Environmental Stability of Polymer Radiation Detectors

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1. Introduction

Alpha detection properties are proven indication of neutron detection performance[1]. Alpha detection with organic based semiconductor devices is proven[2]. Ambient effects such as air exposure and humidity are investigated across a range of organic layer thicknesses and up to 45 days exposure. Furthermore, a single device is treated under a constant bias in addition to air exposure.

2. Experimental Setup

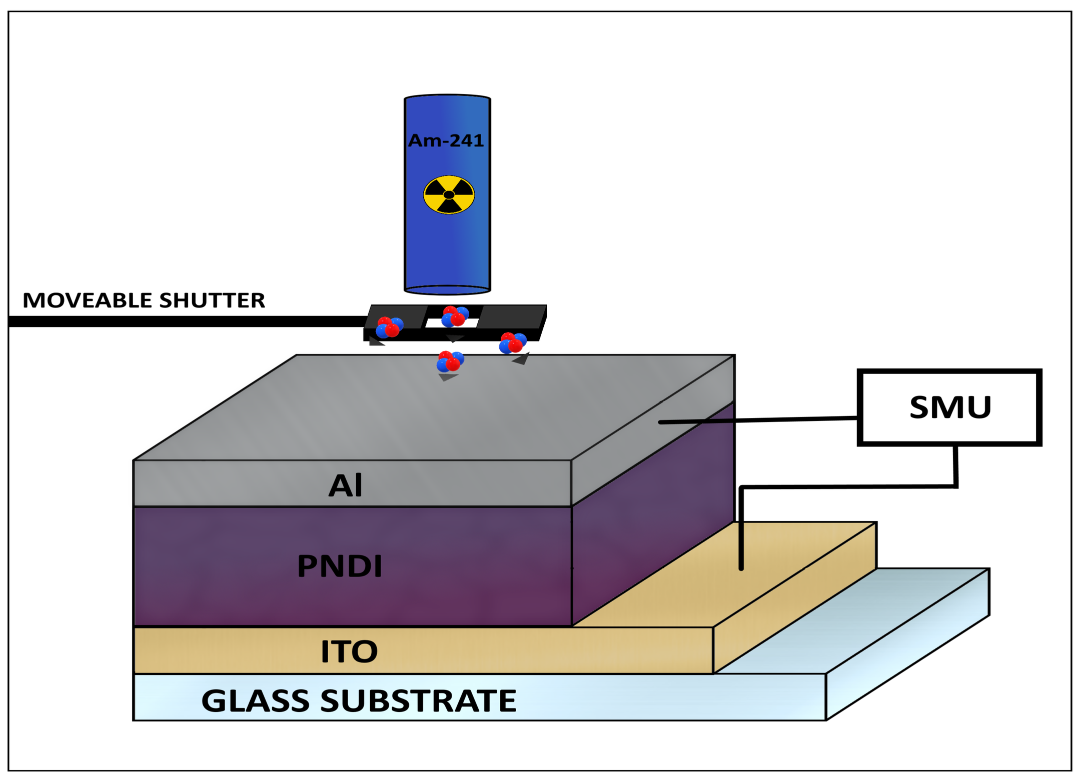

Figure 1: Composition of the organic device and experimental setup.

