivity also opens the door to use these materials as sensors

Acknowledgements

- Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL8500.
- This work was supported by Sandia's internal Laboratory Directed Research and Development
- Advisors Jim Lee and Art Epstein at OSU
- This material is based upon work supported in part by fellowship support from the National Science Foundation under Grant No. 0221678.

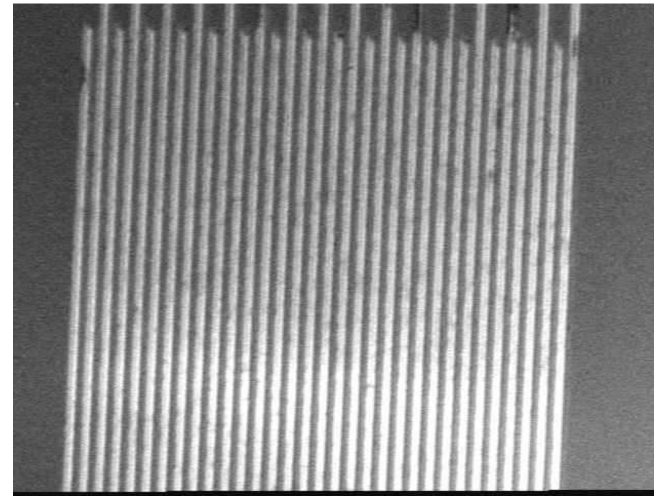
THE OHIO STATE UNIVERSITY

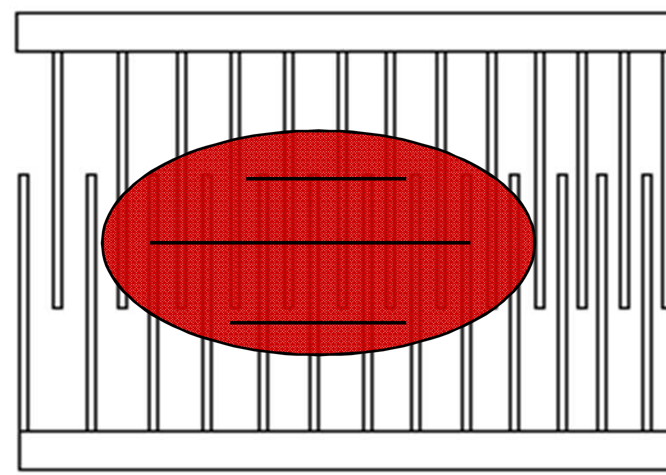
Sandia National Laboratories

Supplemental Materials

Electrical Testing

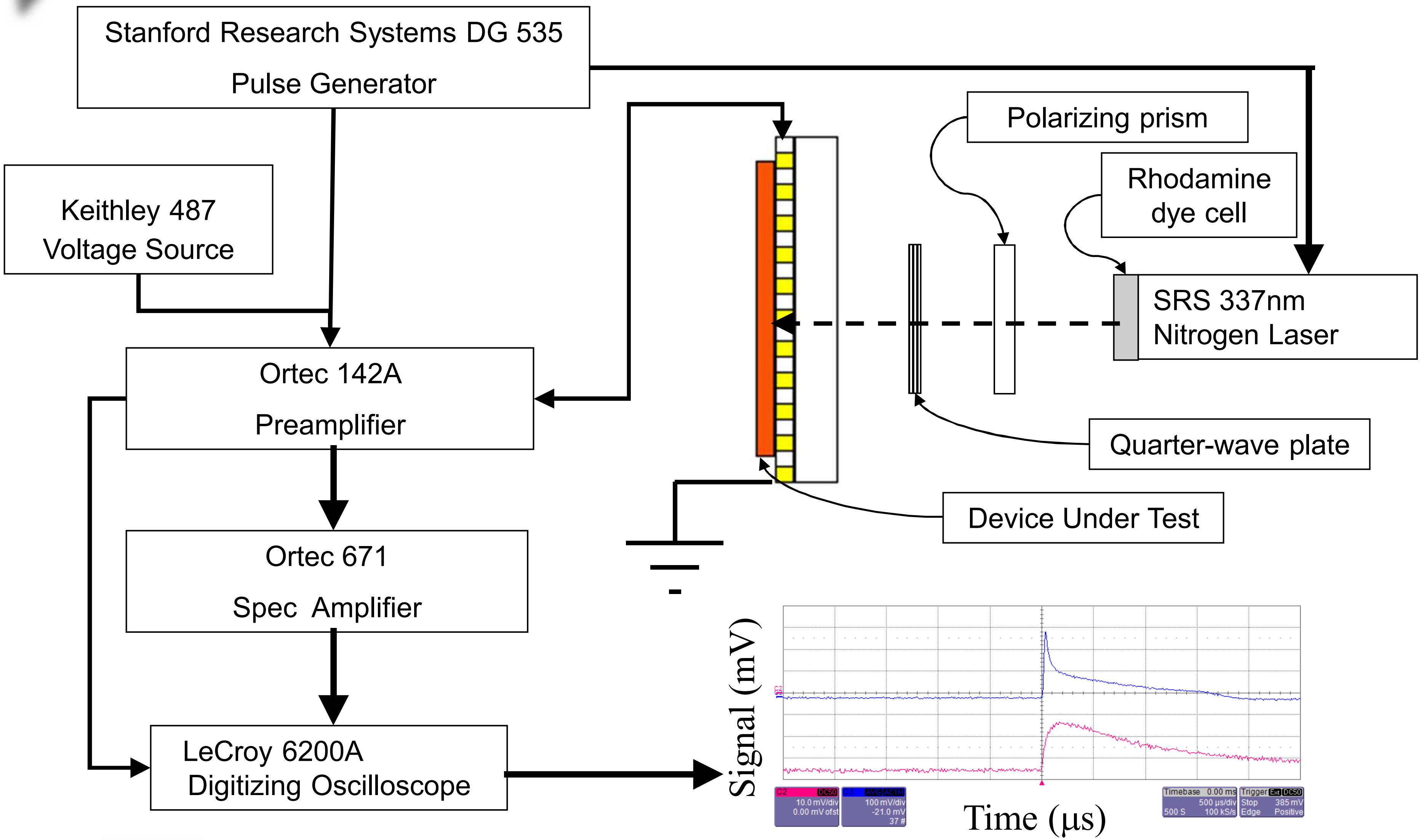
- Interdigitated electrodes (IDEs)
- Gap of 4 - 64 μm, typically 16 μm
- Bias between electrodes
- Can orient film for bias to be parallel or perpendicular to the orientation direction
- Can also directly apply solution with no orientation



