Large Area Organic Photodetectors for Radiation Detection Applications

Oliver Moreno
Center for Organic Photonics and Electronics
Georgia Institute of Technology
July 8th, 2020

ETI

NNSA National Nuclear Security Administration

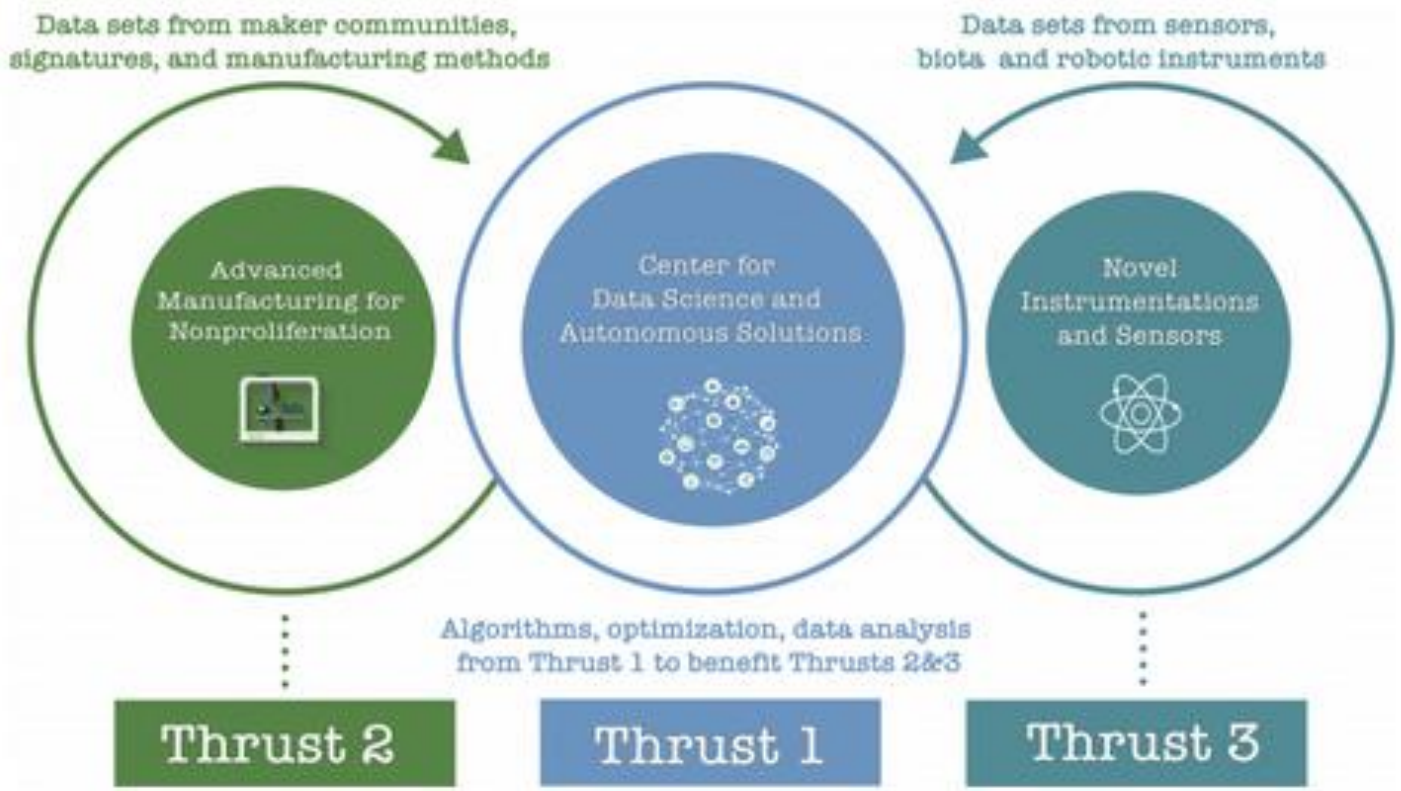
About Us

- Organic electronics, photonics, and optics
- Device simulation, fabrication, and characterization
- History of collaborations across campus with chemists, ubiquitous computing experts, designers, and nuclear engineers
- Focus on device fabrication and characterization for radiation detection

Mission

- **Maintaining the safety, security, and effectiveness of the nuclear weapons stockpile**
- **Reducing the threat of nuclear proliferation and nuclear terrorism around the world**
- **Providing nuclear propulsion to the U.S. Navy's fleet of aircraft carriers and submarines.**