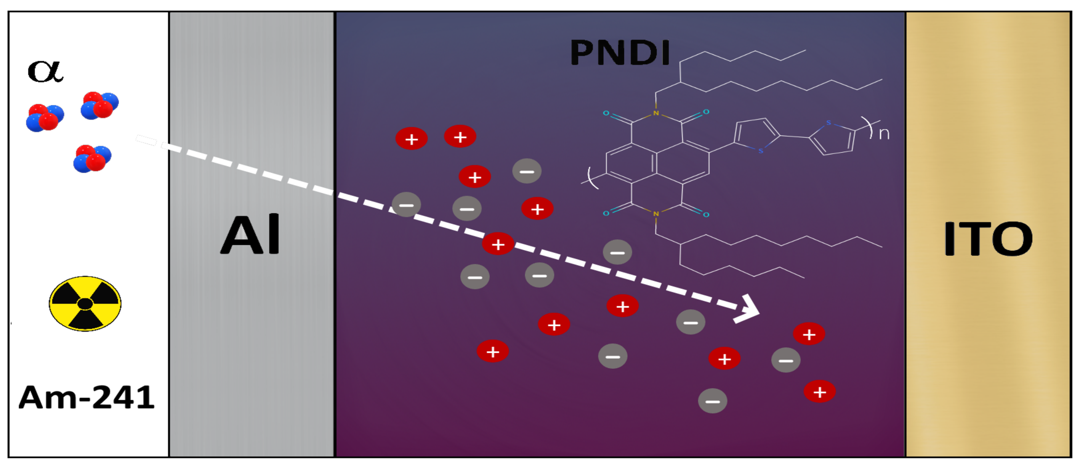

Figure 2: Formation of electrons and holes via alpha irradiation. The structural formula is represented in the organic layer.

3. Alpha Detection

The devices are biased at a range of voltages and exposed in 30s intervals to alpha radiation.

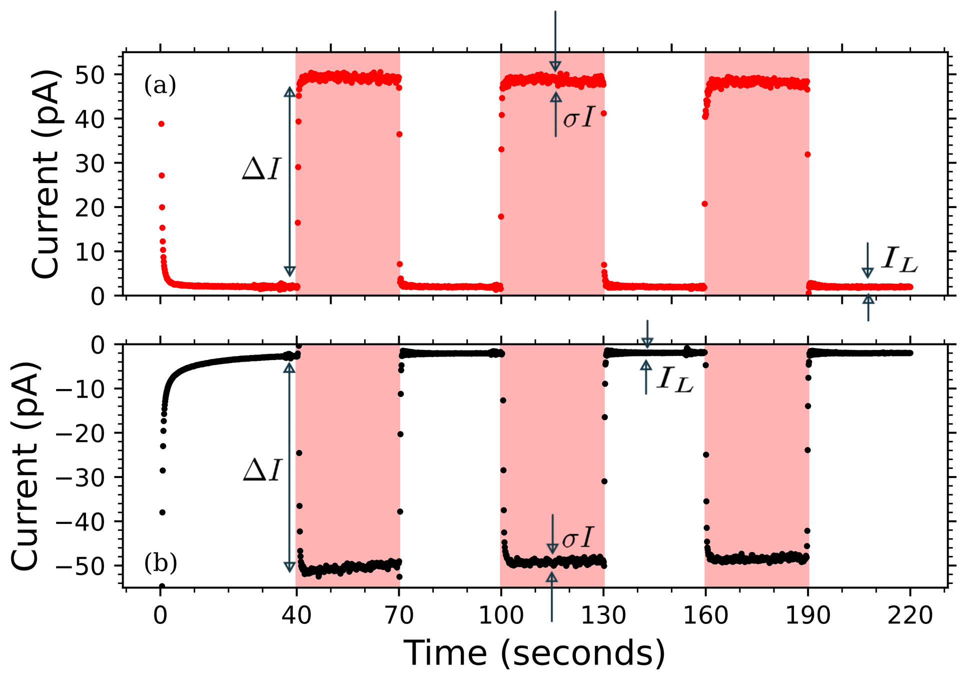

Figure 3: Example alpha response of a device (10 days air exposure) with an organic layer thickness of 15.6 $\pm$ 1.47 μm at **(a)** +10 V (forward bias), **(b)** -10 V (reverse bias).

Detection of 4.34 MeV alpha particles is achieved at voltages from 1-100 V in both forward and reverse bias over 30-45 days. The leakage current (I_L), response current (ΔI) and signal-to-noise ratio (SNR) are some of the variables produced from the Current vs Time data collected.

