Queen Mary
University of London

Organic Semiconductor Radiation Detector research at QMUL

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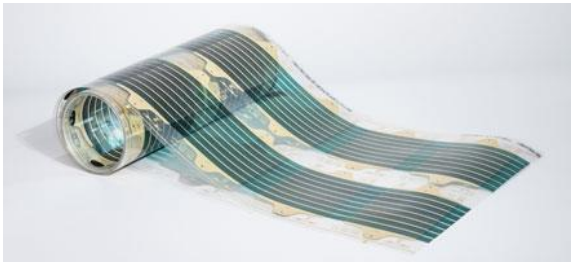
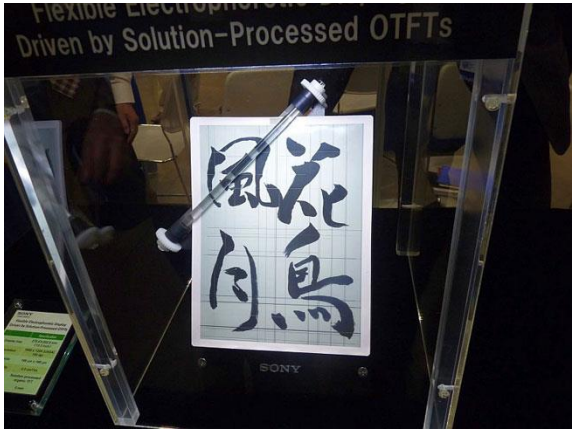
Commercial Organic Semiconductor devices

Samsung OLED mobile telephone

- LG OLED television



Merck prototype photovoltaic



Sony OTFT driven display

Commercial Organic Semiconductor devices

Samsung OLED mobile telephone

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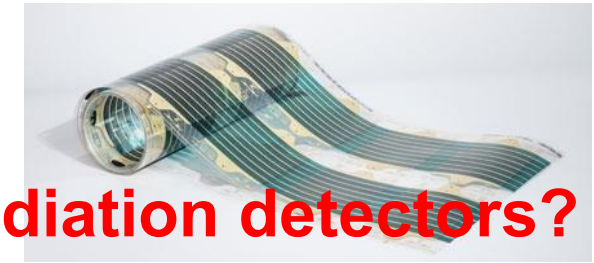
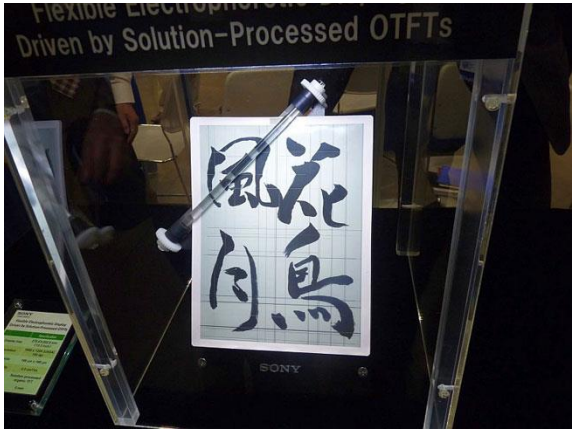
What's this got to do with radiation detectors?

