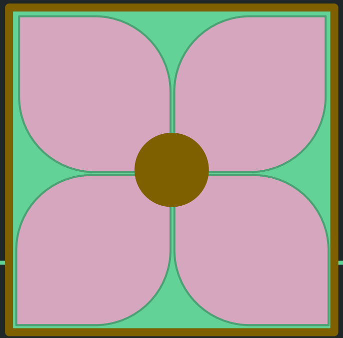
Snowmass white paper planning meeting
Friday May 8, 2020



Light & Charge Pixel Readout

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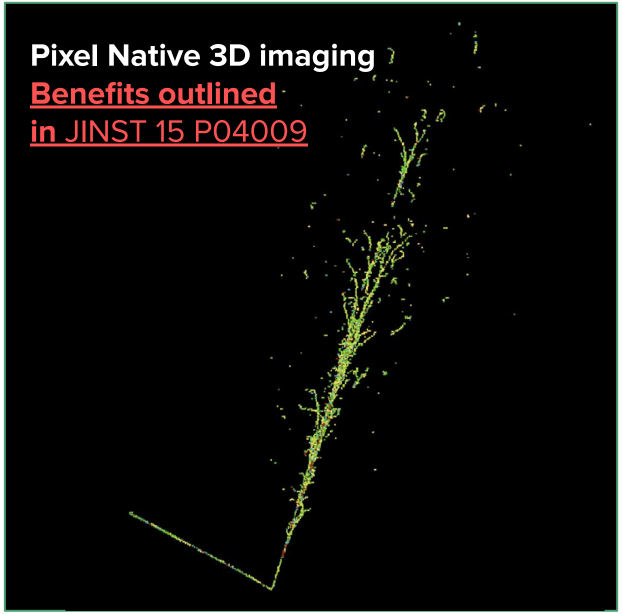
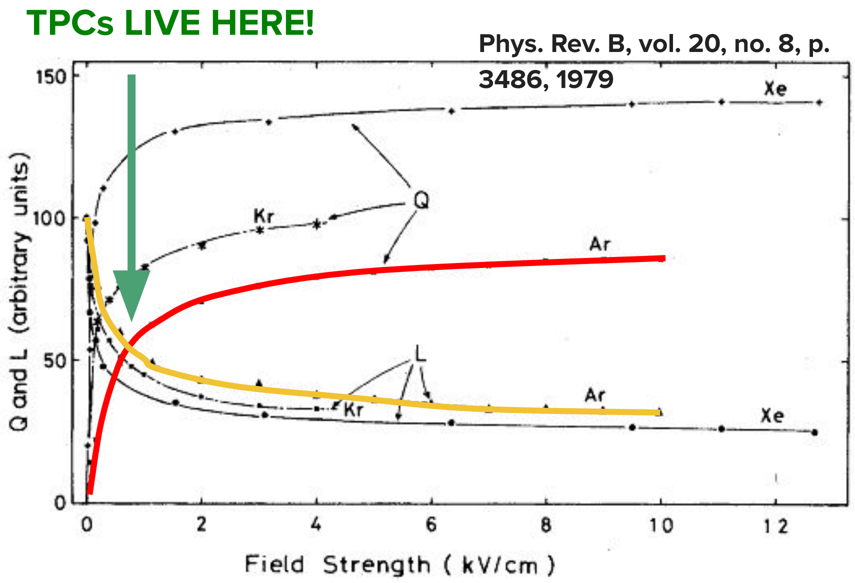
Idea in a nutshell

Idea: Develop a pixel that reads simultaneously both fC ionization charge and VUV light for nobel element time projection chambers.

Scope: Combine the benefits of 3D pixelated charge readout and a full exploitation of the scintillation light (native 3D reco, improved energy resolution w/ light augmented calo, lower energy thresholds) for detailed neutrino/low E events detection.





