Metal Halide Perovskite Single Crystal for Medical Imaging Systems Radiation Detectors

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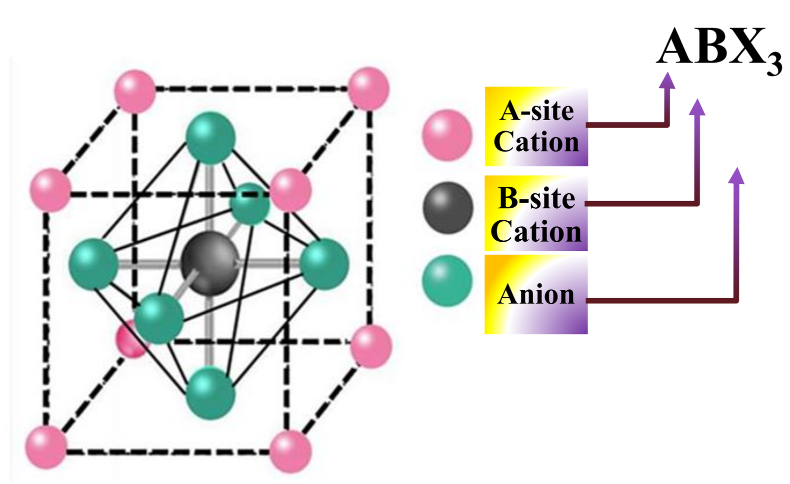
Nano Innovation 2026 Conference & Exhibition, Rome, 14-18 September

Metal-halide perovskites (MHPs) are considered ideal candidates for gamma-ray detectors in medical imaging systems. However, halide ion migration and dark current instability are common issues facing MHP detectors under high bias voltages. By suppressing halide ion migration and reducing dark current, we have enhanced the stability and radiation detection performance of the detectors under high-bias operating conditions.

Perovskite Detector

Perovskite is a class of material with the general formula ABX_3. Its unique crystal structure can accommodate a wide range of elements, giving rise to exceptional properties. Among other perovskite classes, $FAPbBr_3$ MHPs materials have emerged as promising candidates for next generation medical imaging radiation detectors due to their strong high energy photon absorption, high carrier mobility, and comparable performance at significantly lower cost than traditional semiconductors CsZnTe (CZT).

