A review of lead leakage monitoring in perovskite solar cells: emerging detection technologies, just transition to clean energy and perspectives

Lead-based perovskite solar cells (LPSCs) offer promise for low-cost, highly efficient alternatives to current solar energy technologies, with the potential for scale-up production and high-throughput coating. However, lead leakage, which is considered a health hazard, instability due to moisture intrusion into the perovskite core, and degradation challenges remain unresolved. Without reliable monitoring and mitigation strategies, the scalability of LPSCs raises regulatory and environmental problems. Currently, systematic detection and quantification of lead (Pb) leakage are scarcely developed. Therefore, there is urgent need for real-time monitoring systems for better Pb leakage detection and monitoring to ensure public and environmental health protection. Accordingly, leakage of Pb into the environment has far-reaching etiological risks to animal and plant health. For instance, the bioaccumulation of Pb in the human body can exacerbate the development of cardiovascular diseases and damage to the central nervous system. This study provides a detailed overview of the approaches used to monitor leakage in perovskite solar cells (PSCs), closing the loop in Pb recycling, and the outlook for perovskite recycling. Here, we analyse Pb leakage monitoring and prevention approaches undertaken in recent years by reviewing scholarly databases. This study also explores the latest and emerging detection technologies, such as spectroscopic methods, electrochemical sensors, fluorescence assays, and *in situ* monitoring techniques. Just transition toward green energy access together with environmental sustainability has been explored in the event that LPSCs are ultimately deployed and commercialised. Further, the potential of artificial intelligence (AI) systems has been reviewed to understand leakage events associated with the degradation of LPSCs. To this end, this review not only provides up-to-date state-of-the-art research and developments in perovskite research but also provides insights into suitable Pb leakage monitoring and prevention strategies toward mechanically stable and environmentally sustainable LPSCs.