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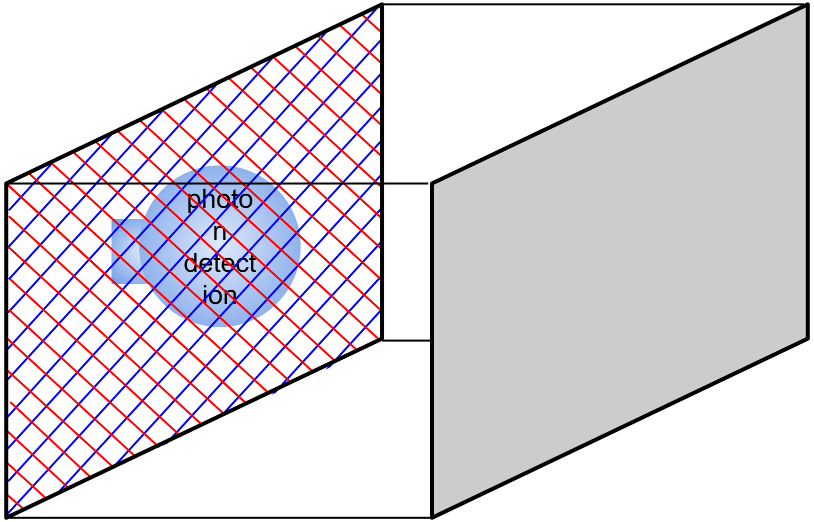

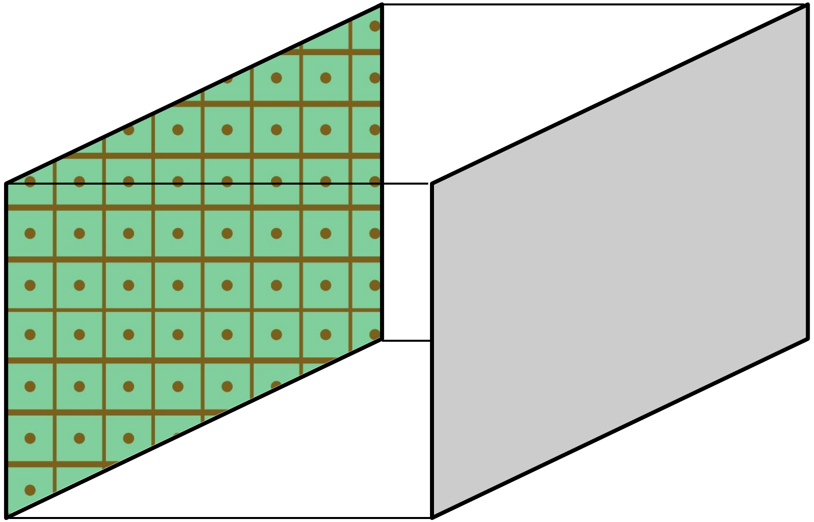

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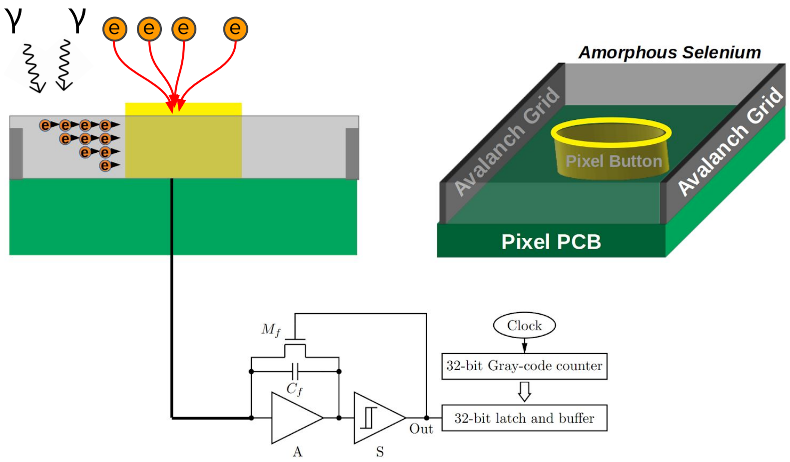
How: Coat the pixels with a thing films sensitive to VUV light. First choice is amorphous selenium (A-Se) other materials are under consideration. Ionization charge is collected by the pixel central button. The VUV photon creates an electron-hole pair in the semiconductor. This charge is amplified by biasing the pixel and is read out after gain amplification via Q-pix readout.