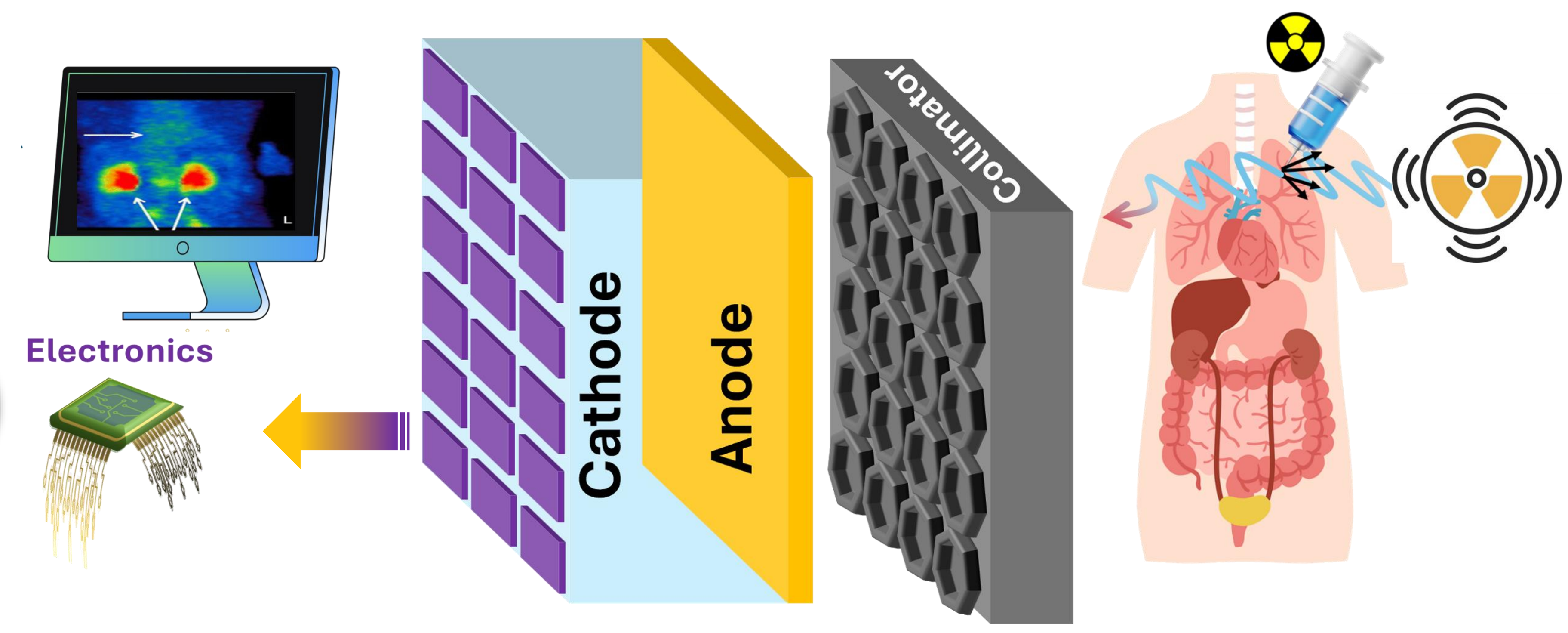


The main limitation of $FAPbBr_3$ detectors is halide ion migration, which restricts long-term operation.

