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COMMENT

Dynamic repair regulation: a new paradigm for sensitive and stable perovskite radiation detection

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The detection of high-energy radiations, such as X-rays, electrons and protons exceeding 1 MeV, is critical for radiation therapy, astrophysics, nuclear safety and space exploration. Over the past decades, however, a trade-off has made between the high sensitivity and long-term radiation stability. For instance, ionization chambers exhibit excellent stability but suffer from intrinsically low sensitivity, whereas solid-state semiconductor detectors provide high sensitivity yet are vulnerable to radiation damage. In a recent breakthrough published in *Nature Photonics*, Yin et al. invented a paradigm-shifting strategy (**lattice-anchoring-enhanced dynamic repair**) to fabricate sensitive and stable perovskite radiation detectors [1]. By rationally engineering the $FA_{0.9}Cs_{0.1}PbBr_3$ single crystals, the authors demonstrated record-high sensitivity together with unprecedented radiation hardness under 6 MeV X-ray and 1.2 MeV electron irradiation. This commentary highlights the key innovation of dynamic repair regulation, its significance for next-generation dosimetry, and its transformative potential across multidisciplinary applications.

Unlocking the sensitivity–stability trade-off in perovskite radiation detection: the dynamic repair regulation

For years, extensive efforts have been devoted to improving the radiation hardness of semiconductor detectors by strengthening their chemical bonds. Unfortunately, such approach eventually failed because even the toughest bonds (3−10 eV) cannot withstand MeV-level recoil energies [2]. Recently, Yin et al. discovered a new radiation hardness mechanism by taking advantage of the self-healing capability of hybrid perovskites (Fig. 1a) [3,4]. The key innovation lies in A-site alloying with inorganic Cs^+ acting as lattice "anchors". In particular, organic FA^+ cations could be displaced under irradiation, but the Cs^+ ions stabilize the perovskite framework and prevent structural collapse. Meanwhile, ionizing energy loss (IEL) generates localized thermal energy through strong electron-phonon coupling, enabling displaced FA^+ to diffuse back to their lattice sites (Fig. 1b). *In situ* TEM directly visualized such process: $FA_{0.9}Cs_{0.1}PbBr_3$ maintains lattice integrity even after prolonged electron irradiation, while pure $FAPbBr_3$ irreversibly decomposes into metallic Pb. As a consequence, this innovative mechanism transforms perovskites from fragile materials into resilient radiation transducers, significantly enhancing the sensitivity and long-term radiation stability.

High-performance detector prototypes: toward precise radiation therapy

High-quality, homogeneous A-site alloyed single crystals were synthesized by identifying a mixed-solvent system that equalized the migration barriers of Cs^+ and FA^+ and enabled simultaneous and uniform incorporation of both cations into the crystal lattice (Fig. 1c). Clinical radiotherapy validations of the $FA_{0.9}Cs_{0.1}PbBr_3$ detector prototype (Fig. 1d) showed extraordinary volume sensitivity, which is orders of magnitude higher than that of commercial diamond detectors and ionization chambers. The dark current and sensitivity remained nearly unchanged even after exposure to high fluence MeV X-ray and electron beams, clearly demonstrating the signature of radiation-induced self-repair. Moreover, the detector successfully withstood ultrahigh dose-rate FLASH irradiation without exhibiting polarization and signal loss, thereby addressing a critical unmet need in modern FLASH radiotherapy [5]. These compelling outcome strongly suggest that dynamic-repair-