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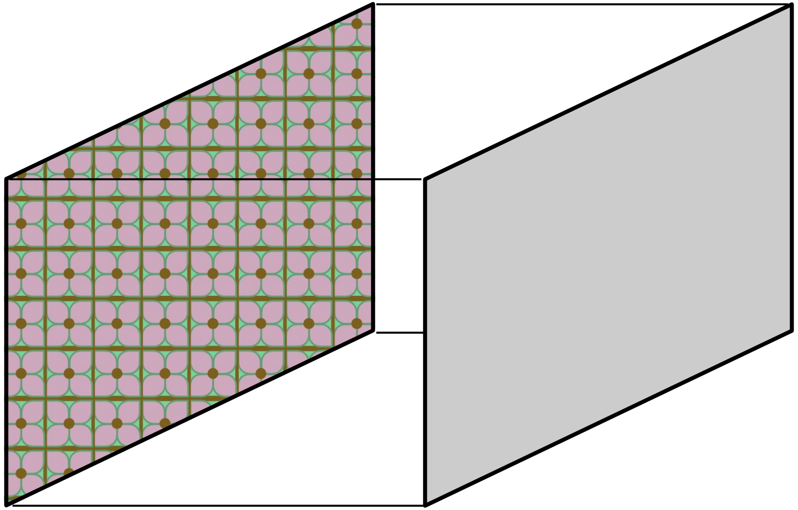
Potential: extremely vast active surface (= cathode), high QE