NATIONAL NUCLEAR SECURITY ADMINISTRATION

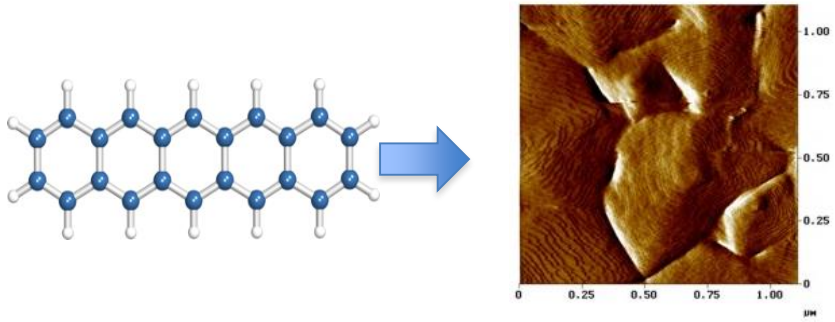


Goal: **Develop flexible large-area organic photodetectors to integrate with plastic scintillators as radiation detectors for nonproliferation**

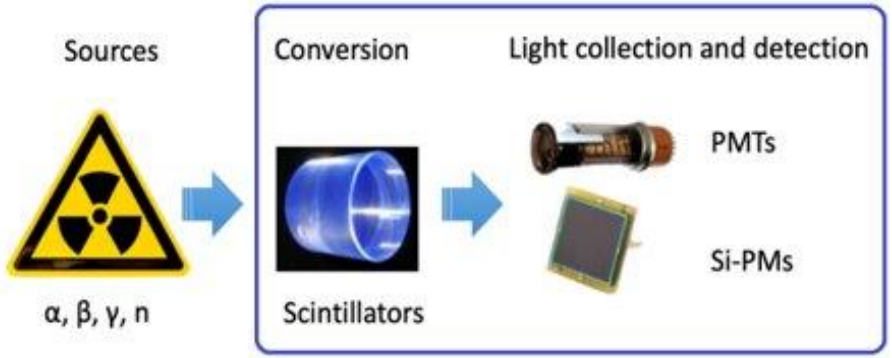
Our approach

- **Material selection and photodiode design**
  Emphasis on interface engineering:
  - **Charge-collecting electrodes, and donor/acceptor heterojunction**
- **Fabrication (thermal evap. & printing) and characterization:**
  - ***J-V*, Electronic noise, Responsivity, Noise equivalent power (*NEP*), specific detectivity (*D**)**
- **Modeling:**
  - **Optical properties of devices**
  - **Steady-state photodiode characteristics**
  - **Electronic Noise**

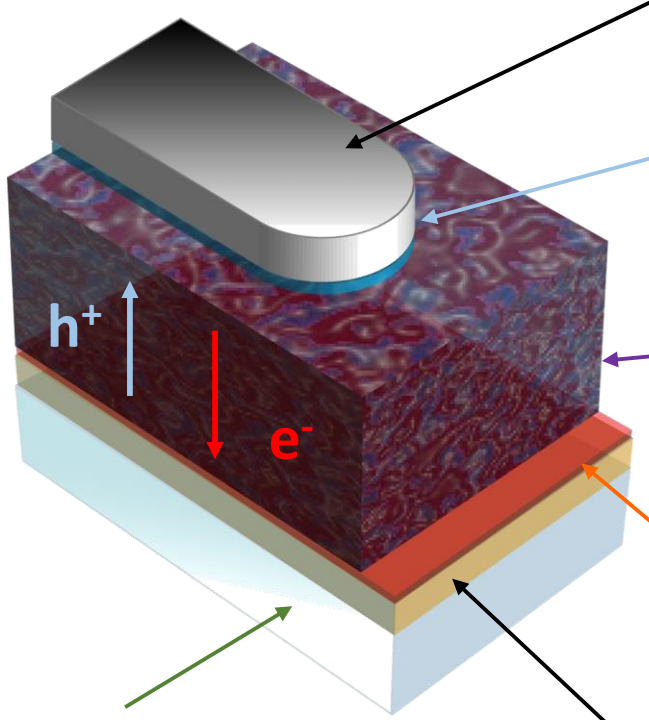
Material-level



Device-level



Organic Photodetectors (OPD)