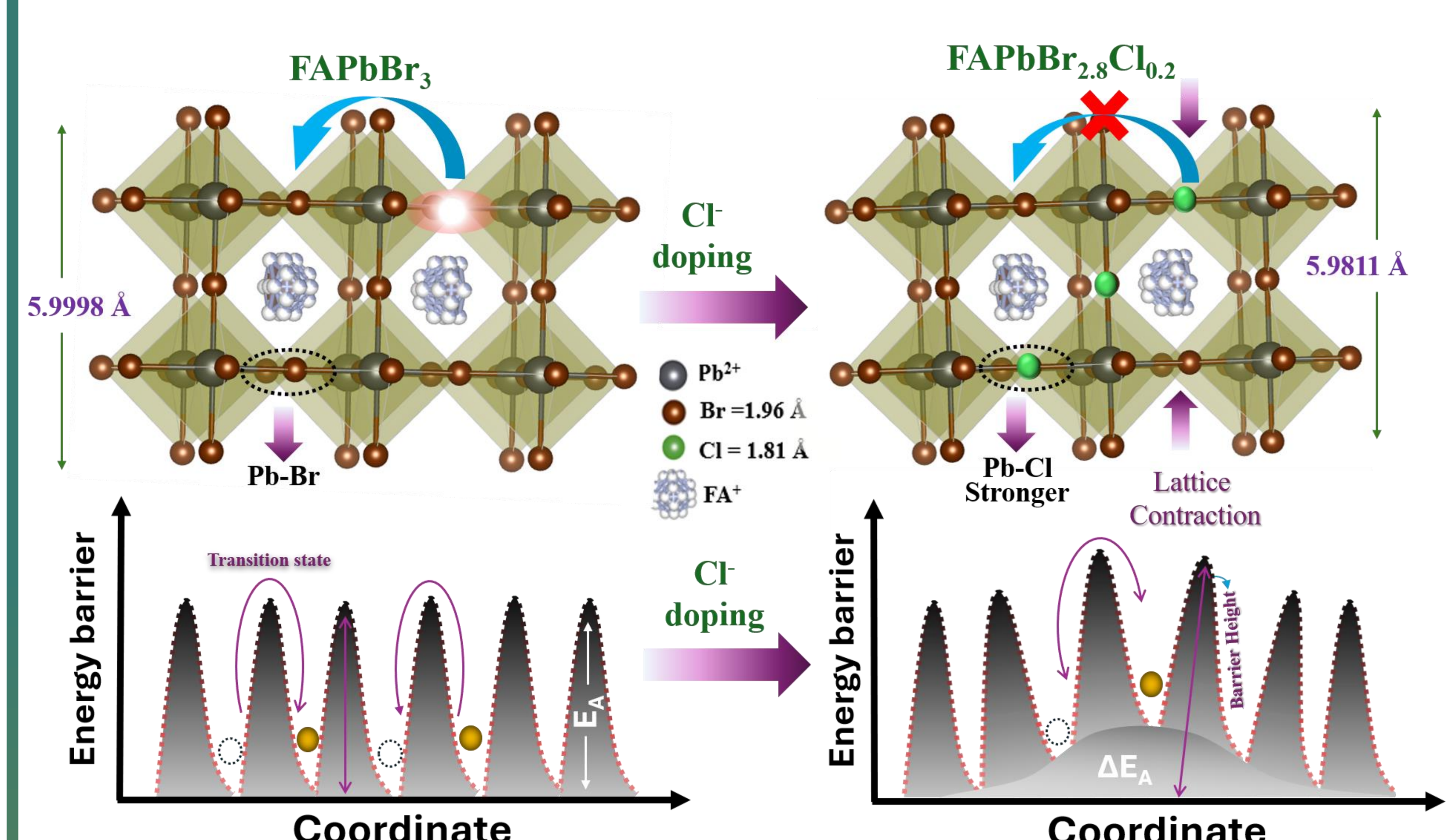
Single Photon Emission Tomography

Single Photon Emission Computed Tomography (SPECT) is **nuclear imaging techniques** that provide **3D functional imaging using gamma.** Conventional SPECT systems use NaI(Tl) scintillators converting gamma rays emitted from the radiopharmaceutical into visible-light photons, which are then detected by photosensors. Alternatively, semiconductor detectors such as CZT can be used instead of scintillators and photosensors. These detectors directly convert incident gamma rays into electrical signals, offering superior resolution and a compact design. CZT detectors are particularly promising for SPECT due to their high detection efficiency; however, the high cost of growing CZT crystals limits their widespread adoption in clinical practice.

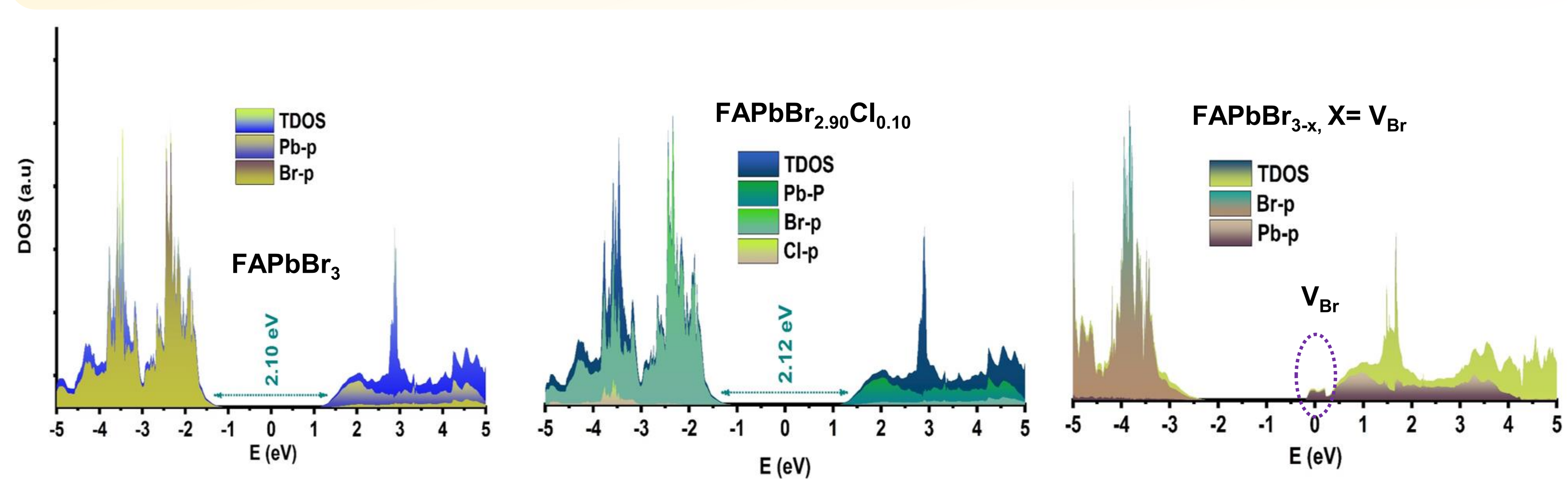
Therefore, nearly two decades of research have shown that perovskites have the potential to overcome these limitations and exhibit better performance.