Applications: TonPlus Scale TPCs:
DUNE module of opportunity, DM and ν0ββ



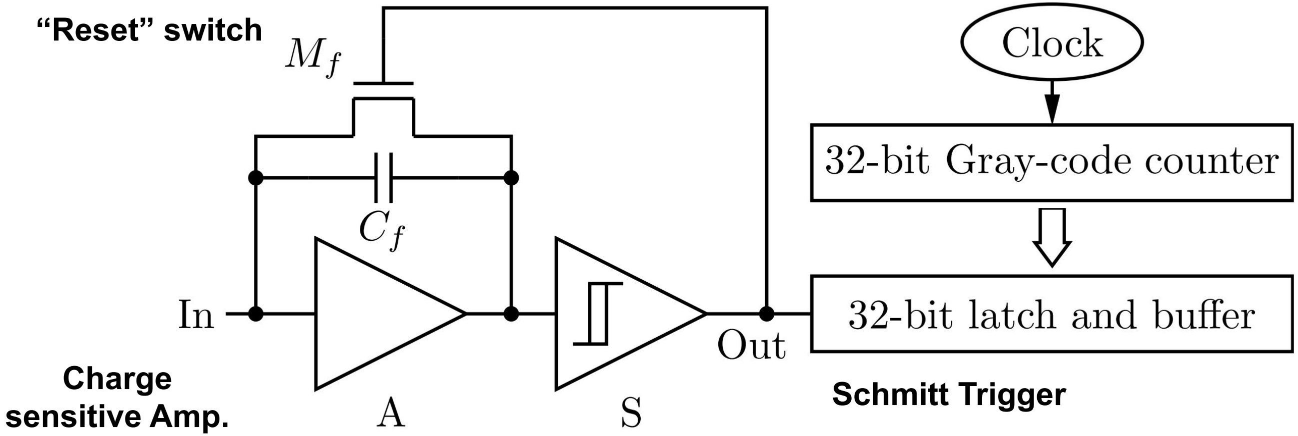
Readout cornerstone: QPix

Supported by DOE via DE-SC0020065 award

Qpix readout under development for charge in LArTPC

https://arxiv.org/pdf/1809.10213.pdf

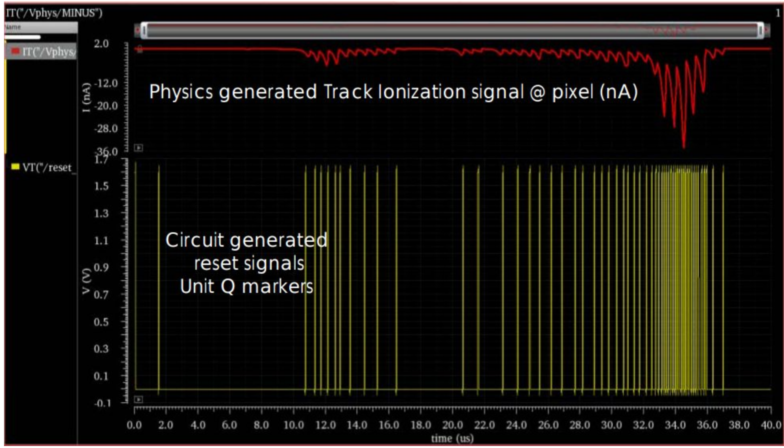
Charge Integrate-Reset Block: Charge from a pixel (In) integrates on a charge sensitive amplifier (A) until a threshold (V_{th}~$\Delta Q/C_f$) is met which fires the Schmitt Trigger which causes a reset (M_f) and the loop repeats. Charge estimate counting number of resets.



Snapshot of QPix ongoing R&D

ASIC development ongoing to realize Q-Pix readout

➜ LArTPC based neutrino simulations as input to ASIC design software: understand the performance of the Q-Pix system

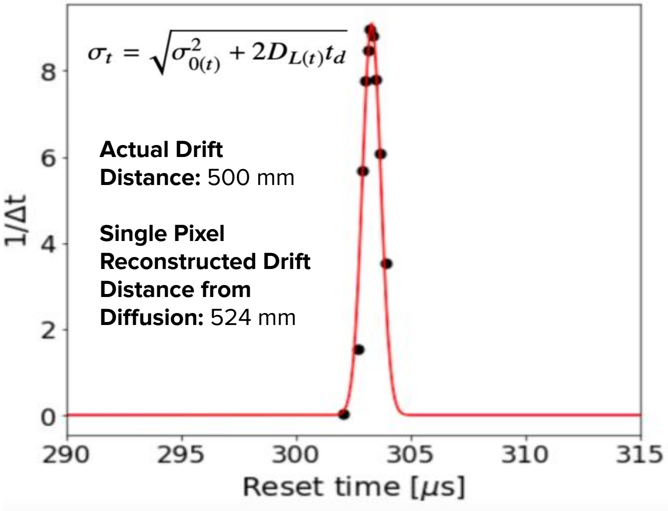


Physics simulations to show the physics capabilities of a Q-Pix based pixelated LArTPC

➜ Enhancement of neutrino identification and classification for pixel readout vs projective wire readout [JINST 15 P04009]

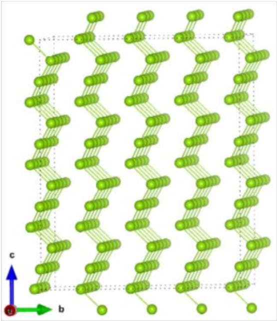
➜ Detailed measurement of charge deposition:

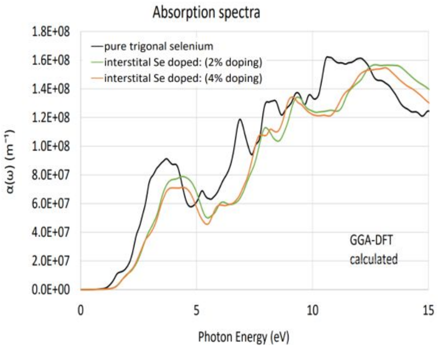
e.g. a full characterization of a novel technique to measure drift distance based on charge only is underway