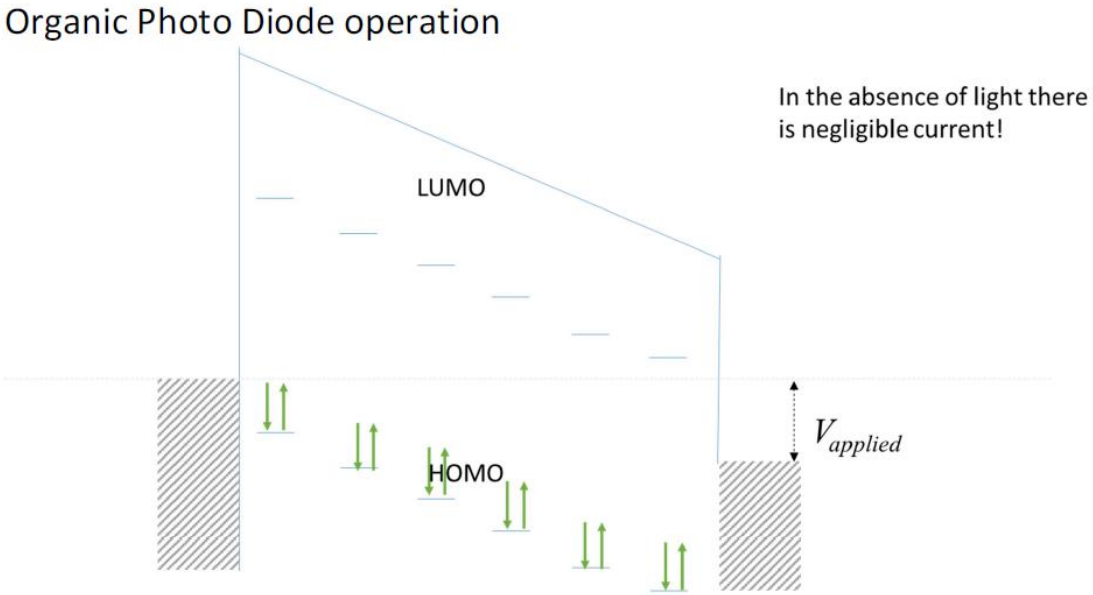


Merck prototype photovoltaic

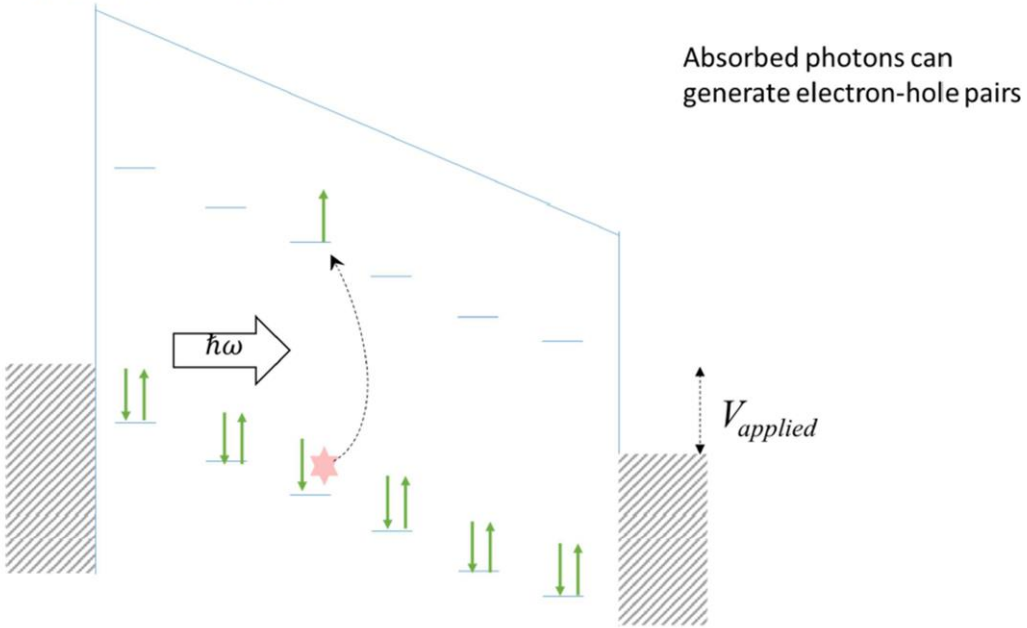


Sony OTFT driven display

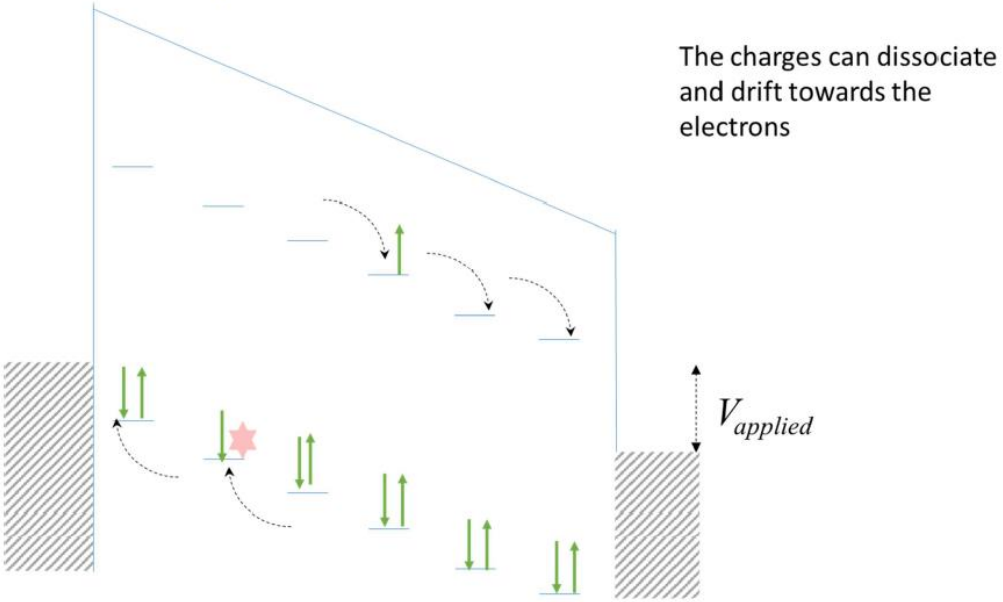
can fabricate a photodiode



Under illumination



Produces a signal

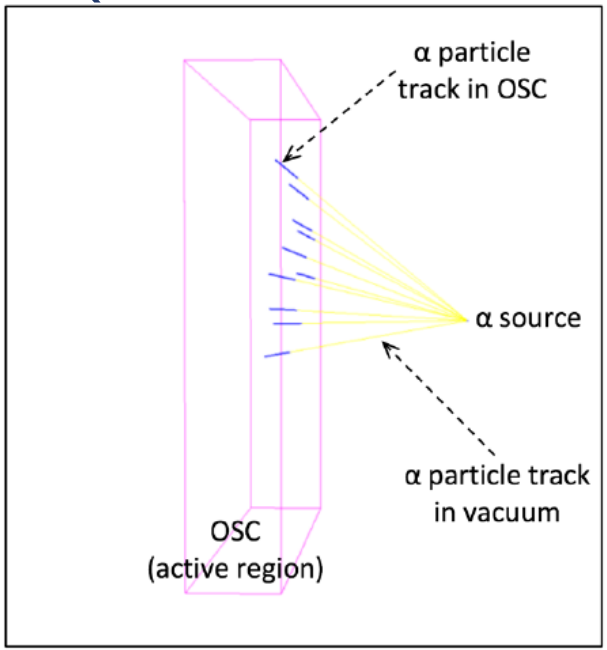


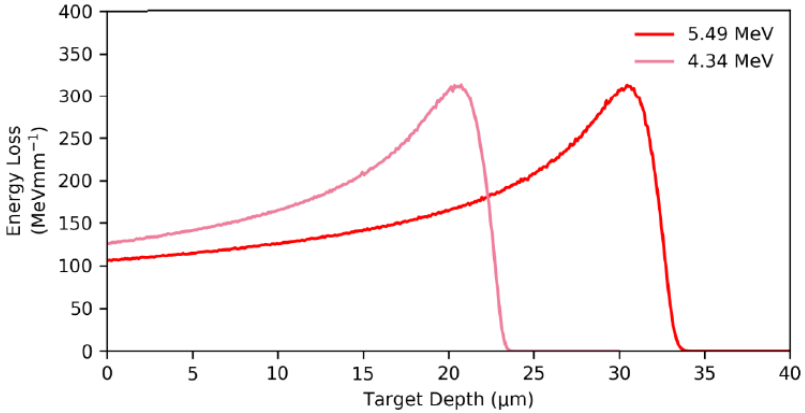
…surely Organic Semiconductors (OSCs) are unsuitable…

- Organic Fabrication Methods
  - Spin coating generally ≤ μm thickness
  - Vacuum deposition generally ≤ μm thickness
  - Drop casting Ok for up to ~100μm thickness
  - Hot pressing ~30μm to 100+μm thickness

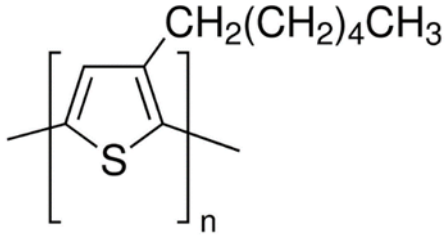
…but also inkjet printing, roll to roll printing…

α particle detection penetration modelling (Geant4 Timis/Ali)

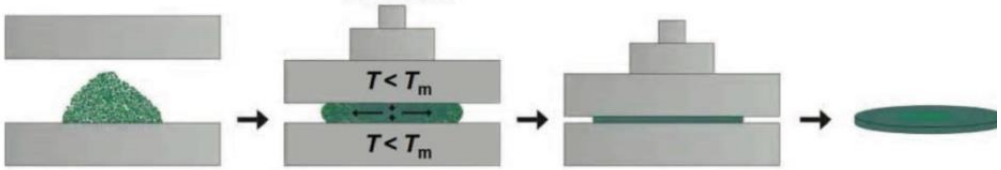




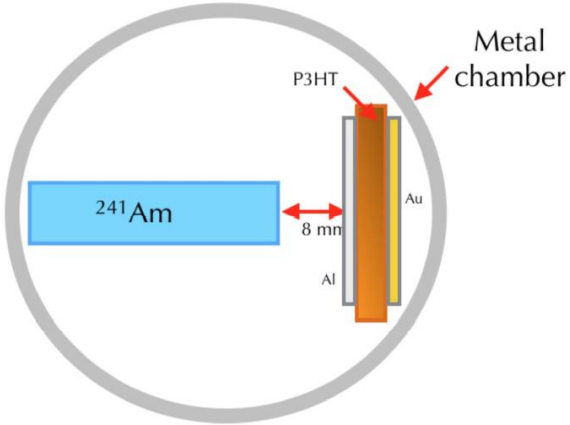
early P3HT samples (Liu)



Hot Pressing

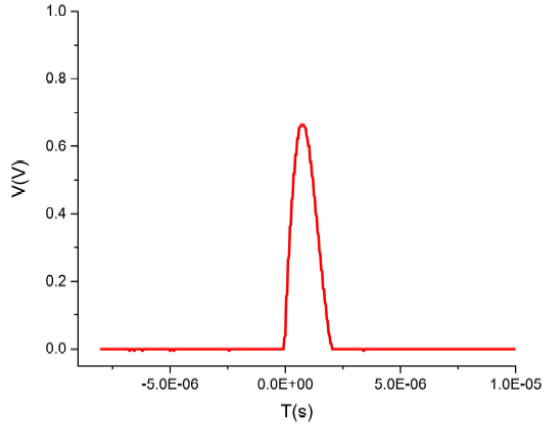


Diode and source arrangement

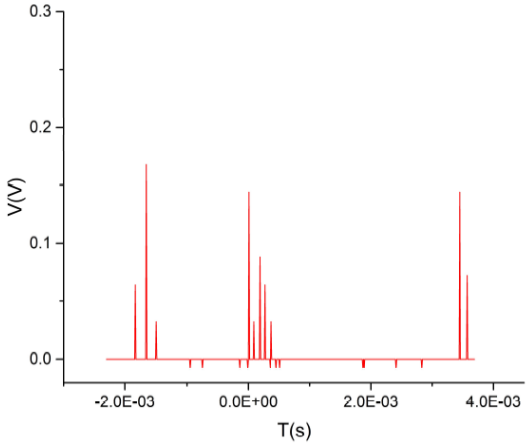


early P3HT samples

Single signal in avalanche mode (V bias 500V-1kV!)



Multiple signals from 370 kBq ^{241}Am source



why α detection anyway?

- Can use ^{10}B thermal neutron capture reaction

$$
{}^{10}_{5}\mathrm{B} + {}^{1}_{0}n \rightarrow \begin{cases} & Q-\text{value (MeV)} \\ {}^{7}_{3}\mathrm{Li} + {}^{4}_{2}\mathrm{He} & 2.792,\ (6\%) \\ {}^{7}_{3}\mathrm{Li}^{*} + {}^{4}_{2}\mathrm{He} & 2.310,\ (94\%) \end{cases}
$$

Less is more (Taifakou, Borowiec et Al.)

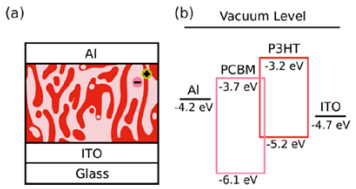
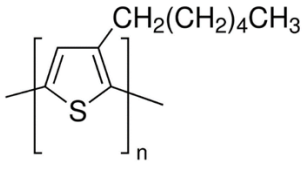
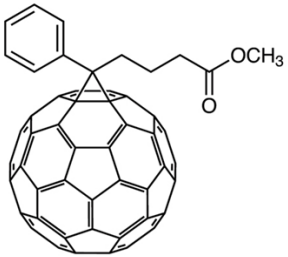


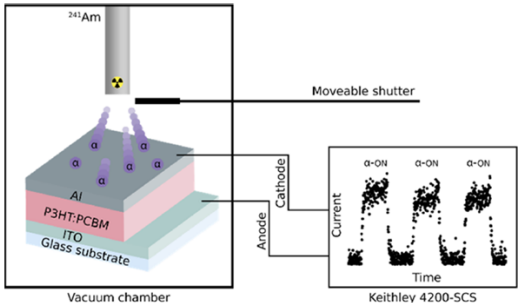
Figure 1. (a) Schematic bulk dispersed heterojunction device structure. Electron–hole pairs dissociate at the interfaces between the P3HT donor (red) and $PC_{60}BM$ acceptor (pink) and drift toward either the anode or cathode depending on the applied bias. (b) Nominal device energy level schematic.