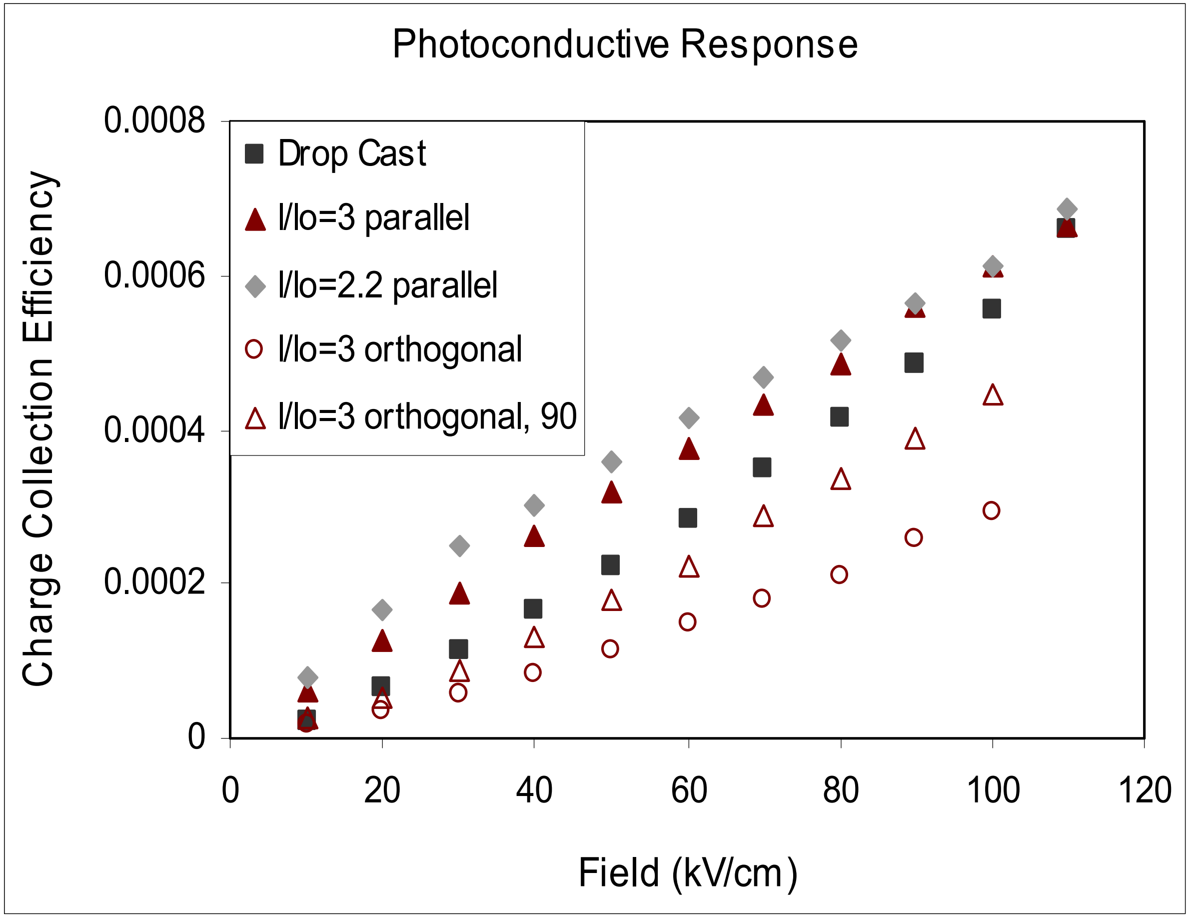


Parallel Orientation

Pulsed Photoconductivity setup



Stretched v. Drop-Cast



- **Drop Cast v. Stretched to I/Io=2.2, 3**
- **16 μm IDTs**
- **581nm pulsed laser**
- **Stretched samples shows increased photoconductive response in one direction, decreased in orthogonal direction**
- **Possible plateau effect**