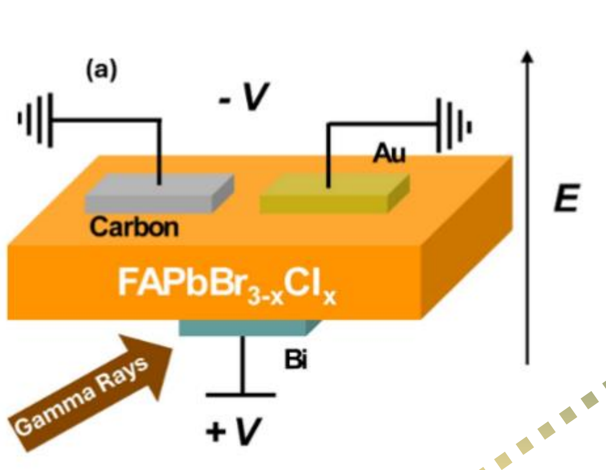
Approach

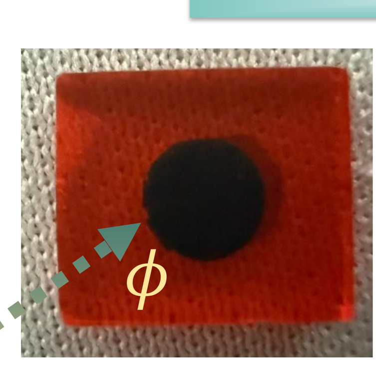


We suppressed the halide ions migration by partially substituting Cl^- into the halide lattice: which strengthens the Pb–X bond, raising the activation energy for vacancy hopping, while simultaneously passivating Br vacancies(V_{Br}) and reducing the mobile-ion concentration. The Density of states analysis of $FAPbBr_{3-x}$ reveals that the conduction band is primarily composed of Pb-p orbitals, while the valence band is mainly formed by Br-p orbitals; the introduction of V_{Br} disrupts the ordering of the Pb-Br octahedral network and generates defect states near the conduction band edge, indicating the formation of traps originating from Pb 6p orbitals.