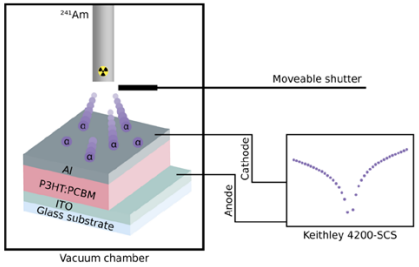


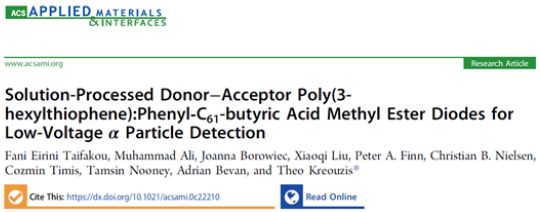
P3HT



PCBM







Current enhancement

$$|\Delta I_\alpha| = GeN\dot{}_\alpha \Phi_\alpha \left(E_\alpha / E_g\right)$$

- $G\Phi\alpha$ - gain-efficiency product
- $|\Delta I\alpha|$ - current enhancement
- $\dot{N}_\alpha$ - alpha flux over sample
- E_α - alpha particle energy
- E_g - bandgap*

- *could use ionisation potential – if so $G\Phi\_\alpha$ up to 80-90%

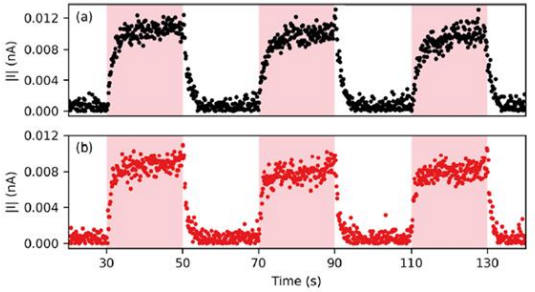


Figure 3. Time-dynamic α particle responses. (a) Current–time plot obtained from a 32.0 ± 0.4 μm device under reverse bias (−5 V). (b) Current–time plot from a 32.0 ± 0.4 μm device under forward bias (+5 V). The device α particle exposure is controlled by a shutter, with the shaded regions indicating α particle irradiation (On).

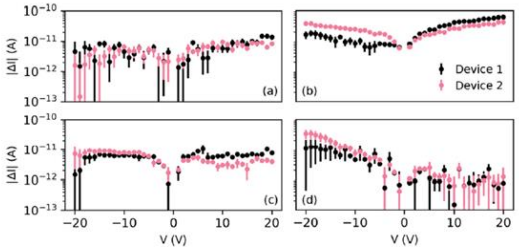
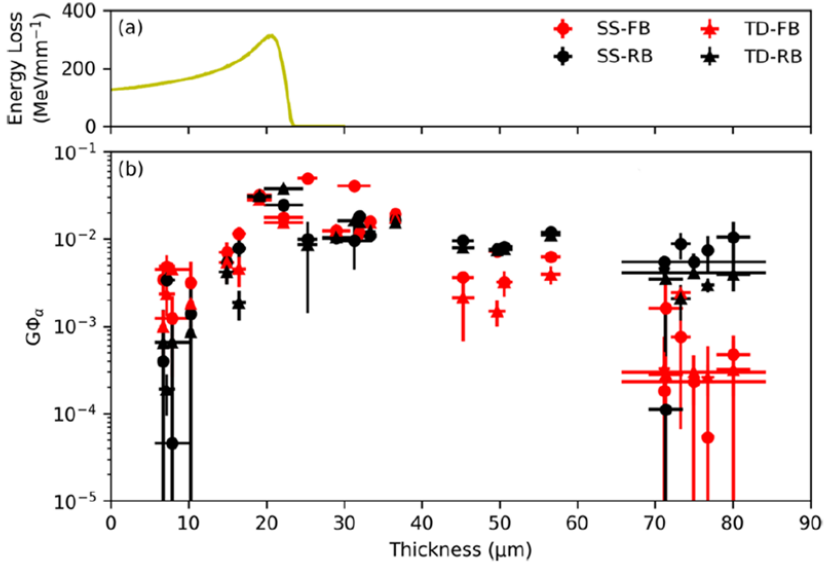
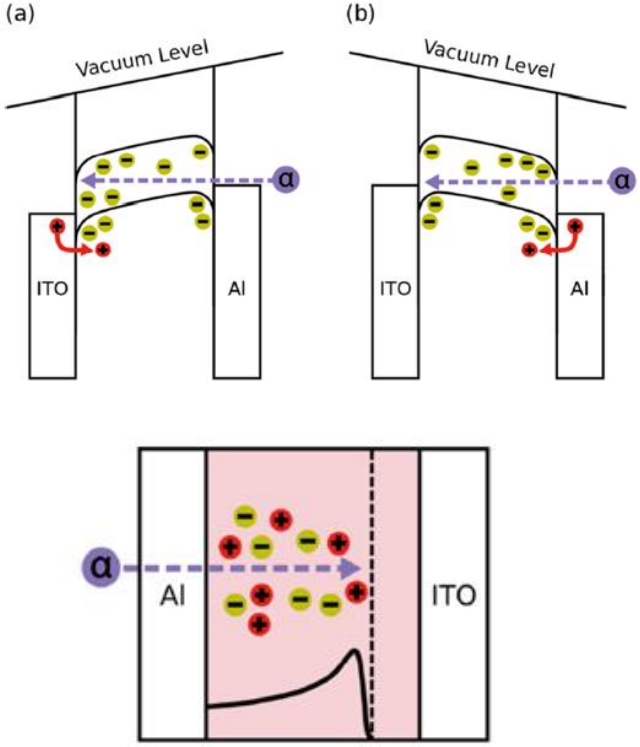


Figure 4. Steady-state α particle exposure current enhancement versus bias obtained from pairs of devices (of similar OSC thicknesses) fabricated on a given substrate across a range of OSC layer thickness. (a) 14.9 ± 1.0 μm (black) and 16.5 ± 0.9 μm (pink), (b) 25.3 ± 1.3 μm (black) and 19.1 ± 1.6 μm (pink), (c) 49.7 ± 1.1 μm (black) and 45.3 ± 1.4 μm (pink), and (d) 71.2 ± 0.7 μm (black) and 73.3 ± 1.3 μm (pink).

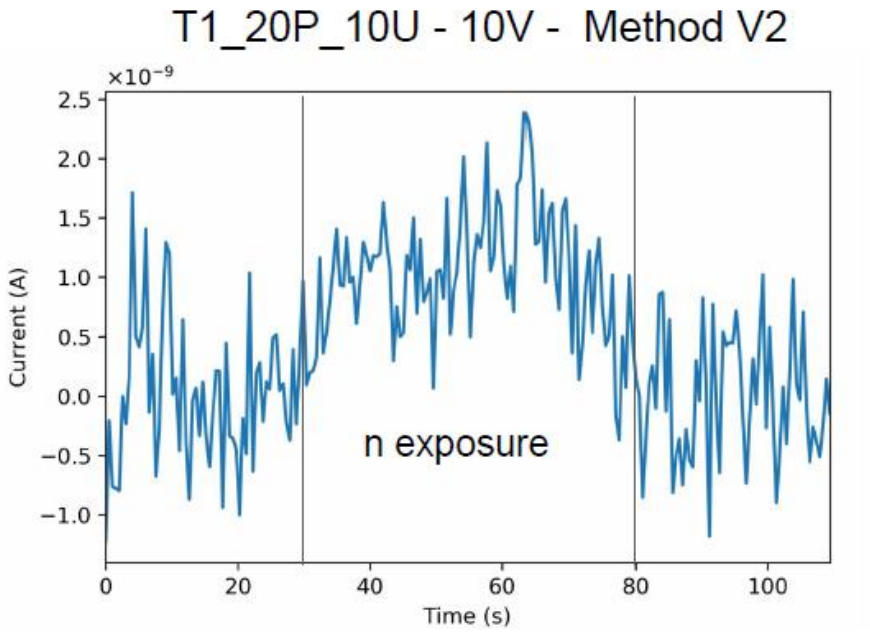
Variation with device thickness



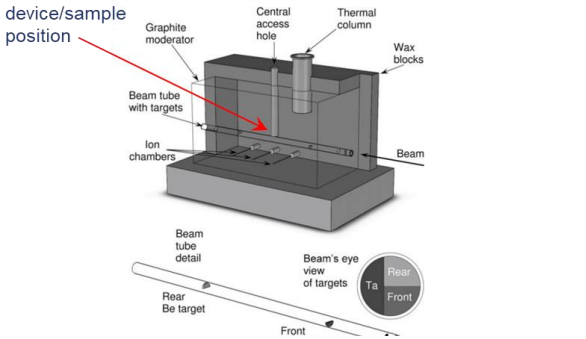


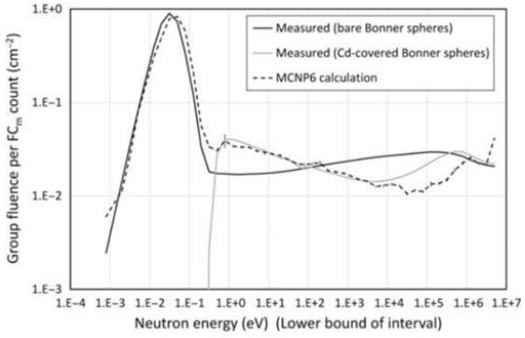
Early attempts at neutron detection (Ali)