Reflective electrode (or semi-transparent). 10 Ω/☐ sheet resistance or better

Hole-collecting interlayer

Photoactive layer: Bulk heterojunction comprised of Donor and Acceptor materials

Electron-collecting interlayer

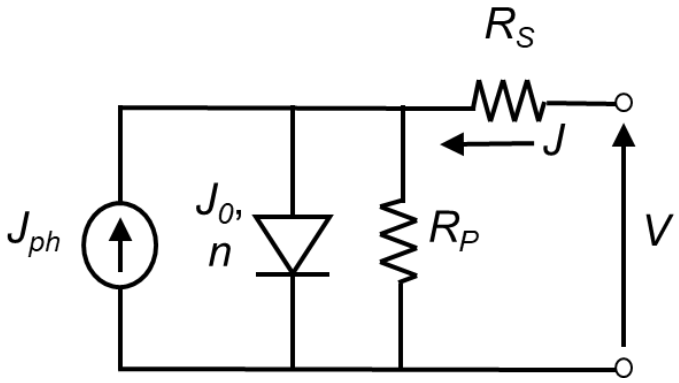
Y. Zhou et al., Science 336, 327–332 (2012)

Substrate:
Recyclable/flexible/transparent

"Transparent" electrode >70% Tx of visible light (or better); 10 Ω/☐ sheet resistance or better

Steady-state characterization and modeling

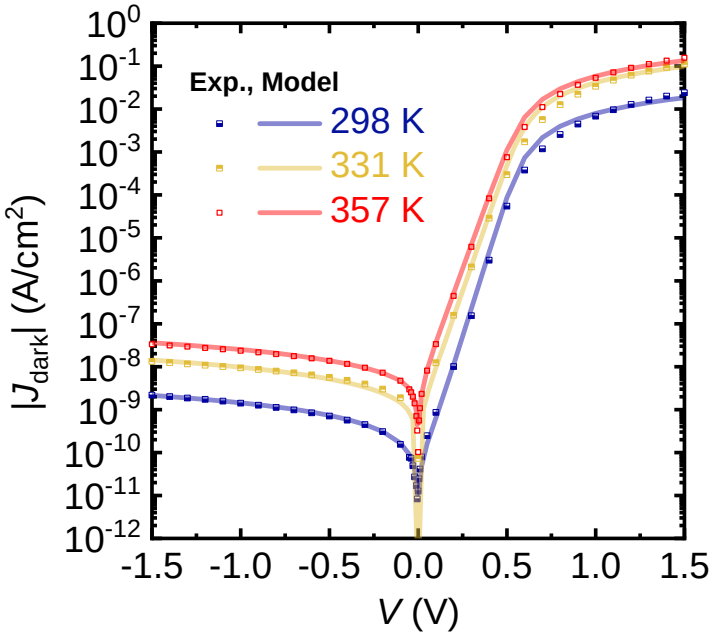
Prince's equivalent circuit model



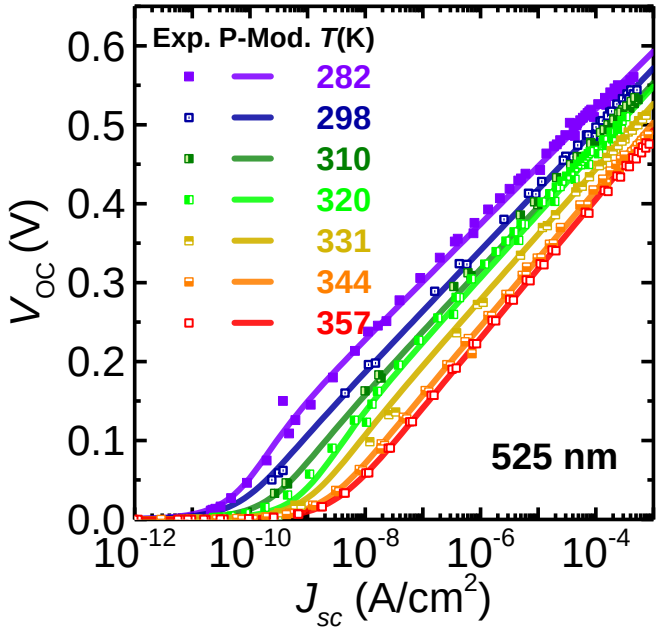
$$J(V,T) = \frac{R_p}{R_p + R_s}\left\{ J_0 \left[\exp\left(\frac{V - J(V,T)R_s A}{n_{id} k_B T / q} \right) - 1 \right] - \left(J_{ph} - \frac{V}{R_p A} \right) \right\}$$

Goal: derive reliable J_0 and R_p values

Dark



Illumination



W. Shockley, H. J. Queisser *J. Appl. Phys.* **32**, 510-519 (1961).
C. Fuentes-Hernandez et al, *2016 IEEE Symposium on Radiation Measurements and Applications* (2016).