4. Stability with Air Exposure

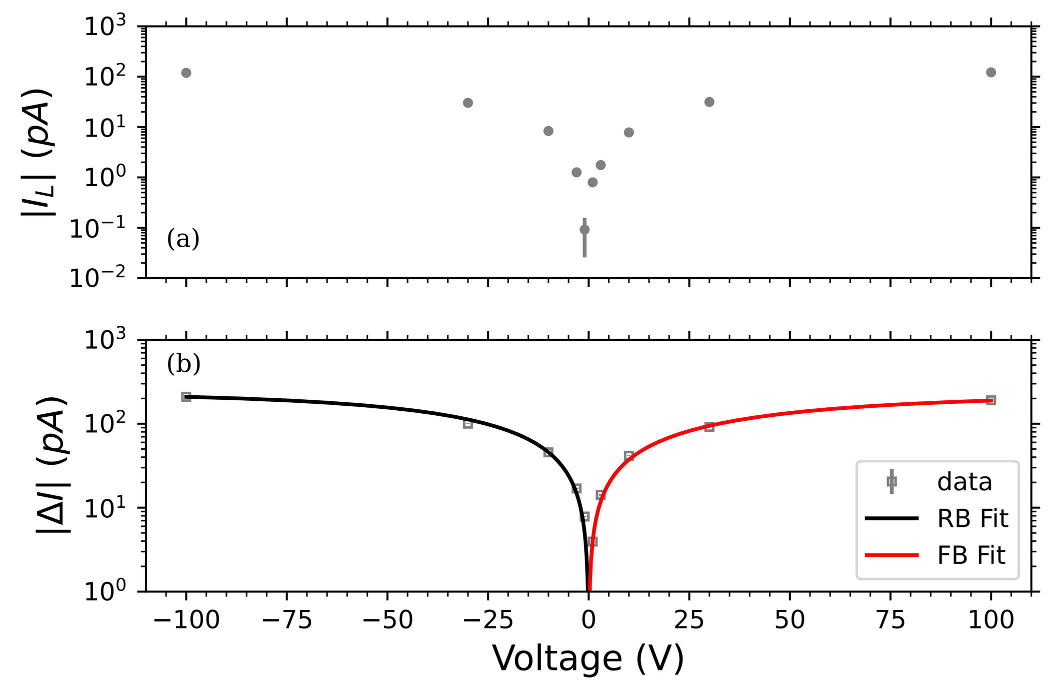

Figure 4: **(a)** I-V characteristic compiled with leakage current data from current-time measurements. **(b)** Current enhancement under alpha irradiation against voltage. Both plots show a 15.6 $\pm$ 1.47 μm thick device after 30 days of air exposure. The solid lines represent fits using equation (1).

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

Fitting parameters: Saturation current (I_{sat}) and characteristic voltage (V_0).

