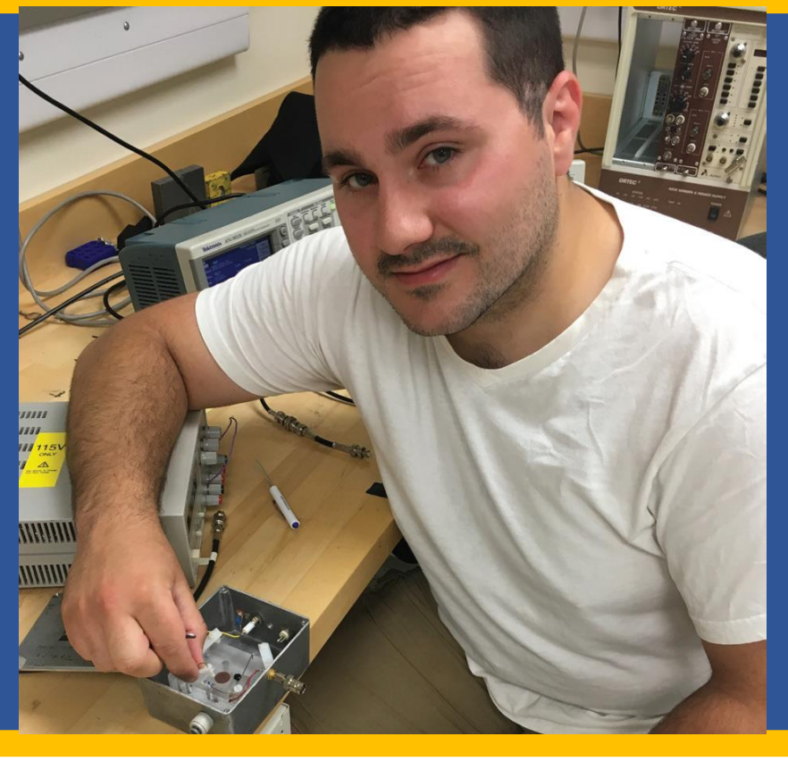

Engineering of a High Sensitivity X-Ray Detector for Low-Dose Medical Imaging

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ALARA imaging

Radiation medical imaging is the cornerstone of diagnostic medicine. In Canada, CT was the most used diagnostic imaging modality in 2019-2020 [1]. However, the radiation utilized in medical imaging is **ionizing radiation** which has drawbacks like **damaging effects on DNA that can lead to cancers.** To reduce this risk a new protocol has emerged of **using a dose that is As Low As Reasonably Achievable (ALARA)** during imaging.

Good news is we got the last batch of radioactive isotopes in Ontario for your medical treatment. Bad news is the batch was a bit strong.