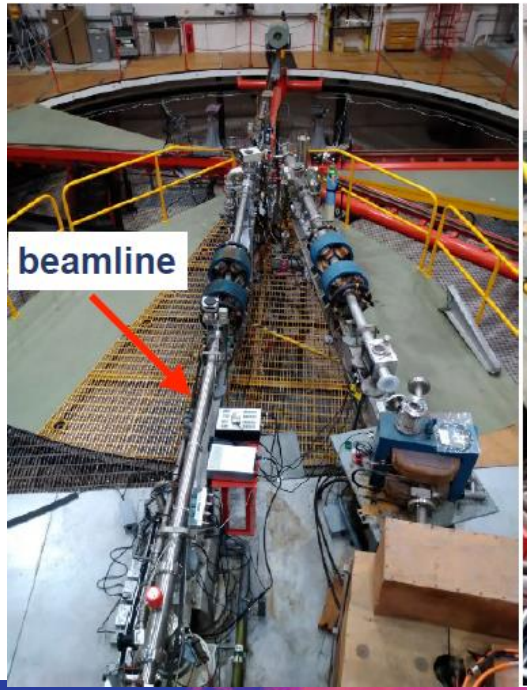
- P3HT + PCBM + B
- AmBe source
- Extremely poor (SNR <2)

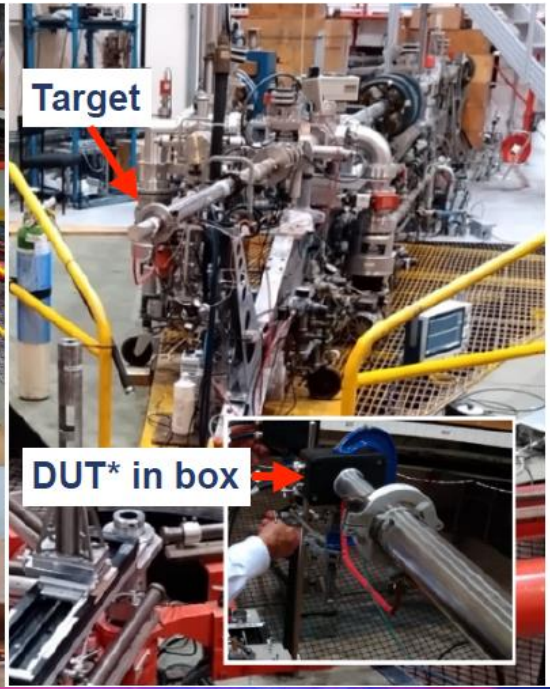


NPL thermal and high energy neutrons (Borowiec, Taifakou et Al.)



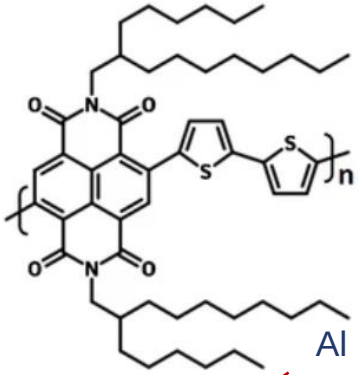


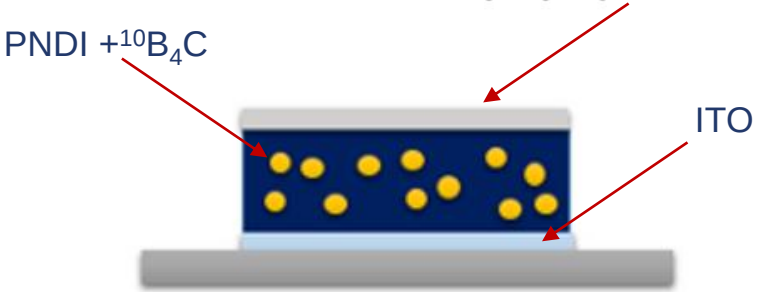


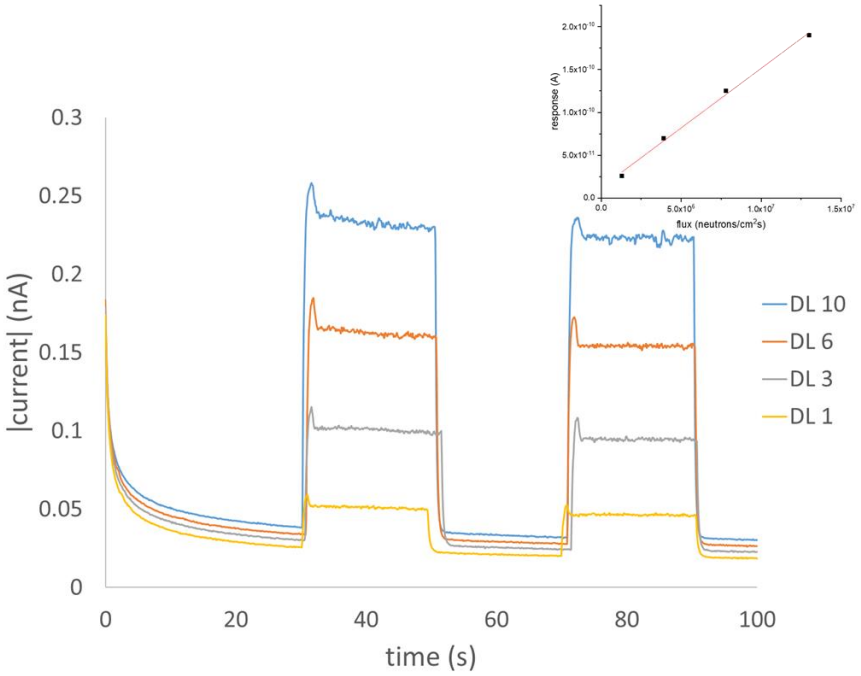


QMUL neutron detection (thermal)

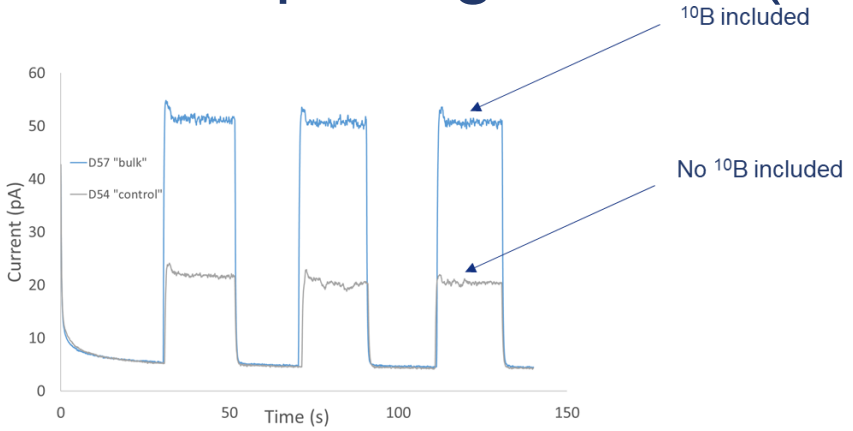
PNDI

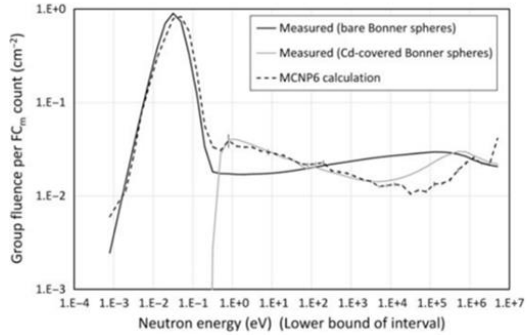


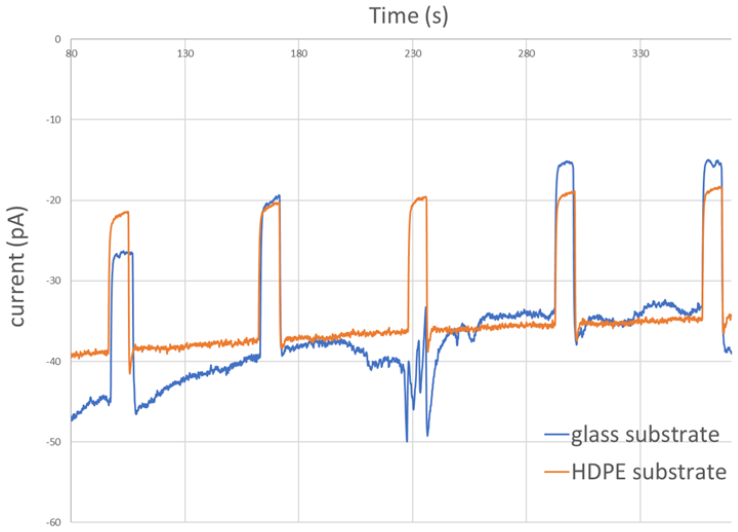




…surprising results (thermal)