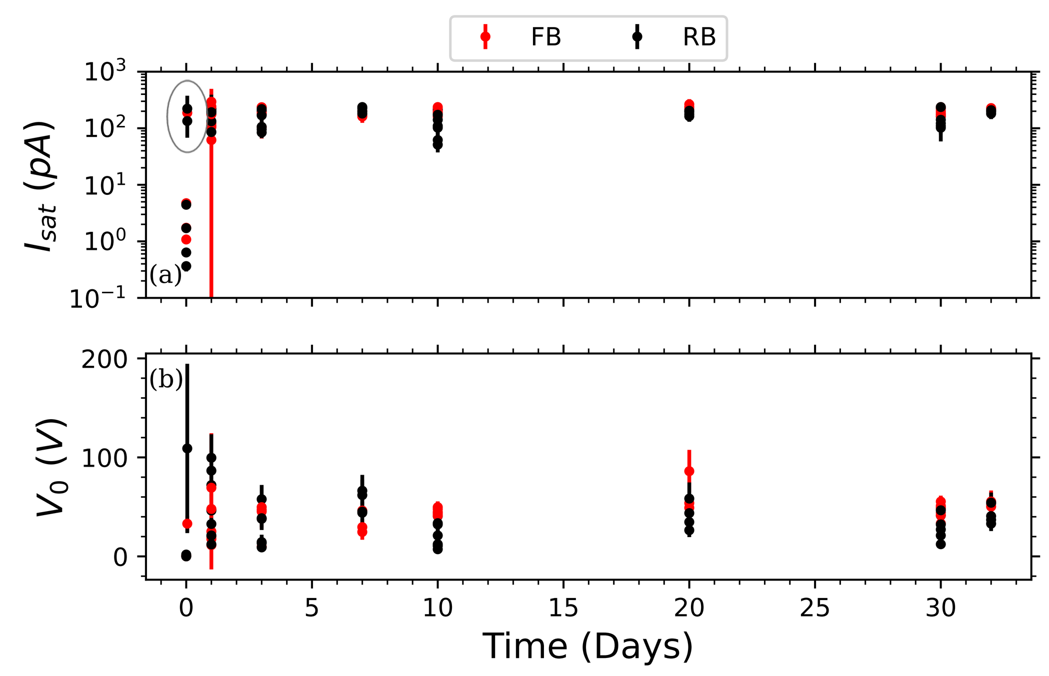

Figure 5: Fitting parameters extracted using equation (2) versus exposure to air for all device thickness ($5-35\,\mu m$). The circled data obtained at 1-5 hours of air exposure. **(a)** Saturation current. **(b)** Characteristic voltage.

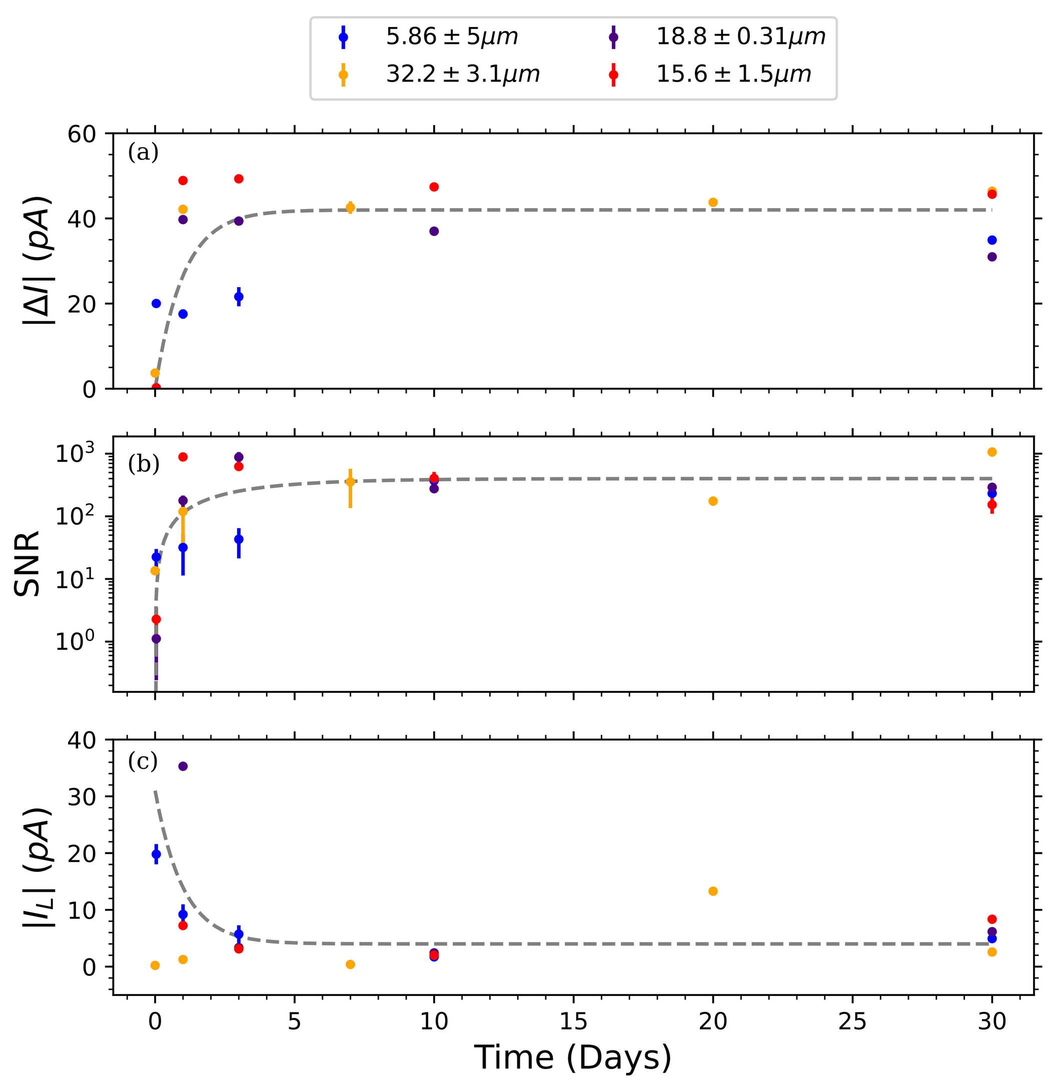

Figure 6: Air exposure results obtained from a range of different device thickness biased at -10 V. **(a)** Current enhancement under alpha irradiation. **(b)** Signal-to-noise ratio. **(c)** Leakage current. The grey dashed lines represent a guide to the eye.