Digital Solid State Flat Panel Radiation Detectors

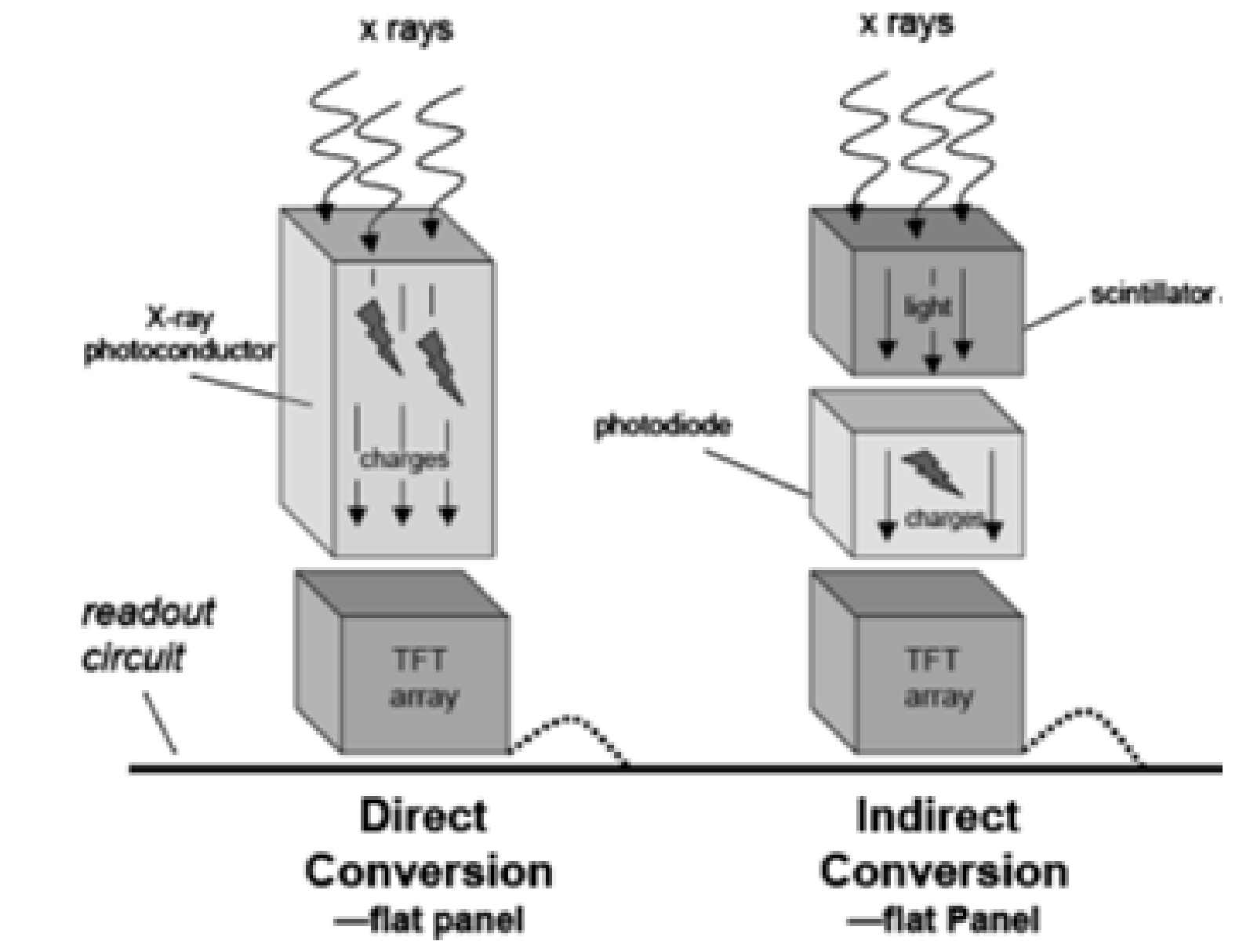

Figure 1. Schematic diagram illustrating the different x-ray-to-charge conversion methods in detectors [2].

New direct conversion radiation detectors are making ALARA adherence possible. **Direct** conversion boasts better image contrast due to **high spatial resolution and excellent signal-to-noise (SNR) ratios** compared to their indirect counterpart [3]. Currently, the only commercially used direct conversion detector is based on a layer of **amorphous selenium (a-Se)** that revolutionized mammography with **unmatched performance and sensitivity**. However, a-Se low atomic number (Z=34) makes it **impractical for use in higher energy diagnostic imaging.** The search for an ideal photoconductive material for high-energy direct conversion detectors is underway.

Experimental Setup: Dark Current Kinetics

Dark current was measured as a function of time for a **variety of a-PbO, blocking layer thicknesses, and applied voltages. Fields practical** for detector operation range **from 5 – 20V/µm** and such were utilized during experiments. A Stanford Research Systems PS350 power supply **applied a positive bias to the ITO contact** and the **dark current was recorded** by a Keithley 35617EBS electrometer. To avoid any photogenerated carriers during the bias and drain any previously trapped charge, the sample was installed within a light-tight box and allowed to rest in a short-circuit fashion for at least 1 hour.