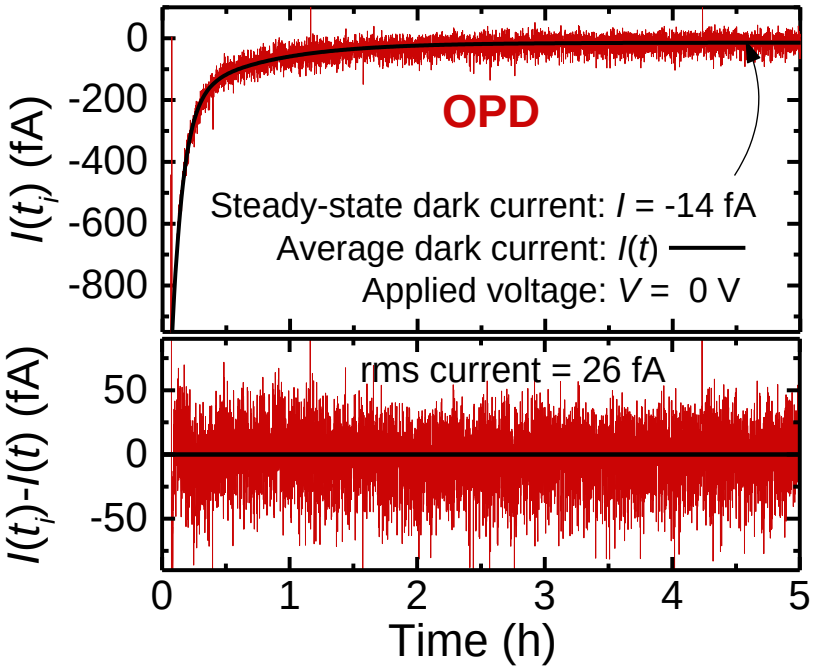
Electronic Noise Characterization

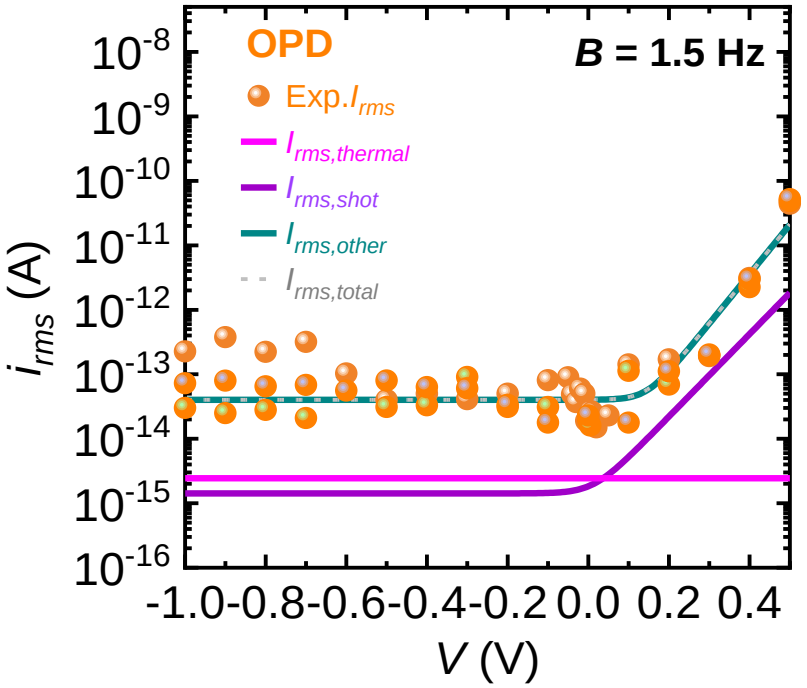
Characterization

- Keithley 6430, with < 1 fA noise floor

Modeling

- Use J_0 and R_p values derived from steady-state modeling to calculate thermal and shot white-noise contributions