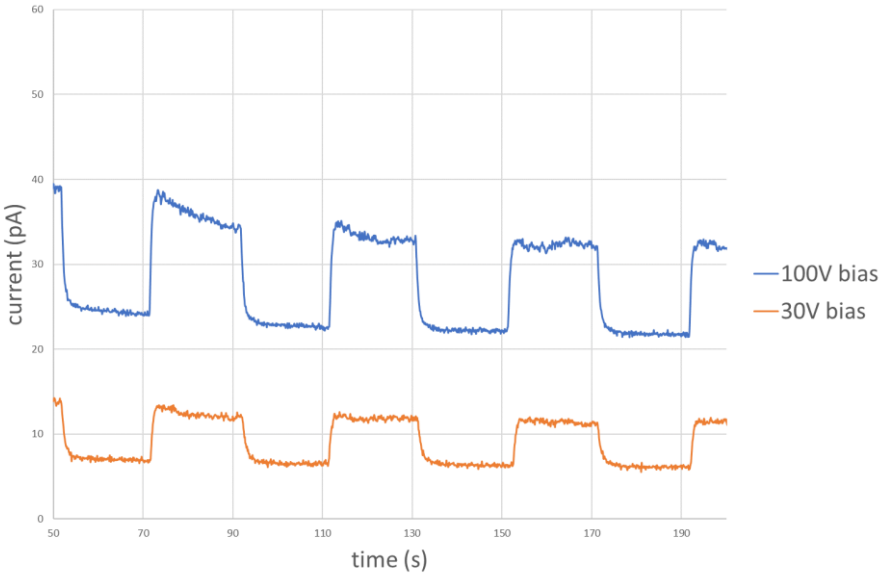




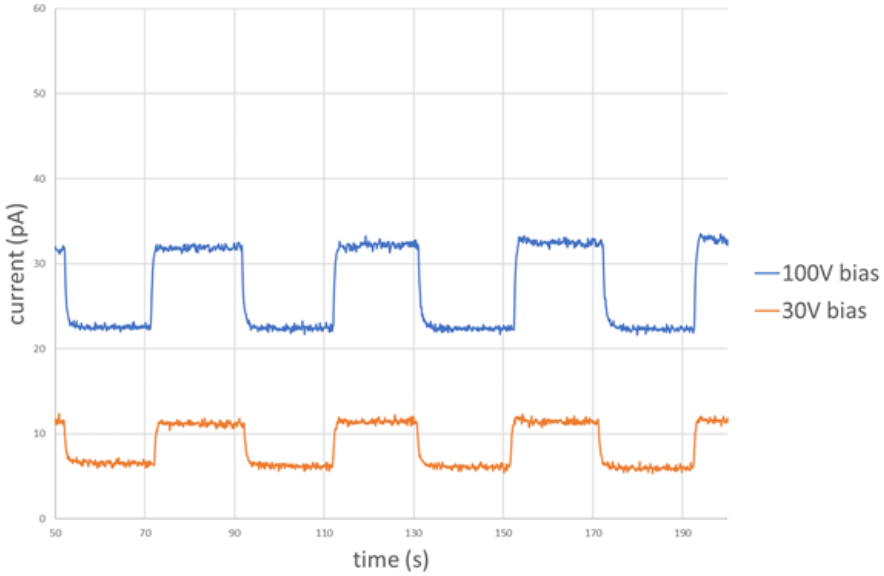


High energy neutron detection (PNDI)

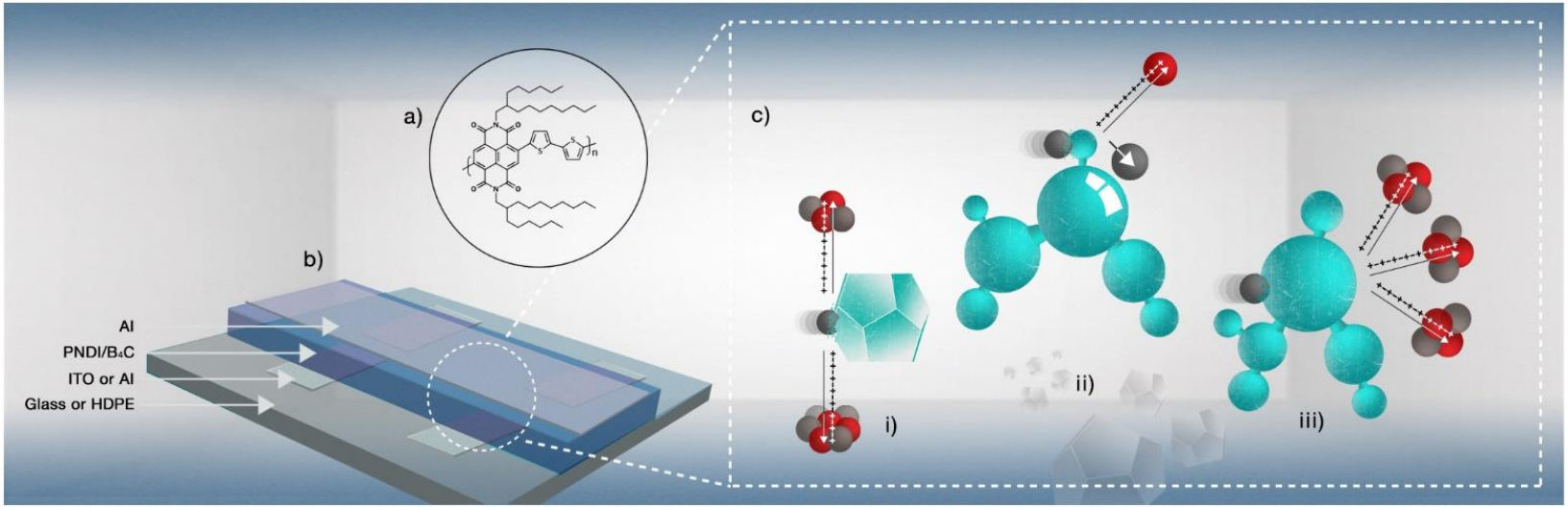
- 16 MeV



- 565 keV



Different mechanisms



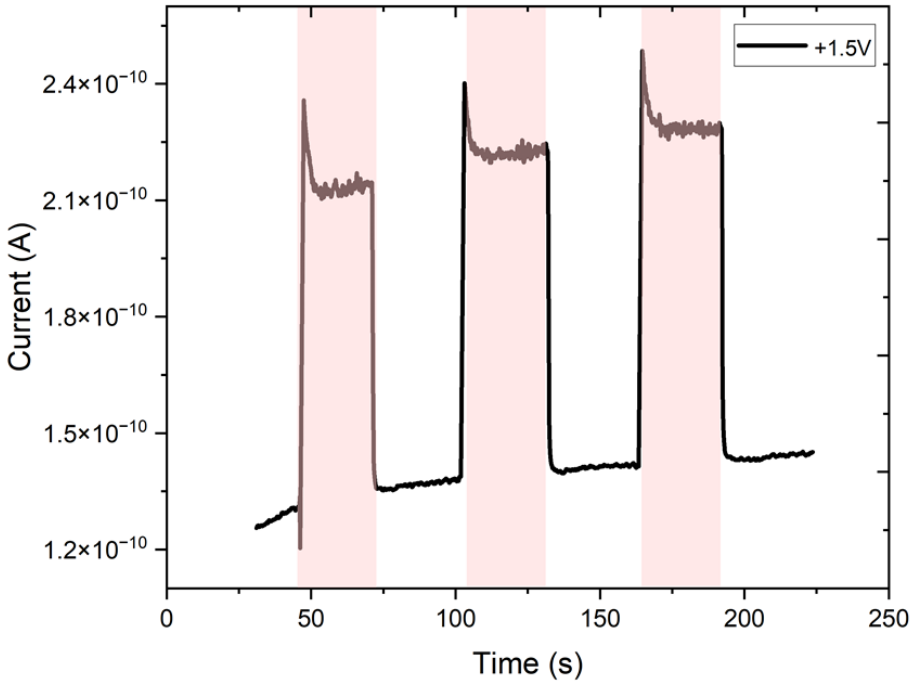
x-ray detection

- Briscoe (QMUL)
- Hoye (Imperial/Oxford)
- Alsharif (QMUL)