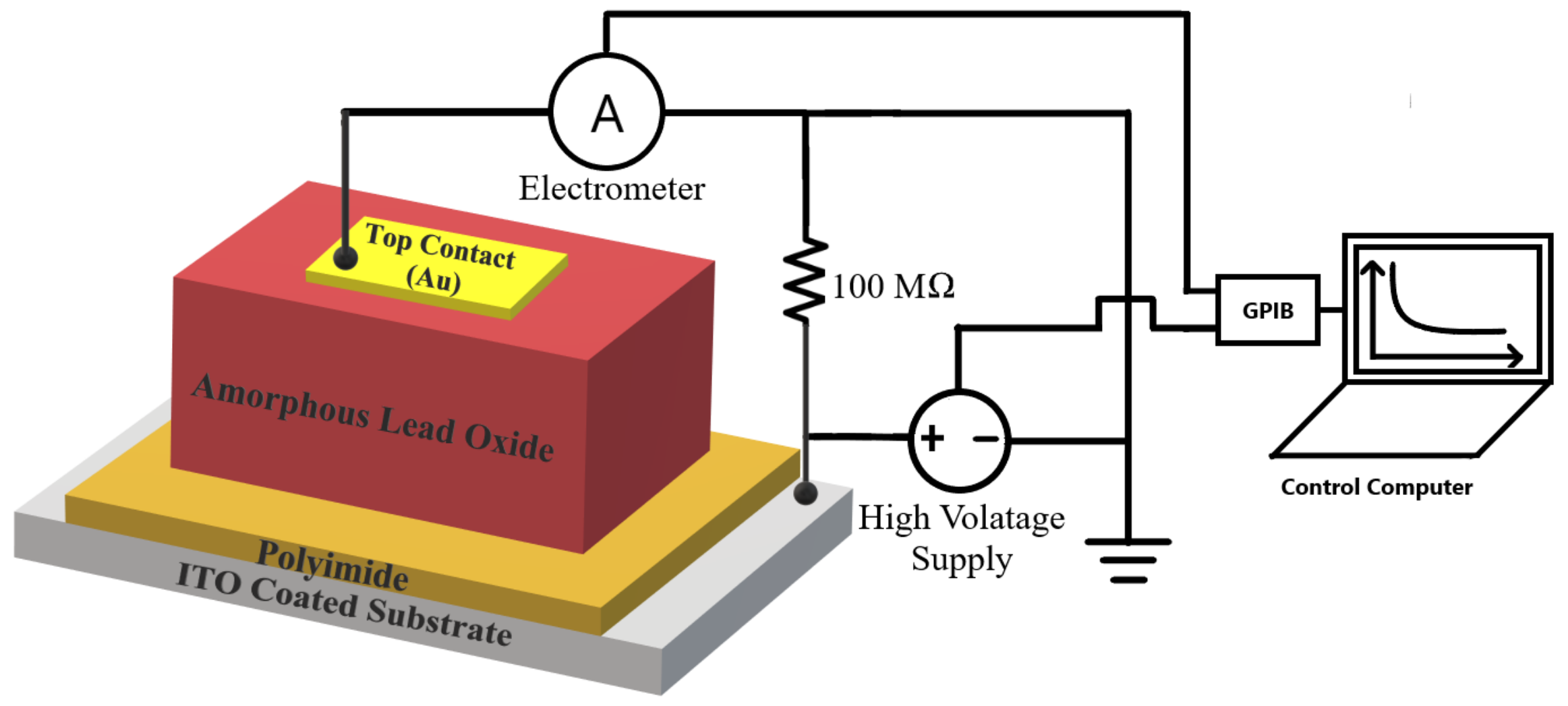

Figure 3. Schematic diagram of PI/a-PbO sample structure as well as experimental setup for DC kinetics measurements.

Material	Criteria for the Ideal Photoconductor		
	Sensitivity	Low Intrinsic Noise	Temporal Performance
BiI_3	☑	☑	☒
PbI_2	☑	☒	☒
HgI_2	☑	☑	☒
ZnO	☒	☑	☒
CdTe	☑	☑	☒
$Cd_{1-x}Zn_xTe$	☑	☑	☒
Perovskites	☑	☑	☒
Amorphous Lead Oxide (a-PbO)	☑	☑	☑

Table 1. Materials currently under investigation for use in high energy direct conversion detectors.

The Most Promising Candidate: Amorphous PbO (a-PbO)

A-PbO was developed and patented in **Thunder Bay Ontario**, by Dr. Alla Reznik and her research team. A-PbO has an effective atomic number of **Z=76.7** and is the **only radiation-sensitive photoconductive material that meets all the criteria** for a high-energy radiation detector [4].

