2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

Dosimetric Response Characterization of a Newly Developed Self-Powered Halide Perovskite Detector Under Proton Irradiation

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ABSTRACT

This study evaluated a self-powered $CsPbBr_3$ perovskite detector for clinical proton beam. The prototype demonstrated stable baseline performance, linear response to delivered dose and monitor units, and sufficient temporal resolution to reproduce the pulsed structure of a synchrocyclotron beam, including a measured 1.35-ms pulse interval. Signals showed strong agreement with treatment-delivery log files. These preliminary results support continued development of perovskite-based detectors for near-real-time, two-dimensional dosimetry and radiation oncology quality assurance.

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Purpose

Halide perovskites, particularly $CsPbBr_3$, are promising materials for radiation dosimetry because of their high atomic number, rapid charge transportation, solution processability, and exceptional radiation tolerance.

While perovskite detectors have demonstrated strong performance in low-energy X-ray detection (<100 keV), their application to high-energy proton dosimetry remains largely unexplored. This study seeks to establish perovskite-based detectors as a transformative platform for real-time, high-resolution dosimetry in clinical settings.

METHODS AND MATERIALS

A 0.3-mm-thick $CsPbBr_3$ perovskite film was deposited onto an indium tin oxide (ITO) substrate with Ni electrodes to fabricate a prototype detector. Detector performance was verified using the 75-kVp onboard X-ray imaging system prior to proton irradiation.

Proton irradiations were performed with a Mevion HYPERSCAN S250i system. Charges induced by the radiation were collected and amplified using a preamplifier, and the resulting signal was recorded and displayed by an oscilloscope.

Dose-response characteristics were evaluated across multiple monitor-unit settings and proton energies. The temporal resolution was assessed using the intrinsic pulse structure of the proton beam.

RESULTS

The detector demonstrated sufficient temporal resolution to track the proton beam delivery structure. As the delivered dose increased from 1 to 50 cGy, a corresponding increase in the number of detected pulses was clearly resolved, consistent with the pulsed output of the synchrocyclotron.

The $CsPbBr_3$ detector successfully resolved a pulse interval of 1.35 ms. The detector response exhibited strong linearity with delivered monitor units and dose, with a coefficient of determination (R^2) of 0.97.

Figure 1. Experimental setup for proton irradiation. A single-spot proton beam from the Mevion HYPERSCAN S250i system was used to irradiate the detector. Before the experiment, the surface dose at the detector position was independently calculated using the treatment planning system (TPS) and Monte Carlo (MC) simulations.