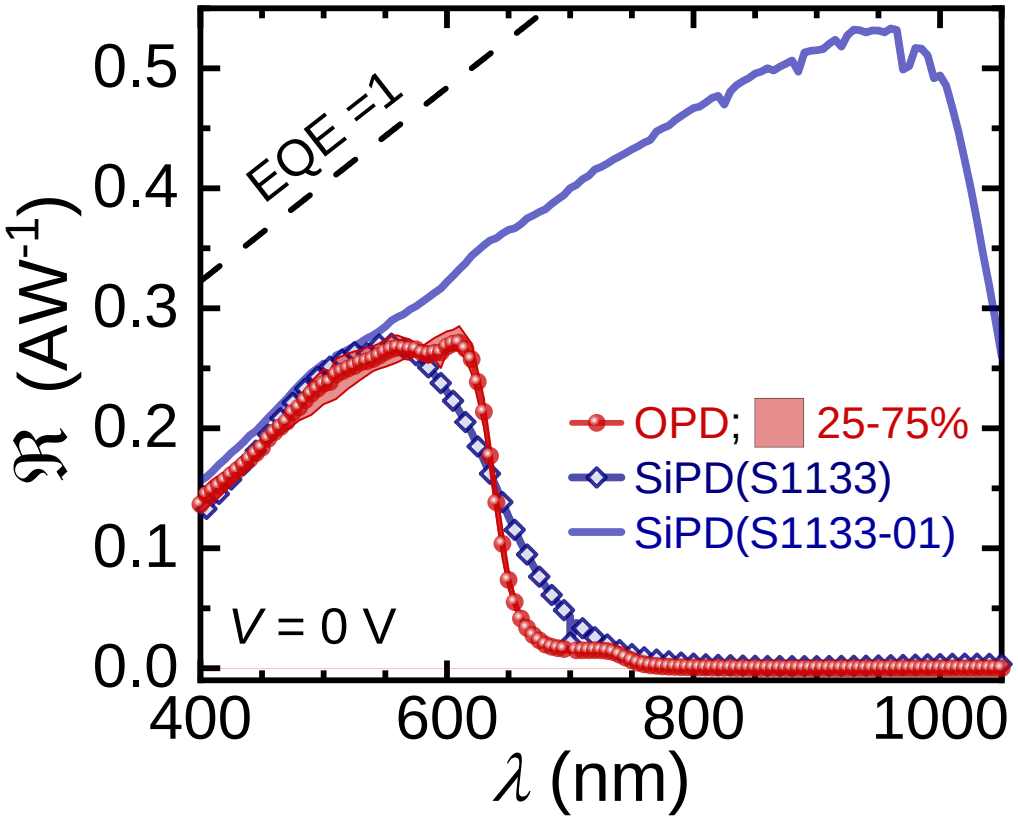




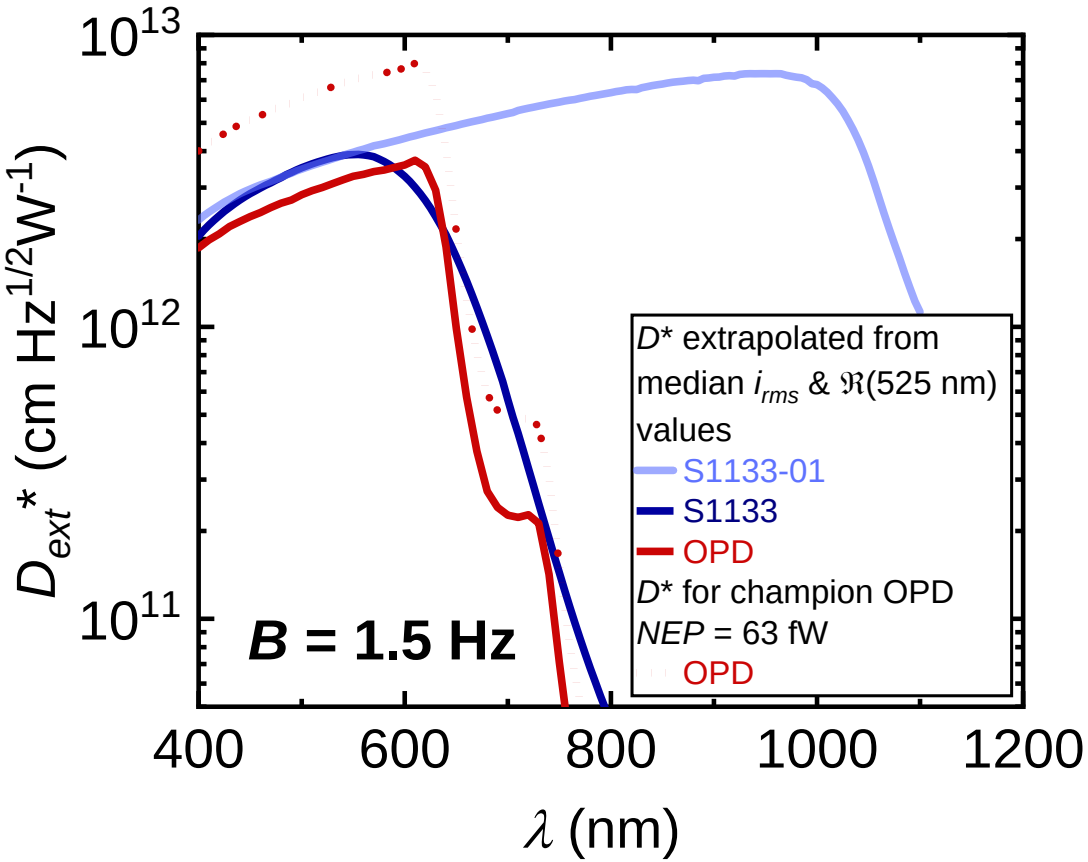
Data credit: Canek Fuentes Hernandez, PhD