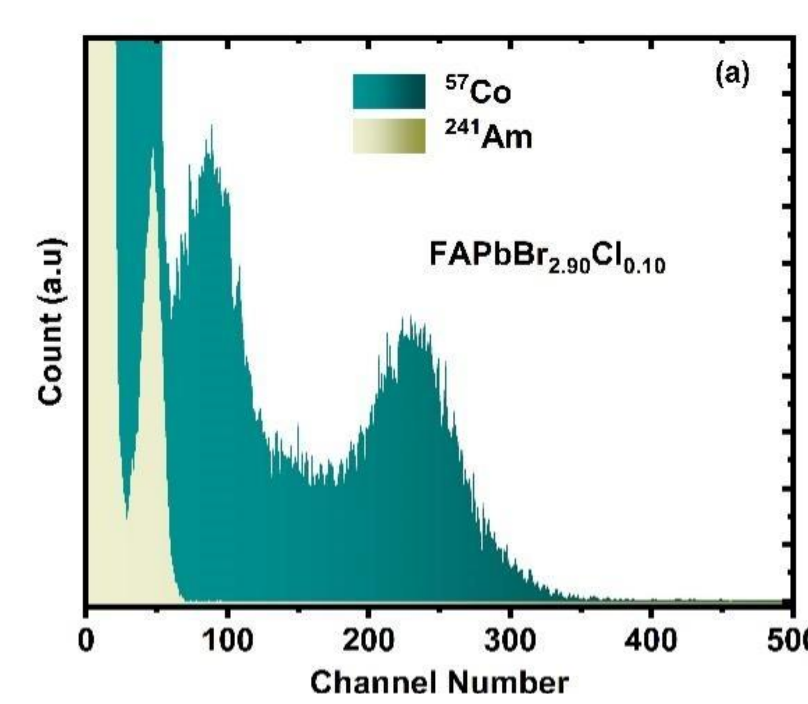


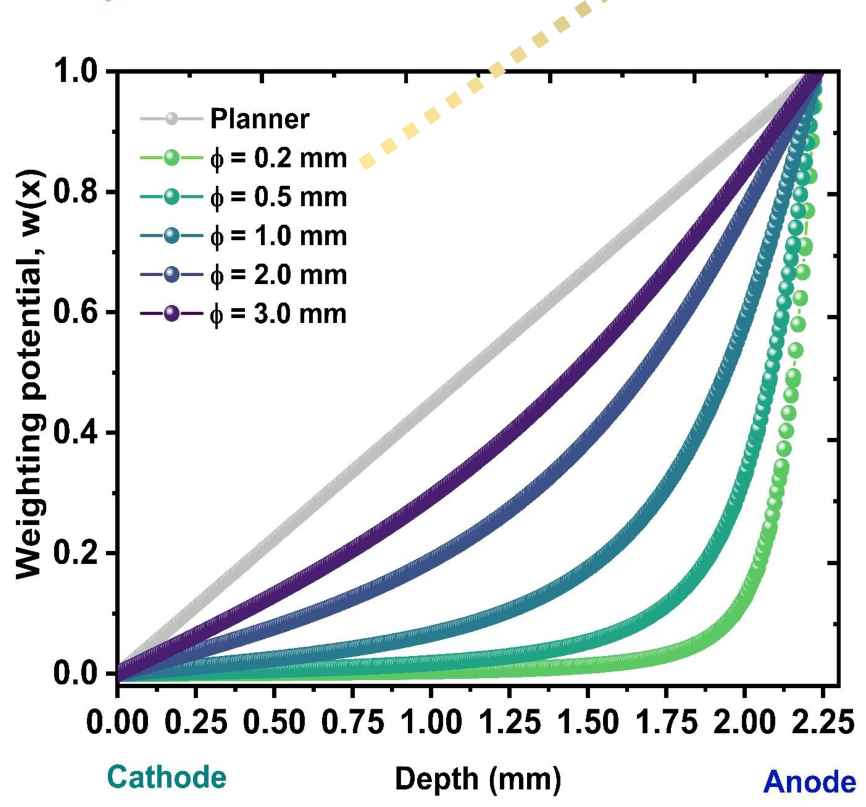
Characterization and Detector Performance