R&D on Light: the LILAr LDRD

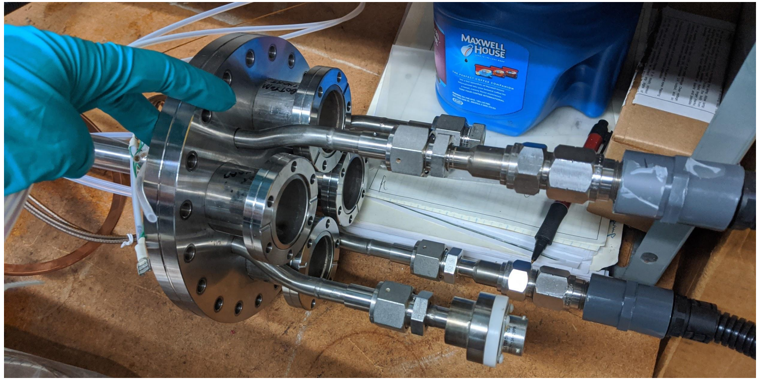
Fermilab





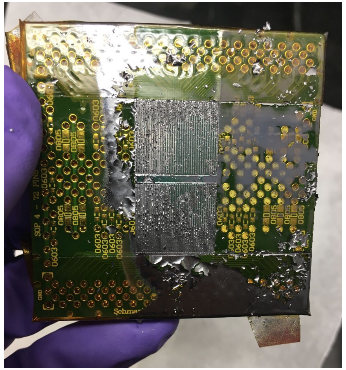
VUV Photosensitive films consistent with q-Pix charge sensitivity:

- A-Se has very positive optical properties for VUV photons, used in medical devices (never in cold)
- A-Se material development in collaboration w/ UTA condensed matter theorists. Simulation of the optical-electrical properties on their way.
- Started building of a setup for cold and vacuum characterization tests of prototype boards at PAB Evaporation of first material started @ UTA. Goal: first results in time for snowmass white paper.
- Other thin films material under consideration, e.g. pyroelectric materials early stages idea here)



LILAr

First coating attempt
A. Raymond & J. Asaadi



Takeaways

Kiloton scale (LAr)TPC's offer many challenges to fully exploit the rich data they offer:
new ideas for readout needed to fully leverage TPCs light & charge capabilities... & optimize for discovery!

Low threshold pixel based readout can optimize for discovery the impact of these detectors, especially if coupled with a powerful light detection system: full exploitation of charge and light interplay in noble TPCs.
Unorthodox solutions required: qpix readout + photosentive thin films.

The successful demonstration of a high efficiency VUV photodetector capable of detecting ionization charge has the potential to revolutionize the use of scintillation light in future liquid noble detectors expanding their physics reach to heavy sterile neutrinos, DM searches, $0\nu\beta\beta$, rare decay searches and supernova neutrinos.

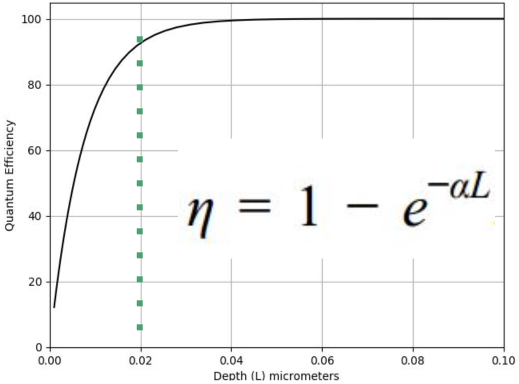
Thank you!

Why is A-Se interesting?

The literature on amorphous selenium reports very high attenuation coefficient α ~130 µm^{-1} for photons at 128 nm (LAr scintillation light).

Just micrometers thick a-Se can suffice to have a very efficient VUV photon to electron-hole pair conversion in the material ➔ **strategy: thin coating via evaporation.**

High gain amplification (~1.5 10^3) at the theoretical breakdown voltage of a-Se (~ 90 Volts/µm) for 100 micrometers thick deposition: ~ 4000 electrons for three 128nm photons on a 4mm pixel pad.



$$\eta = 1 - e^{-\alpha L}$$

Consistency with current Q-Pix design choice of being between 0.3 and 1 fC (1800 and 6000 electrons) for a RTD