OPD vs. SiPDs: benchmarking

Responsivity



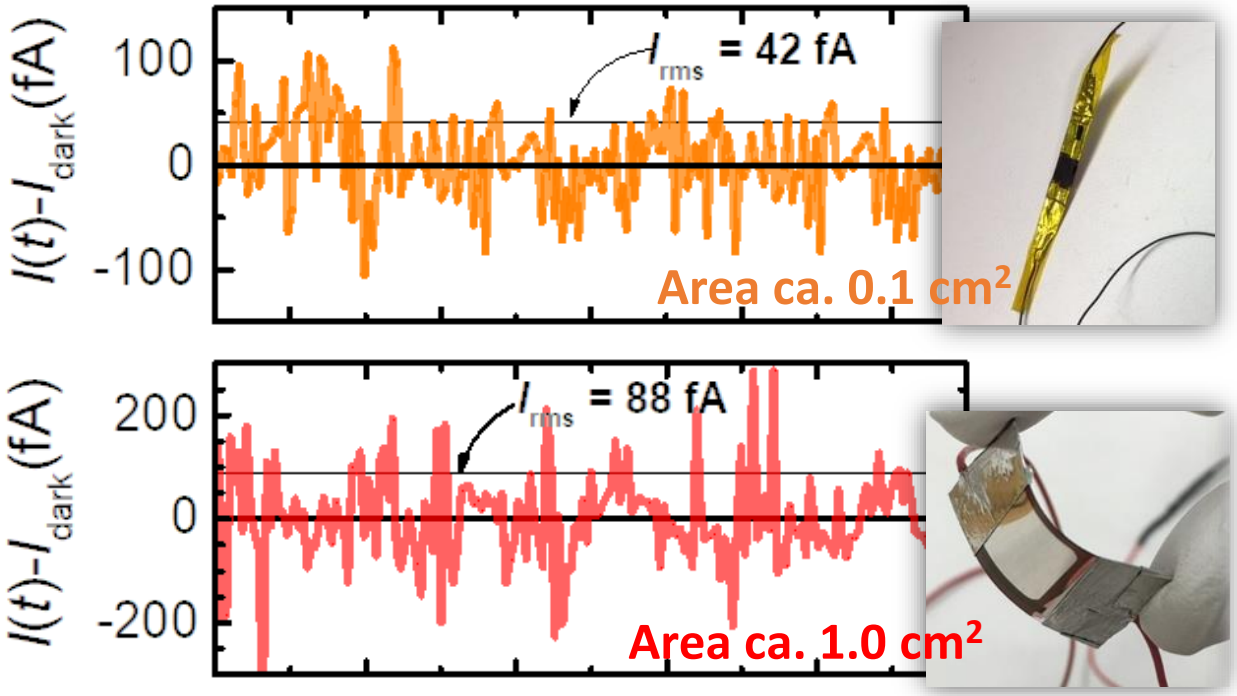
Specific detectivity



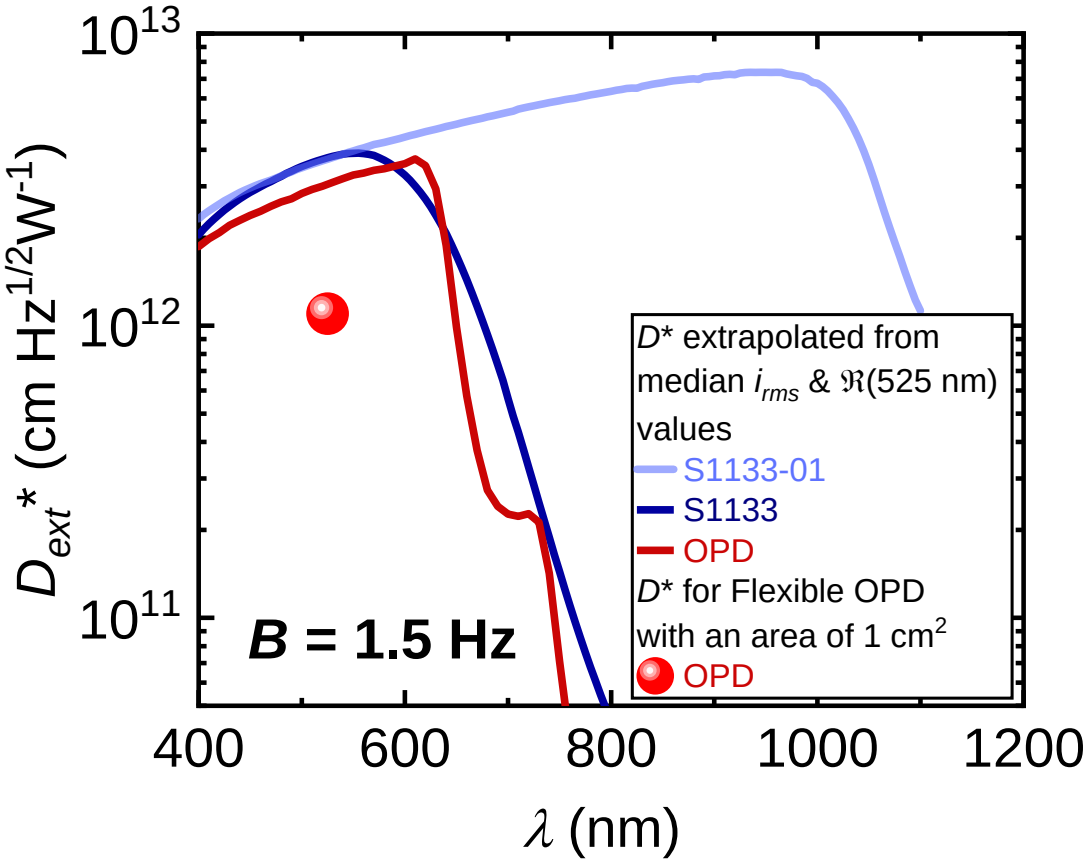
C. Fuentes-Hernandez et al, *2016 IEEE Symposium on Radiation Measurements and Applications* (2016).