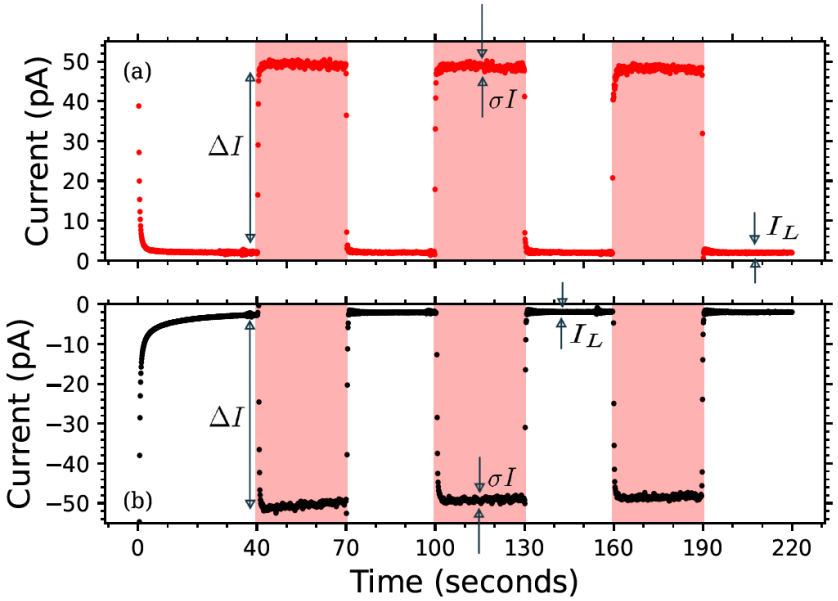
- OSCs have been used
- High Z inclusions

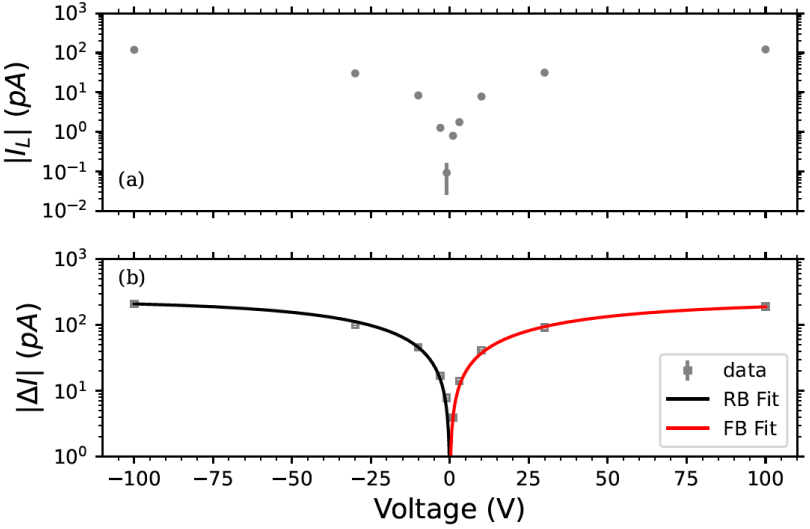
- Perovskites
- BiOI
- P3HT:TiO_2

…also P3HT:TiO_2 (Alsharif)



…back to α, neutron (PNDI Gashi, Horner)

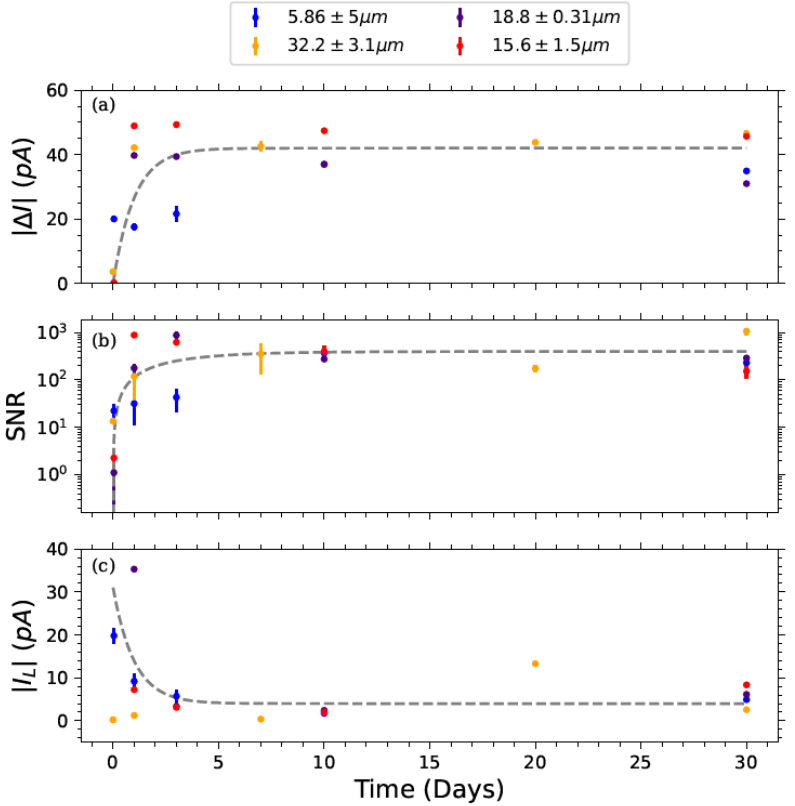




$$\Delta I = I_{sat}(1 - \exp\left\{\frac{-V}{V_0}\right\})$$

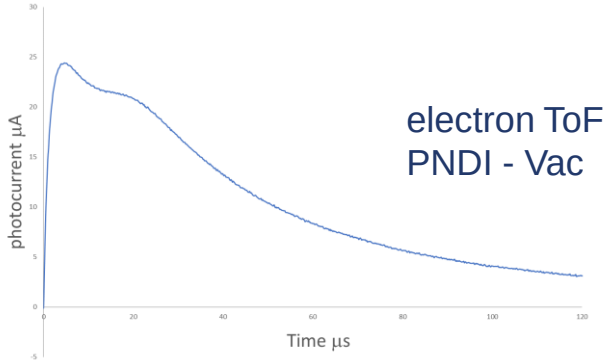
air stability

(enhancement)

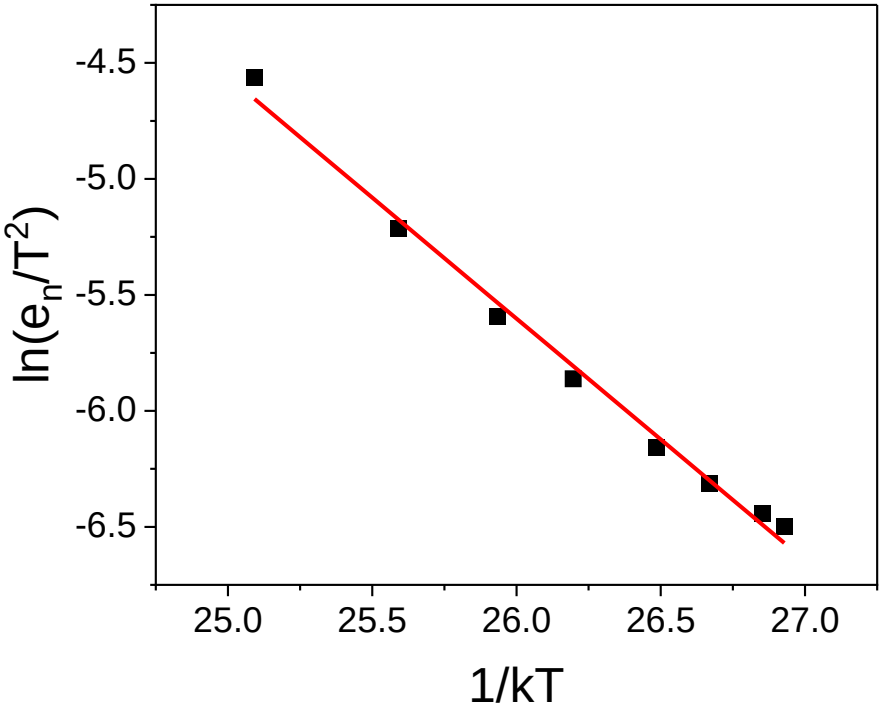


trapping

- Deep traps in OSCs
- Hence DLTS (also inorganic, Zhang)