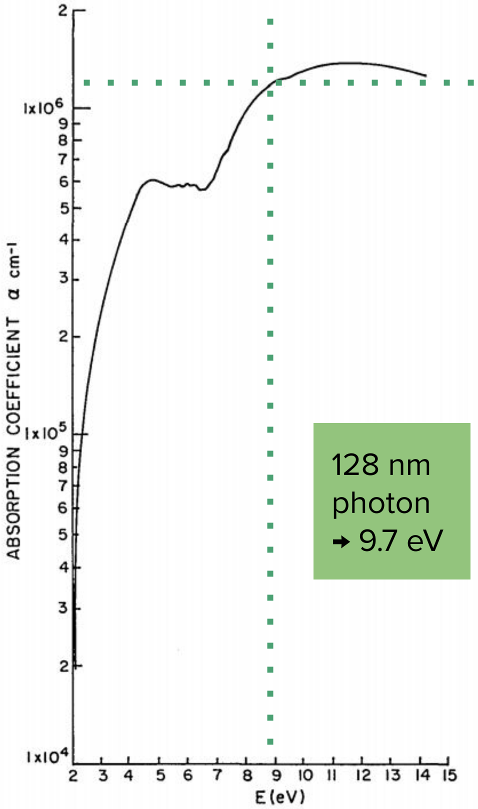


FIG. 6. The spectral dependence of the absorption coefficient, α, of amorphous selenium.

What about the transport?

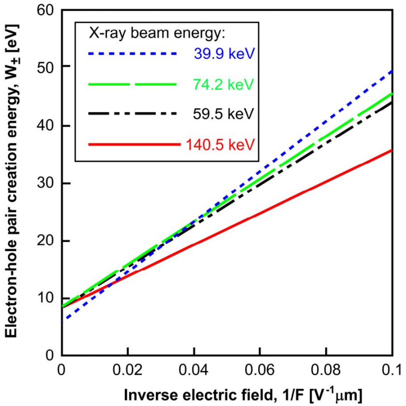
$$\Delta Q = q \frac{\Delta E}{W_{\pm}},$$

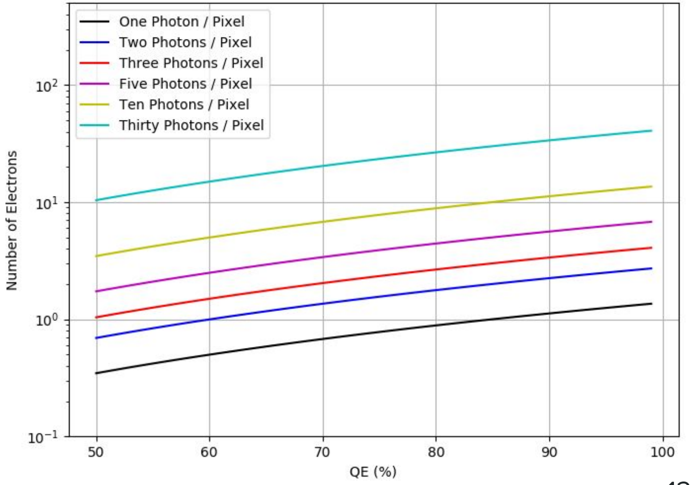
The amount of charge deposited into the a-Se is given by
q is the fundamental charge of the electron and $W_{\pm}$ is a property of the mobility of a-Se which depends on the electric field and temperature. ΔE is the amount of energy absorbed. In a single 4 mm by 4 mm pixel, a reasonable assumption for ΔE is 26.46 eV… You start with ~ 3 photons per pixel at 9.7eV / photon and 0.9 QE.

Literature gives an approximated values of $W_{\pm}$ = 7.07 eV (and a favorable trend with temperature)…

So, transport in the A-Se
ΔQ ~ 26.36/7.07 e

3 photons coming in…
3.7 electrons going out





What about the signal? Estimate summary

You started with 99% Quantum Efficiency for 128 nm photons with a a-Se layer that is >1 micrometers thick

If 3 photons fall on the 4 mm pad, such high QE gives you ~ 3+ electron-hole pairs (where you're being conservative for transport ➔ only 1 electron per photon).