Flexible OPD

Electronic noise

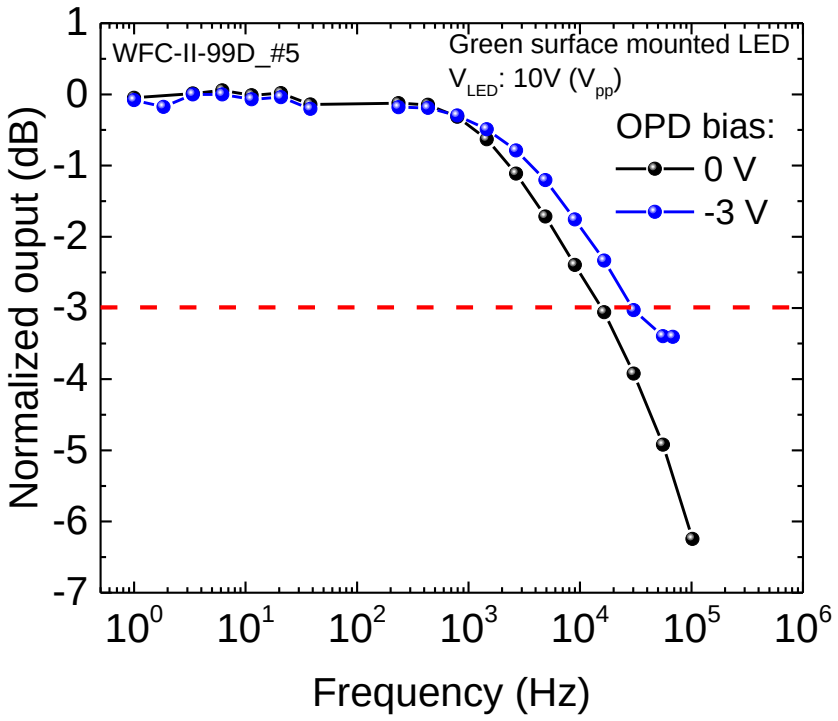


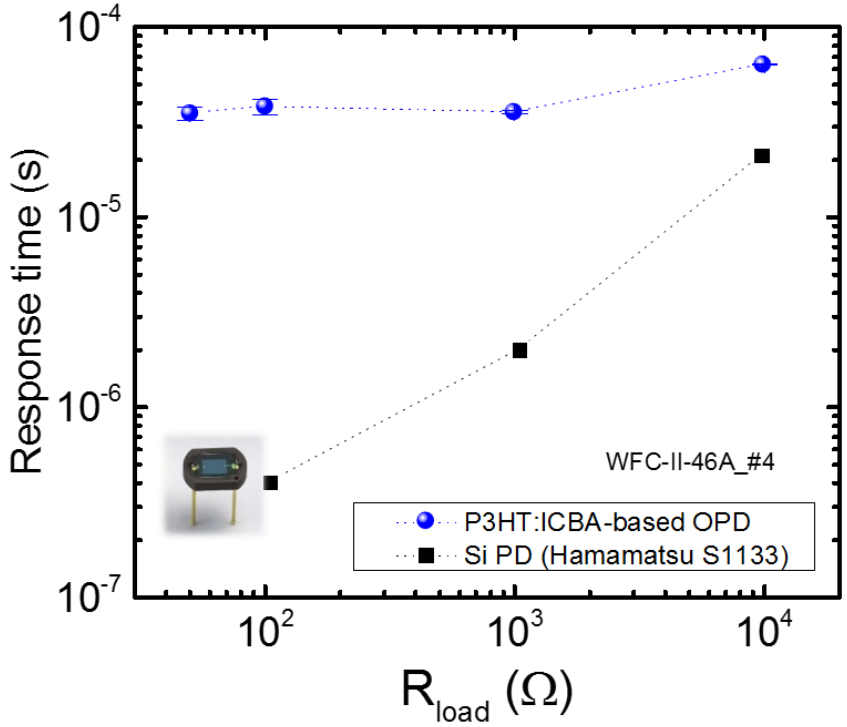
Specific detectivity



Data credit: Wen-fang Chou, PhD

Temporal characteristics of OPD





Response time of OPD needs to be reduced to allow applications in scintillator detectors

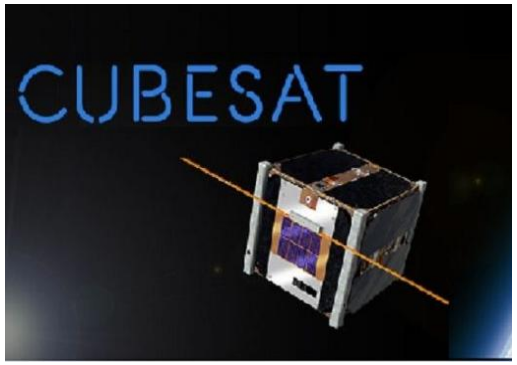
Current Research Focus

Research Question	Hypothesis
What material and device level strategies can we implement to improve response time in OPDs?	Explore bi-layer devices with high-mobility to improve charge extraction and time constant
	Explore small-molecules, spectrally matched to scintillator, and tandem architecture, to increase absorption

Case Studies

Control Point Screening