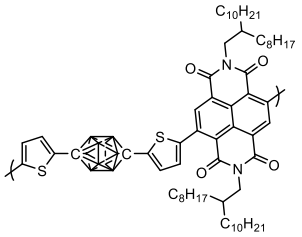


electron ToF
PNDI - Vac

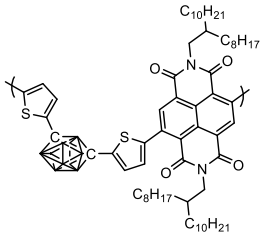


carborane-NDI polymers (Horner)

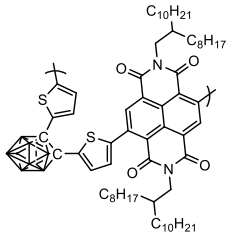
- With Heeney, Aniés (Imperial)



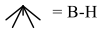
*p*CbT$_2$-NDI

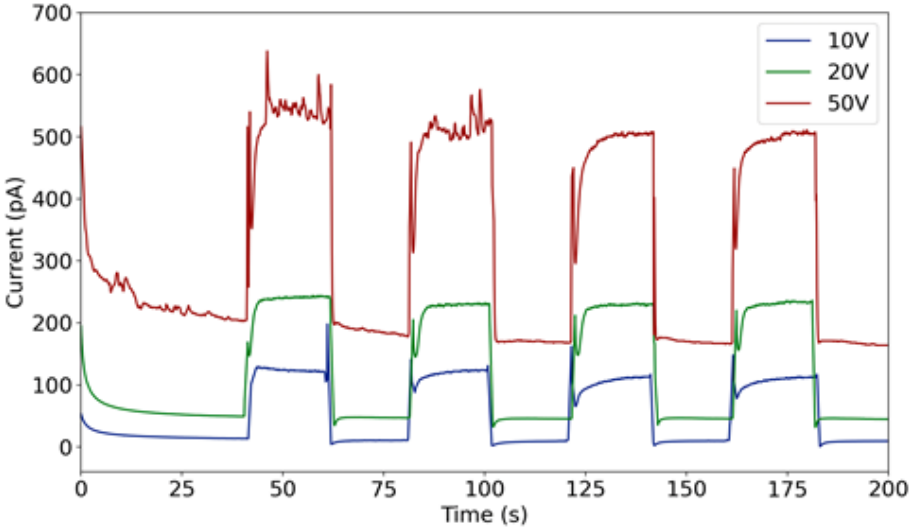


*m*CbT$_2$-NDI



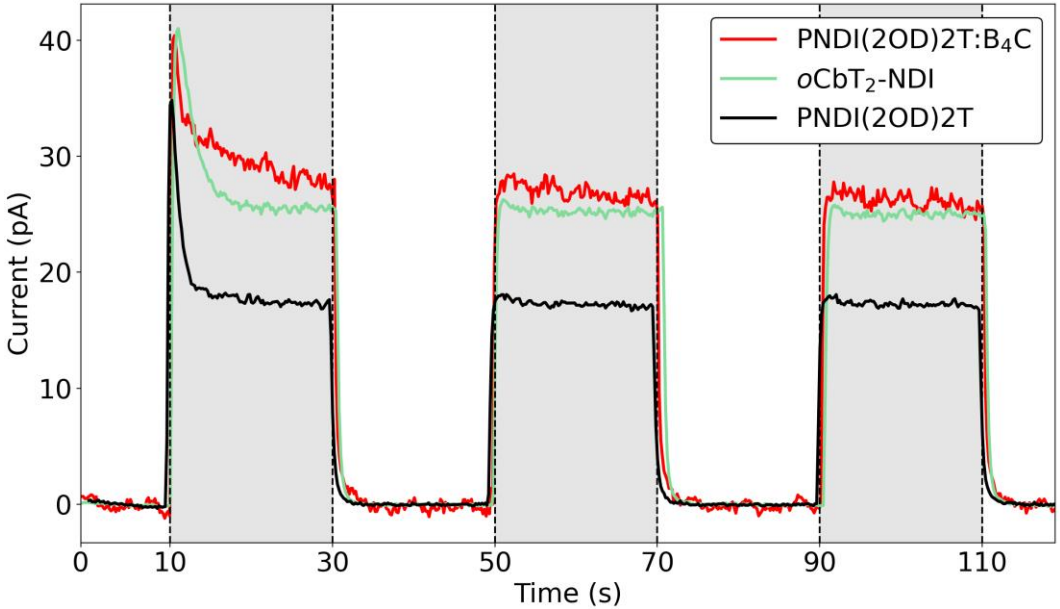
*o*CbT$_2$-NDI





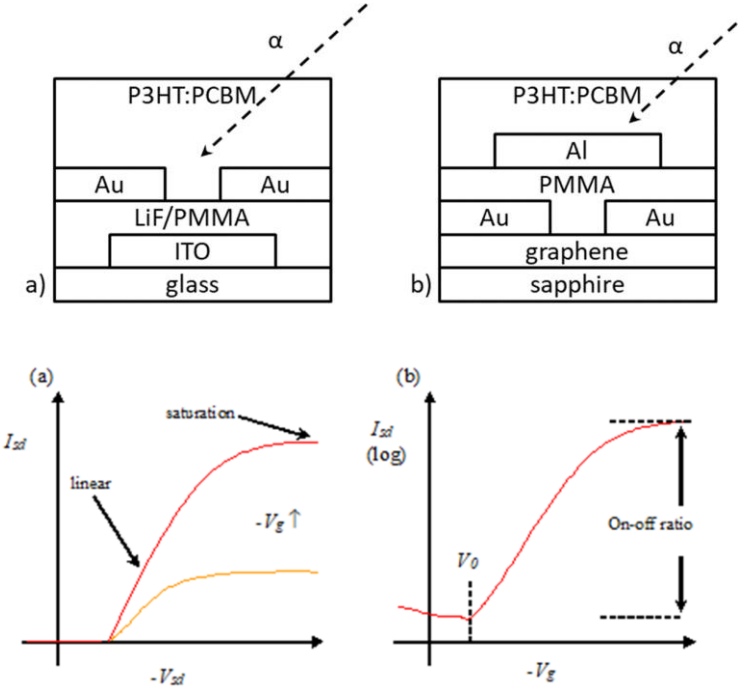
Alpha response

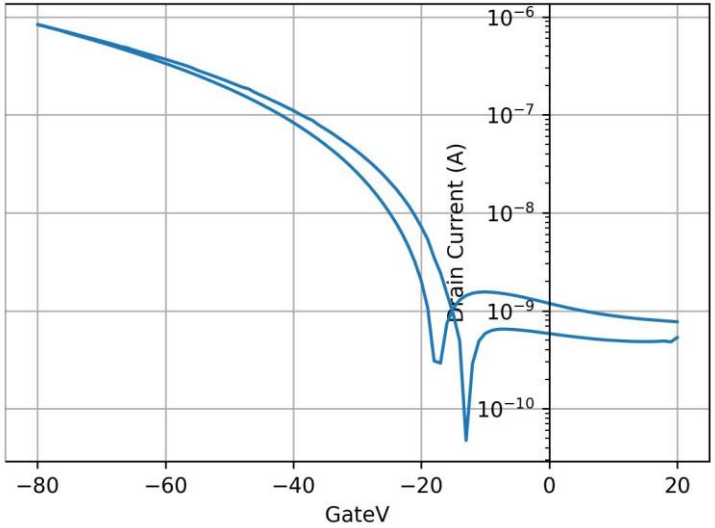
carborane-NDI polymers (Horner)