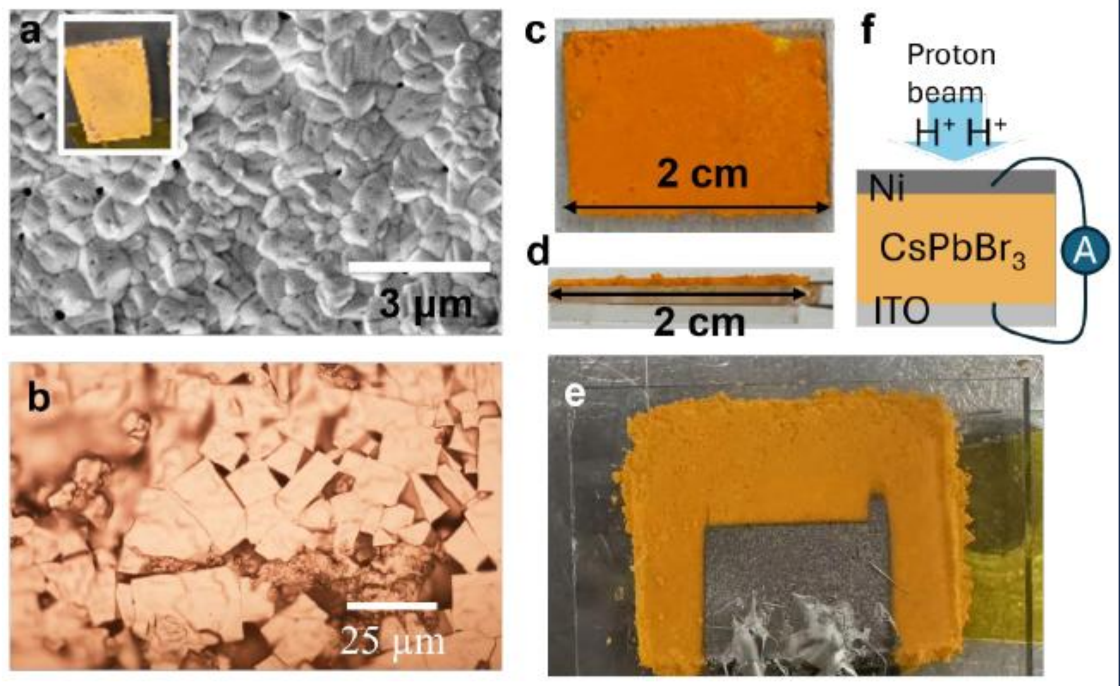

Figure 2. Morphology, fabrication, and configuration of the $CsPbBr_3$ detector. (a) SEM image of an approximately 100-mm-thick perovskite film. (b) Optical image of a millimeter-thick film showing large crystalline domains. (c-d) Photographs of thick-film samples used for preliminary testing. (e) Photograph of the first prototype device incorporating a 0.3-mm-thick perovskite film. (f) Schematic of the asymmetric device architecture used for direct measurement of radiation-induced current during proton irradiation.

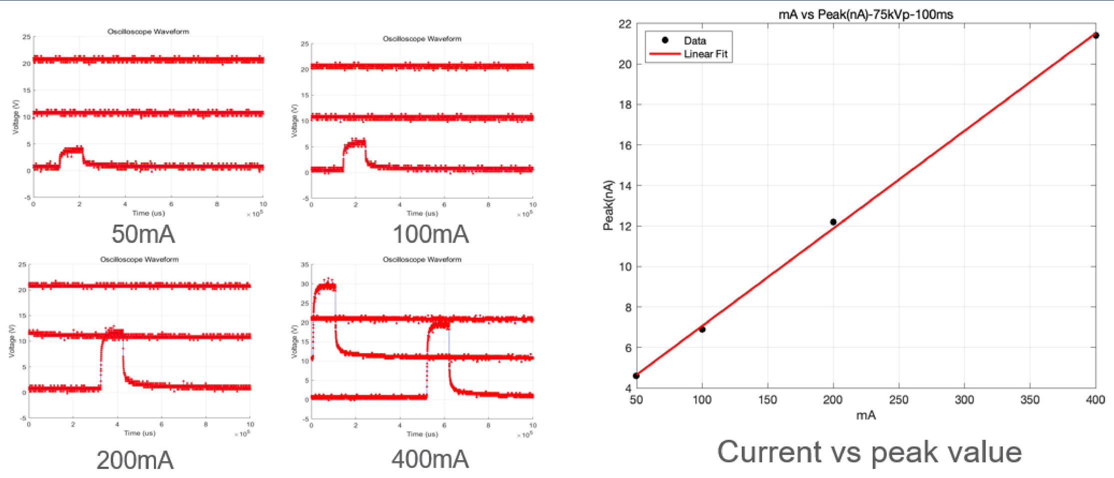

Figure 3. Preliminary evaluation of the prototype detector using the 75-kVp onboard X-ray imaging source. The X-ray irradiation was used to verify device integrity and signal-collection performance before proton measurements. The perovskite detector exhibited a strong linear response to delivered dose under low-energy photon irradiation.