At the theoretical breakdown voltage of a-Se (~ 90 Volts/µm) for 100 micrometers thick deposition,
you can a gain factor up to ~1.5 10^3: ~ 4000 electrons for three 128nm photons on a 4mm pixel pad.

These numbers would be very consistent with the current Q-Pix design choice of being between 0.3 and 1 fC (1800 and 6000 electrons) for a RTD (Reset Time Difference).

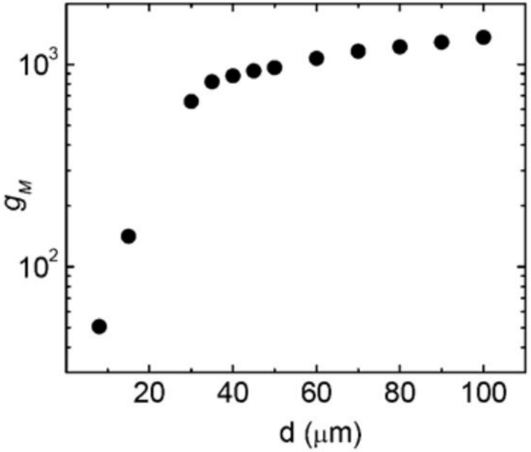


Figure 10 Maximal achievable multiplication gain for different a-Se layer thicknesses.

Modeling of a-Se to understand optical properties w/ VUV light

Professor Muhammad Huda at UTA (condensed matter theorist) and his student (Sajib Barman) have started an A-Se model to better understand and predict the optical-electronic properties we could expect when exposed to 128 nm photons.

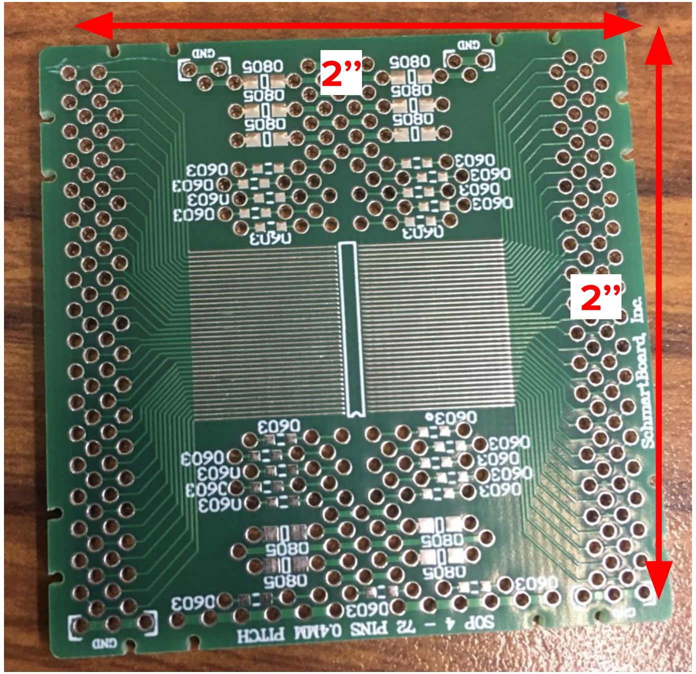
They start w/ Generalized Gradient Approximations in Density Functional Theory and will add further approximations to capture experimentally measured properties. From there, can they use phenomenological models to predict the optical-electronic properties.
A promising way to reduce the breakdown voltage is the use of dopands, whose effects can be studied within the constructed model.

A qualitative agreement for the VUV energy region between old data and a first, crude version of the simulation has been shown… off to a good start, but… we need more experimental data!

Tests of Prototypes & Material

1.) Same battery of tests both in vacuum & cold
(TallBo and/or vacuum vessel).
Characterize the photo emission of each prototype via:
- Dark current,
- I-V curves at fixed source distance and intensity,
- Current dependence on:
    - source distance,
    - intensity
    - incident angle of exposure at operating voltage,
- Q.E.

2.) Tests to be performed in LUKE (when he feels better):
- coating's long term durability
- argon purity



Pyroelectric materials!