5. Biasing & Humidity Variation

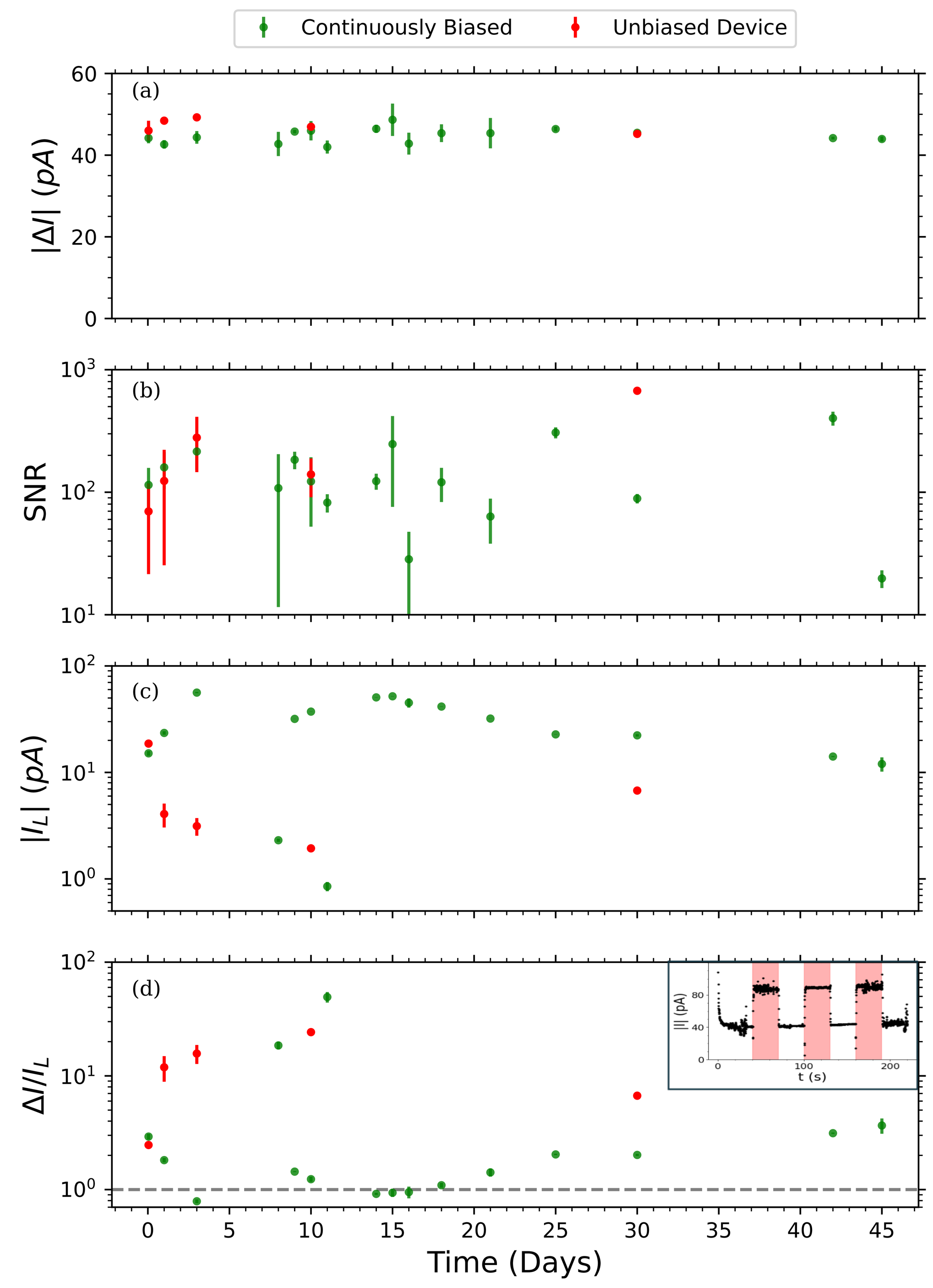

Figure 7: A comparison of performance after air exposure between a continuously biased device 12.1 $\pm$ 5.47 μm and an unbiased device 10.7 $\pm$ 6.47 μm characterised at -10 V. **(a)** Current enhancement. **(b)** Signal-to-noise ratio. **(c)** Leakage current. **(d)** Current enhancement-to-leakage ratio. The inset represents the day 16, $\Delta I / I_L \approx 1$, raw data.

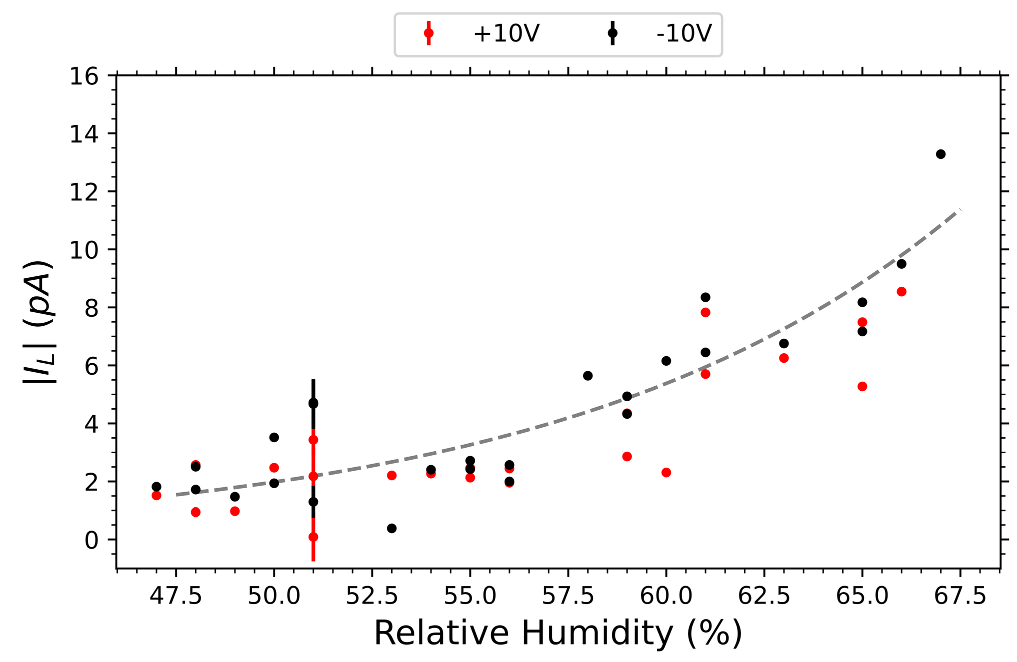

Figure 8: Multi-device analysis of leakage current variation with humidity. All data obtained post 10 days exposure to air (all devices stable). The grey line represents a guide to the eye.

6. Conclusions

- Device performance at a range of voltages quickly improves in the first 5 hours of air exposure between 10-100 fold compared to vacuum.
- At -10 V devices of different thicknesses show varying times to reach stability with the thickest being first and the thinnest last. It can be determined post 10 days of air exposure devices are stable.
- Devices are still operational after 45 days of continuous bias, most likely due to the low leakage current.
- There is a clear leakage-humidity relationship, device encapsulation may be considered for use in neutron detectors.

[1] J. Borowiec *et al*, IAEA TECH Doc proceedings, IAEA Technical Meeting on Advances in Neutron Detectors for Neutron Scattering and Imaging Applications, **2021**.
[2] Taifakou, F. *et al.*, Solution-Processed Donor-Acceptor Poly(3-hexylthiophene) Phenyl-C_{61}-butyric Acid Methyl Ester Diodes for Low-Voltage α Particle Detection, **2021**, ACS Applied Materials & Interfaces, **13**, 6470-6479, doi/10.1021/acsami.0c22210

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