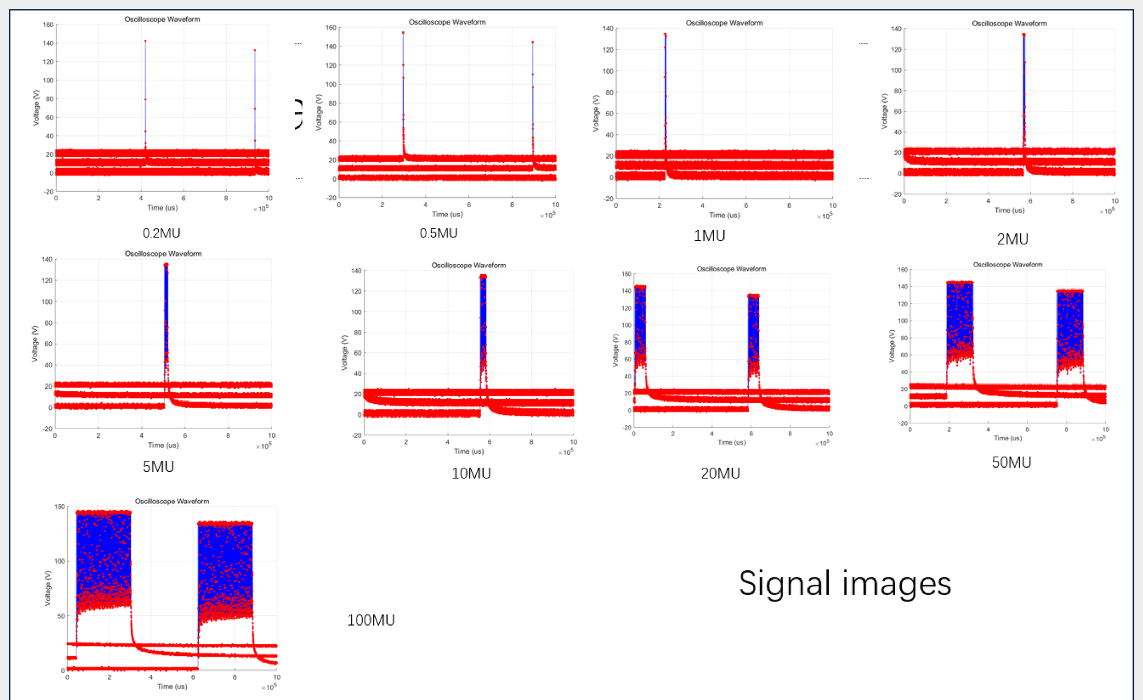

Figure 4. Representative raw current signals recorded from the perovskite detector during proton irradiation over a range of 0.2–100 monitor units (MU).

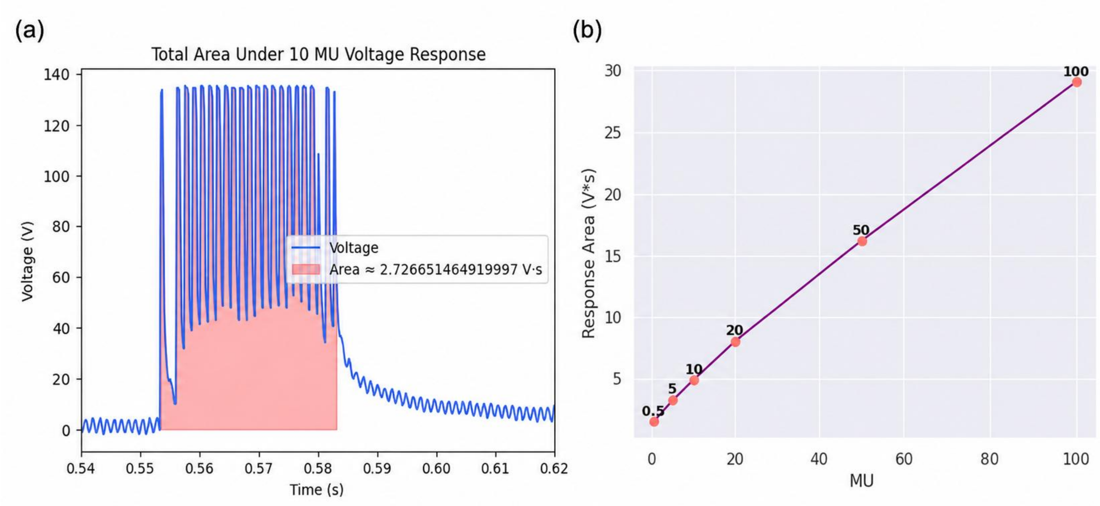

Figure 5. Proton-beam response of the $CsPbBr_3$ detector.
(a) Representative current signal recorded during irradiation with a 10-MU, single-spot proton beam at the maximum energy of 235 MeV. (b) Detector response as a function of delivered monitor units, demonstrating strong linearity over the range of 0.2–100 MU.