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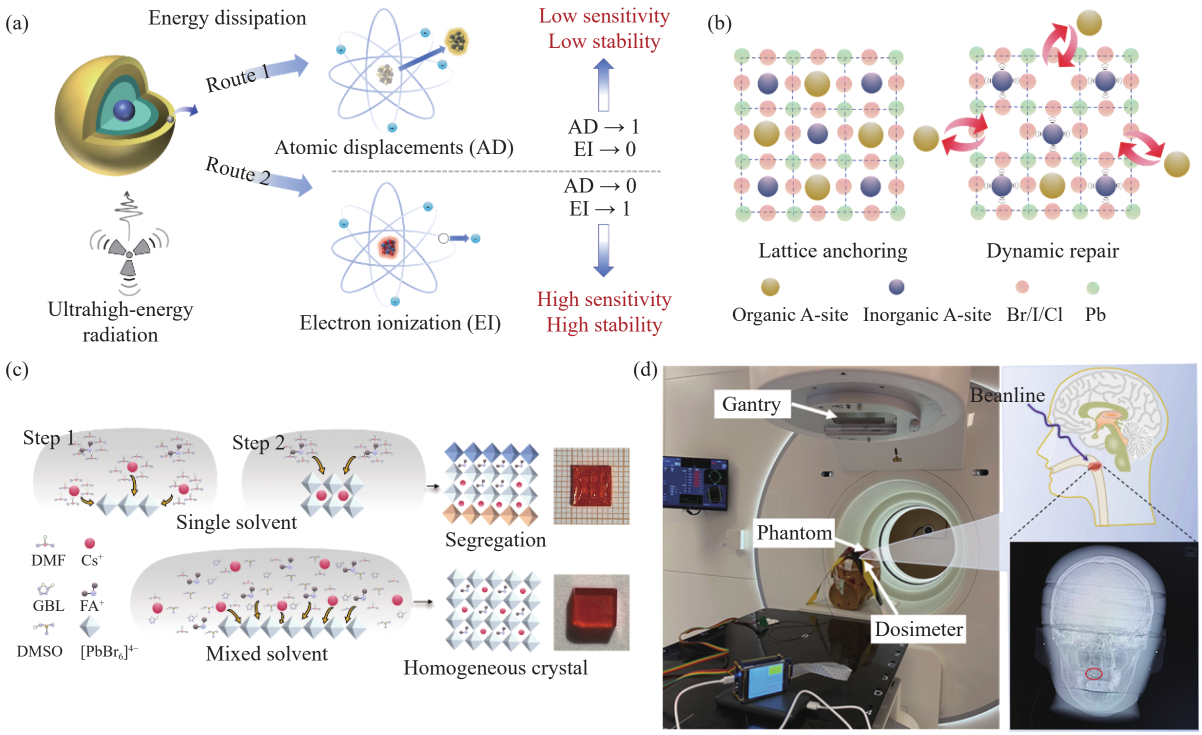

Fig. 1 (a) Energy dissipation route for ultrahigh-energy radiations interacting with matter. (b) Design concept of lattice anchoring-enhanced dynamic repair in organic–inorganic hybrid perovskites. (c) Schematic illustration of growth process for $FA_xCs_{1-x}PbBr_3$ single crystal. (d) Application of dosimeter in monitoring the dose in phantom. From Ref. [1].

based detectors hold great promise for future precise radiotherapy.

Beyond medical physics: broader multidisciplinary applications

In addition, this dynamic repair strategy has also been demonstrated in iodide-based perovskite systems, such as $FA_{0.9}MA_{0.05}Cs_{0.05}PbI_3$, as well as in polycrystalline films and nanocrystals, thus offering new opportunities for radiation-hardened space photovoltaics, nuclear reactor monitors, and electronics for high-energy physics experiments. Future efforts should focus on extending the concept of dynamic repair kinetics to other soft lattice materials and scaling up the production of A-site alloyed crystals for commercial detector arrays. Moreover, the capability to achieve ultralow noise-equivalent dose (NED) detection at the pGy level further suggests exciting potential for single-photon-counting radiation detections.

Conclusion

In summary, Yin and her colleagues unveiled a dynamic repair regulation mechanism in hybrid perovskite detectors to simultaneously achieve record-high sensitivity and exceptional radiation hardness under high-energy X-ray and electron irradiation. This extraordinary research not only establishes a new paradigm for perovskite radiation detection, but also initiates a transformative material design philosophy for a broad range of applications where superior sensitivity and long-term radiation hardness are fundamentally vital.

Author contribution The author read and approved the final manuscript.

Declarations

Competing interests The author declare that he has no competing interests.

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