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Methodology: Optimization of Structure and Operational Parameters

The **flow of current** through a biased photoconductor, in the absence of any irradiation **(dark current (DC)),** constitutes **intrinsic noise** of the material. **SNR** and by extension **image contrast are degraded by an increase in DC.** Thus, in practice, **DC** should be kept at a minimum of **1pA/mm²** [5]. Previous experiments have shown that a layer of **polyimide (PI)** sandwiched between the biased electrode and a-PbO x-ray photoconductor layers, blocks charge injection **reducing DC**. **DC characterization** of PI/a-PbO structures must be performed to find the **optimal PI blocking layer thickness** to receive the ideal SNR. Furthermore, the **mechanisms of DC** must be revealed for precise and practical understanding of preparation/fabrication property relationship in a-PbO detectors. These factors are essential to achieve desired detector performance.

$$\frac{nA}{mm^2} \xrightarrow[\text{(magnitude of DC)}]{\text{PI}} \frac{pA}{mm^2}$$

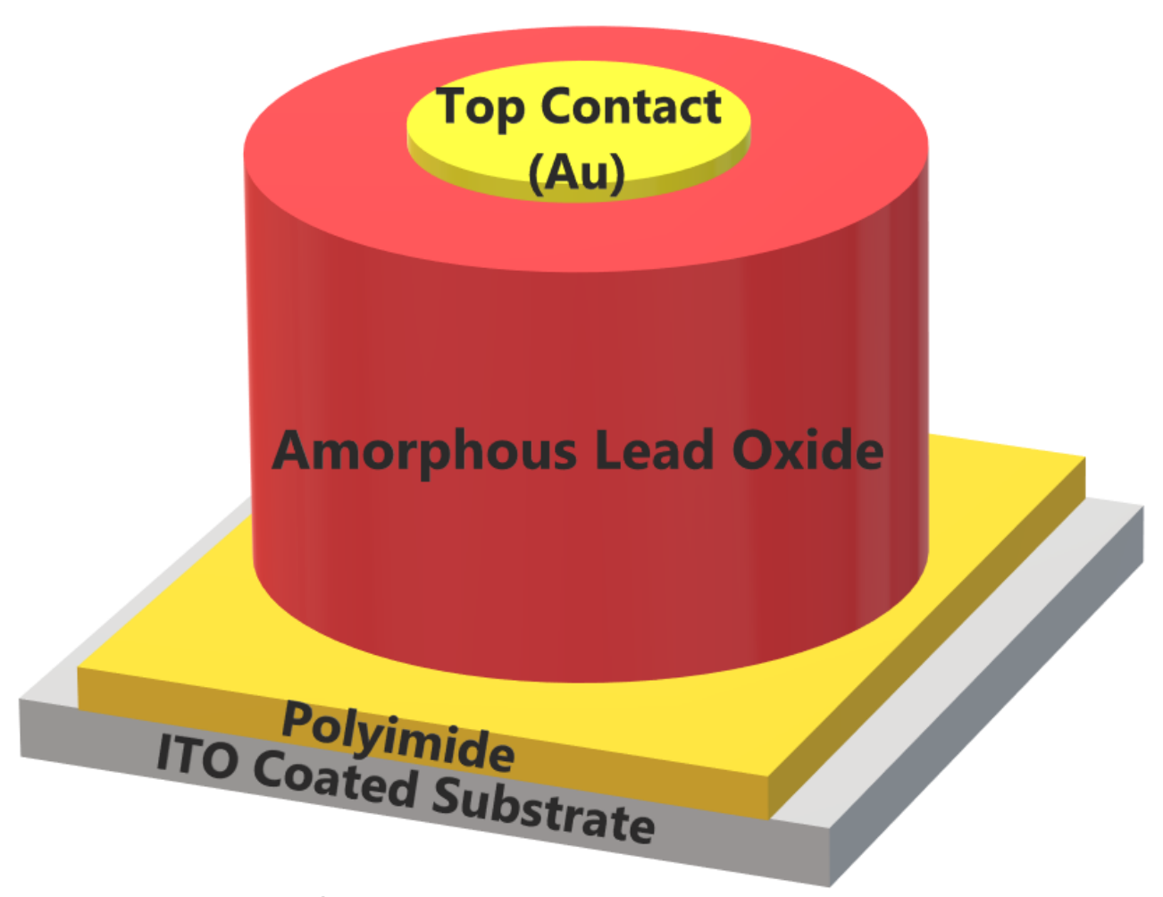

Figure 2. Schematic representation of the structure of a PI/a-PbO sample.