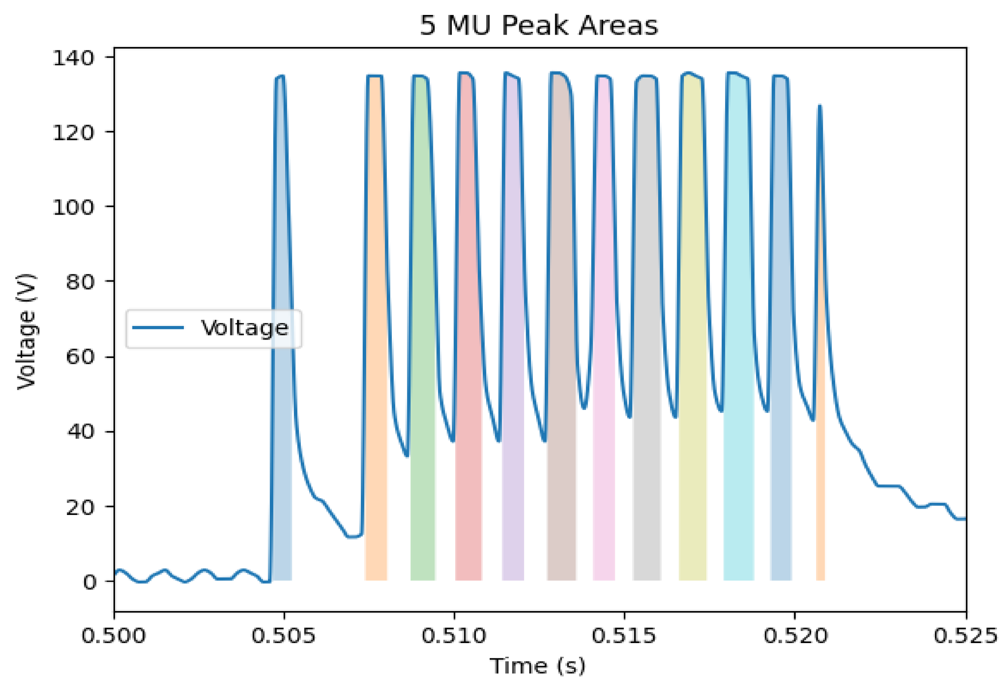

Figure 6. Comparison of the detector-measured pulse structure with the Mevion proton system log file. The measured signal showed strong agreement with the logged beam-pulse timing, and the $CsPbBr_3$ detector successfully resolved the 1.35-ms pulse interval.

DISCUSSION

This study evaluated the dosimetric performance of a prototype $CsPbBr_3$ perovskite detector under clinically relevant kV X-ray and proton irradiation. The detector exhibited a linear response to delivered monitor units (MU) and successfully resolved the pulsed structure of the synchrocyclotron beam. Detector-measured pulses were temporally consistent with the Mevion treatment-delivery log files across proton energies ranging from 51 to 235 MeV, including resolution of the 1.35-ms inter-pulse interval.

At higher proton energies, the detector exhibited voltage-response saturation. One working hypothesis is that the limited active-layer thickness restricts the linear charge-collection range at high signal levels. Further characterization is therefore needed to determine the underlying mechanism and establish the detector's usable dose, dose rate, and energy ranges.

Future work will evaluate reproducibility, radiation tolerance, long-term signal stability, and sensitivity to environmental conditions. Comprehensive characterization across radiation modalities, energies, dose rates, and accumulated doses will support the development of a two-dimensional, self-powered perovskite dosimeter with near-real-time readout for radiation oncology quality assurance.

CONCLUSIONS

The initial $CsPbBr_3$ prototype demonstrated stable dark-current behavior, a measurable self-powered response under clinical proton irradiation, linearity with delivered MU, and sufficient temporal performance to resolve the proton-beam pulse structure. These preliminary findings support continued development of lead halide perovskite detectors as a potential platform for near-real-time radiation dosimetry and clinical quality assurance.

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