UAV: Mounted or Body

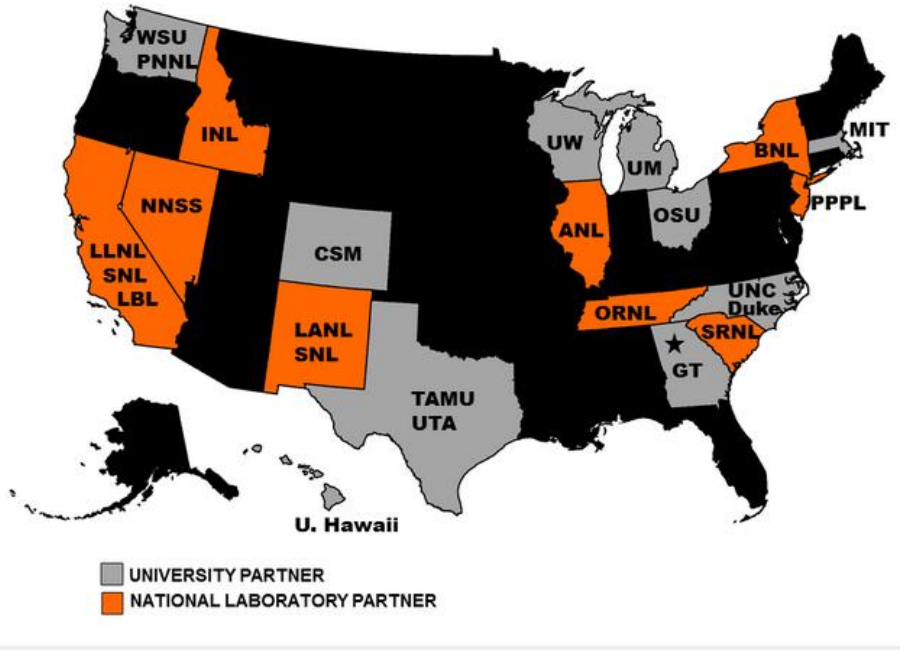


Swarm Robotics

Discover and enable applications with end users!

Roadmap Forward

- Continue advancing the response time of OPD to enable photon-counting
- Collaborations with academic partners in multidisciplinary ETI cohort for integrated advancement of nuclear science
- Collaborations with national lab partners to identify new markets and advance technology readiness
- Explore possibilities for innovation with societal value and commercial impact in nonproliferation



Acknowledgement

This material is based upon work supported by the Department of Energy/National Nuclear Security Administration under Award Number DE-NA0003921.