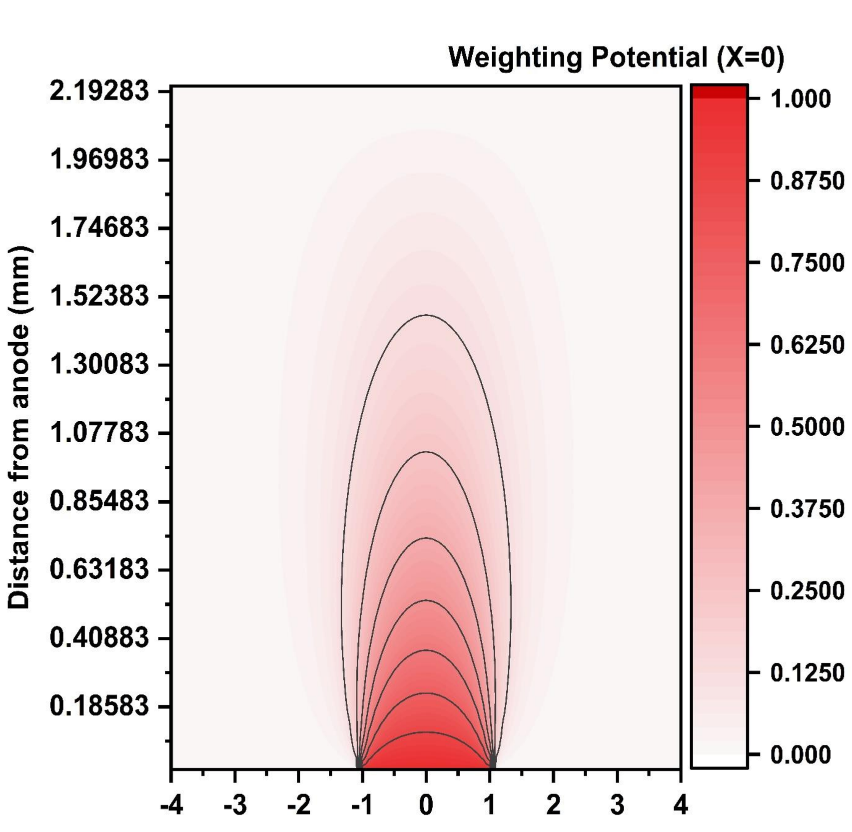




The I-V curves show that, compared to Au electrodes, carbon electrodes exhibit extremely low dark current while maintaining good diode characteristics. The Cl doped detector can resolve gamma-ray energy spectra even under high bias voltages, demonstrating an energy resolution of 32% for ^{57}Co source.

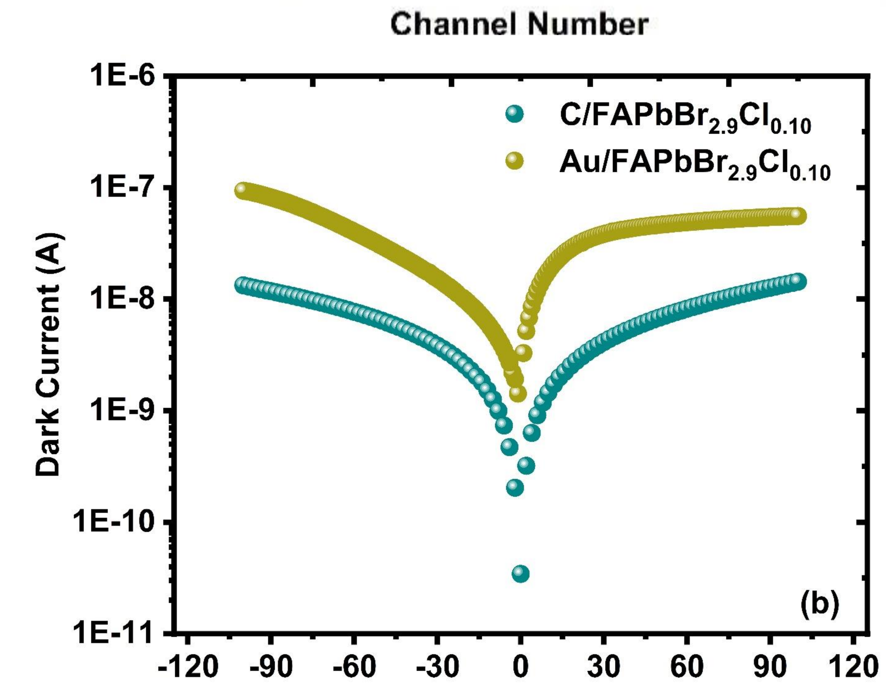






The measured signal is not the charge that reaches the electrode, but the charge induced on it while carriers are still drifting.

By the Shockley–Ramo theorem, weighting potential φ_w is obtained by setting the collecting electrode to unit potential, grounding all others, and removing every space charge. It is a purely geometric quantity: it depends on electrode shape and placement, not on the applied field.



The weighting potential along the central axis of a 2.3 mm thick $FAPbBr_{3-x}$ detector were calculated for circular electrode of diameter Φ = 0.20, 0.50, 1.0,2.0 and 3.0 mm where the gray line shows the planar case, for which φ_w increases linearly from the cathode (x = 0) to the collecting anode (x = 2.3 mm). Reducing the contact diameter progressively suppresses φ_w throughout the detector volume: for Φ = 0.20 mm it remains below 0.05 over the first 1.88 mm, corresponding to 87% of the thickness.