Results: Dark Current Kinetics and Modeling

- At all fields **DC decayed** exponentially with time**,** by nearly **2 orders of magnitude, saturating below 1pA/mm²** after 2 hours.
- A **mathematical model** to account for the decay of DC was derived.
- The model considers the **injection of charge carriers into the PI layer through** the metal contact as the main source of DC. **Thermal generation** of charge within the bulk of a-PbO layer **contributes negligibly to DC** [6].
- The **electric field redistribution** within the structure was evaluated by **solving Poisson's** equation with the condition that the total voltage drop over the sample is equal to the applied bias.
- As time progresses, post bias application, charge is **accumulated at the PI – a-PbO interface,** effectively screening the applied electric field and decreasing injection, hence decreasing DC.
- **1 – 1.1µm of PI** is shown to be a practical approach to **suppress injection** of charge from the metal contact and **reduce DC** in detectors to acceptable levels **below 1pA/mm²** at all fields practical for detector operation.

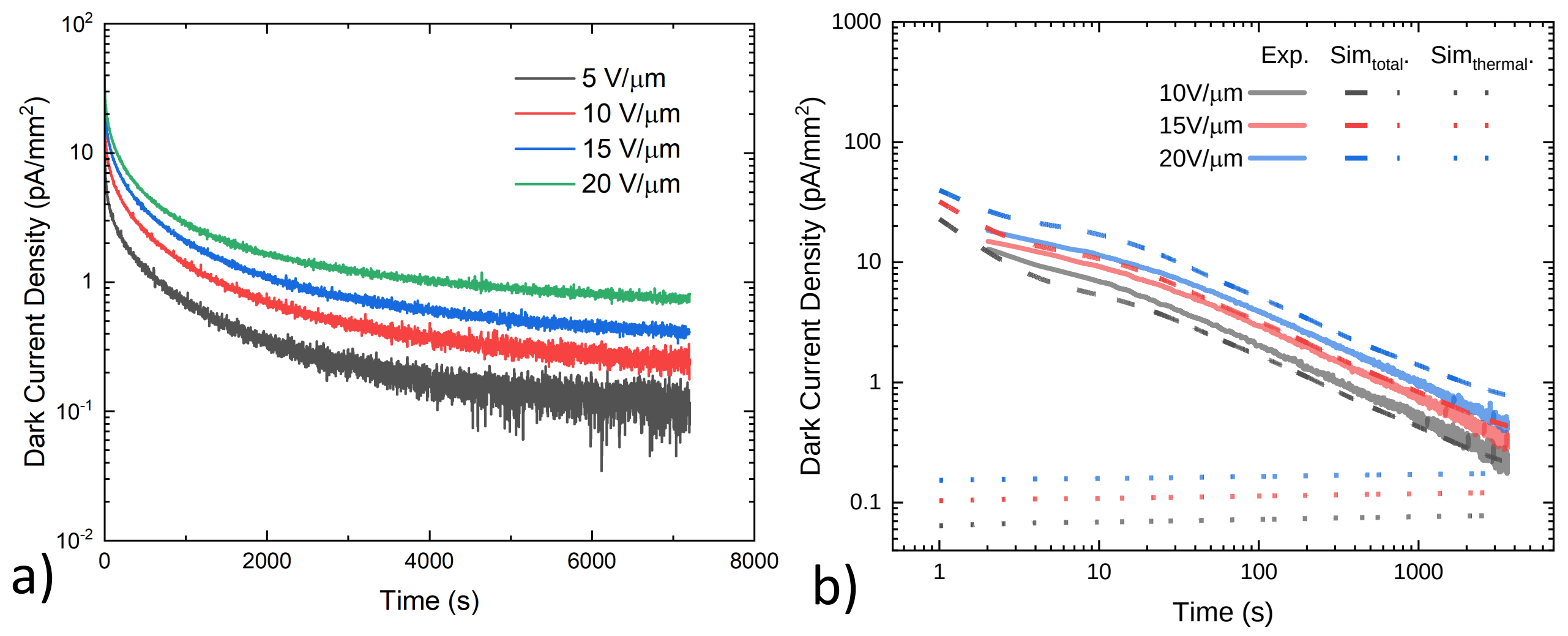

Figure 4. a) Experimentally measured DC as a function of time, of a sample consisting of 1.1µm PI + 18.5µm a-PbO, at various applied fields. b) Experimentally measured DC (solid lines), simulated DC (dashed lines) and simulated thermal component (dotted lines) of DC as a function of time, of a sample consisting of 1µm PI + 10µm a-PbO, at various applied fields.

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