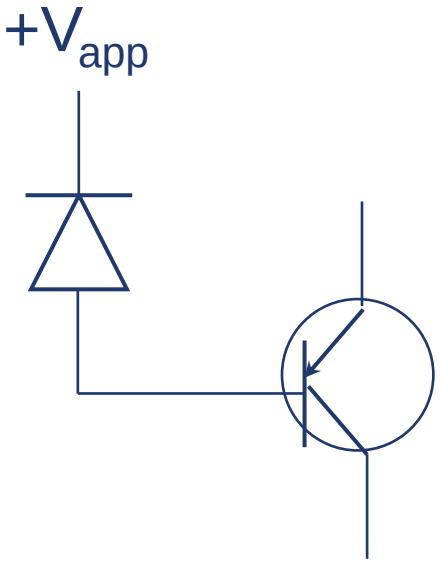
NPL neutron response

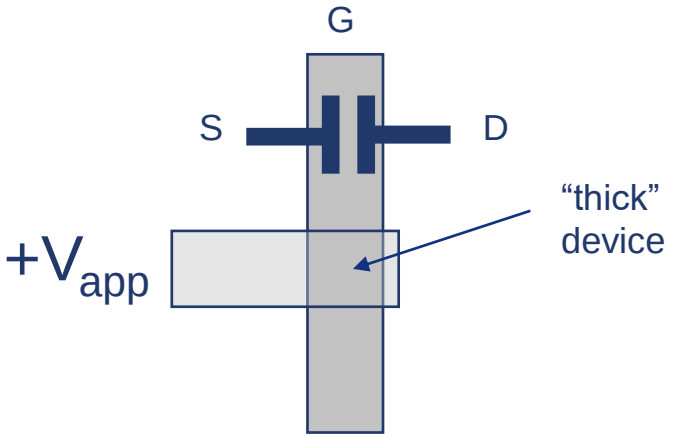
Field Effect Transistor devices (Moss, Amjad)





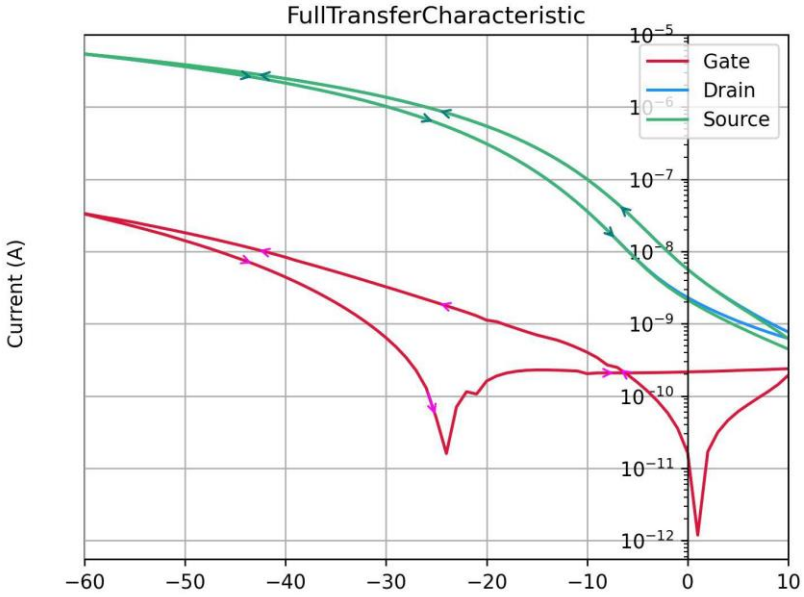
Field Effect Transistor devices (Amjad)



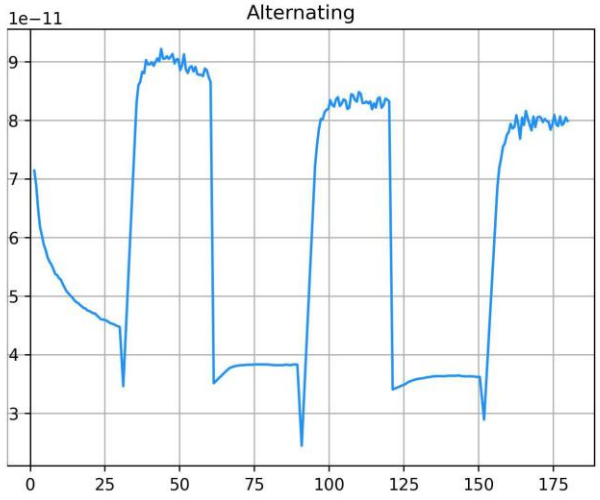


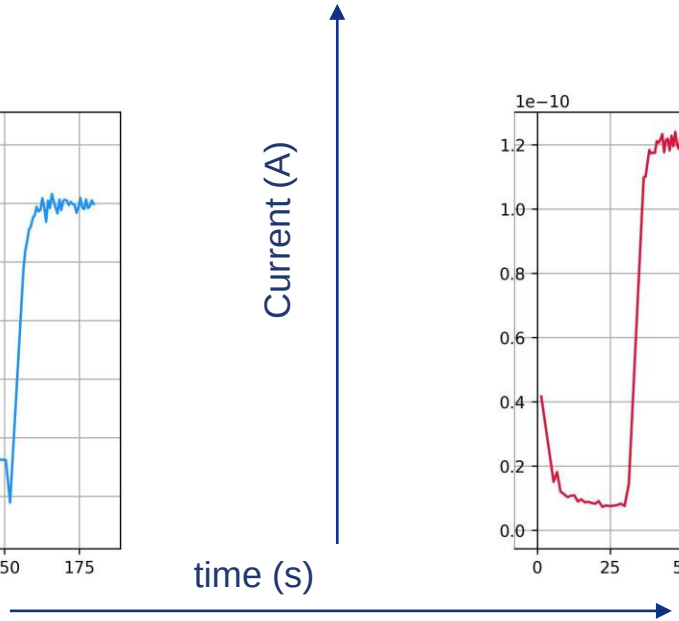
FET transfer characteristic

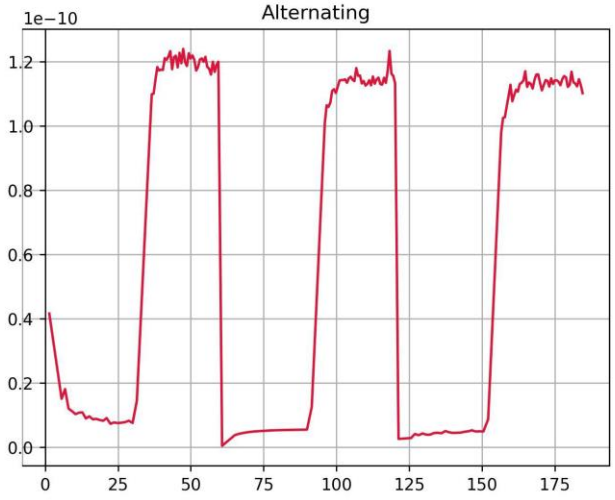
- Fresh FET
- Drain Bias = -10V



“tandem” device results

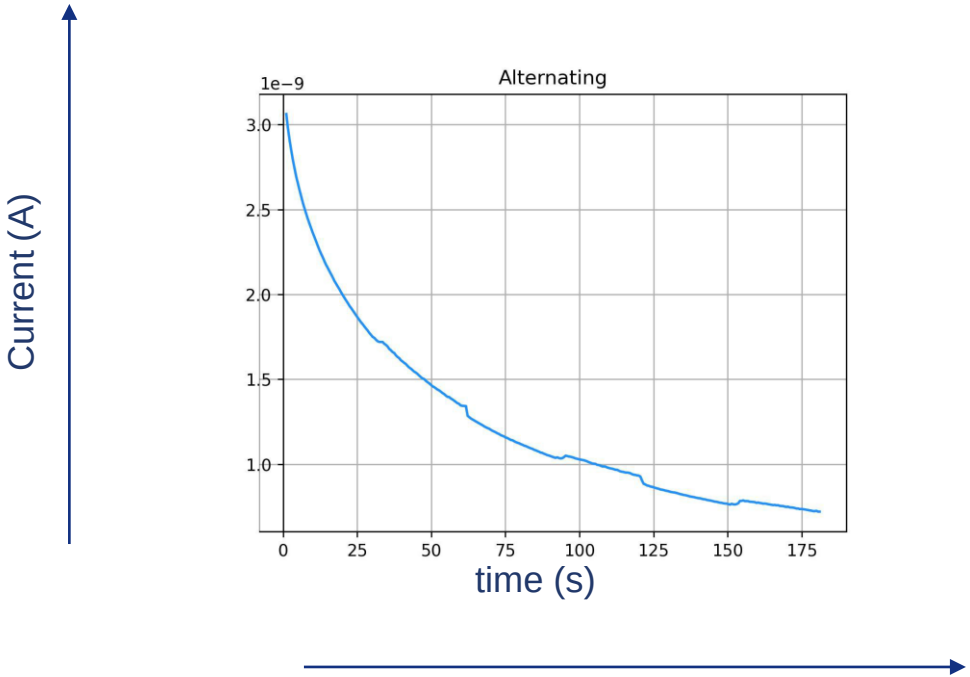






- Diode only alpha response
- Diode + FET alpha response

“tandem” device results



- FET only alpha response

observations

- “conventional wisdom” does not necessarily apply
  - charge generation
  - air stability
  - trapping

- Different research strands interrelated (naturally)
  - fundamental Physics is still important
- There is appetite for growth in the field

acknowledgements

- AWE
- MSL
- STFC
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- NuSec
- CSC
- IsDB
- NPL
- NNL

Thank you