Novel Perovskite X-ray/Gamma Detectors and Potential Applications

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Introduction

Perovskite materials have seen a surge of interest after recent developments in the realm of photovoltaics[1]. Compared with previous materials their photo-electronic conversion efficiency has risen remarkably quickly relative to their competitors. This is due in no small part to their high μτ product[2], a major figure of merit in the field of solar cell research, μ relating to the free charge carrier mobility within the material and τ to the median lifetime of such charge carriers, the combination of which leads to high charge collection efficiency. A high μτ product is not just assistive to materials used for solar conversion, but of all photodetecting materials. Twinned with the revelation that these perovskite materials are primarily composed of heavy elements, Lead along with Bromine and Caesium, we have the design for an ideal X and gamma ray detector[2]. When compared with current X-ray detectors, Silicon, α-Se, CdTe, Gadolinium Oxysulphide, these perovskite materials, particularly $CsPbBr_3$ and $CsPbI_3$, offer a strong competitive edge from this higher internal efficiency for absorbing photons and converting them to extractable free charge carriers.

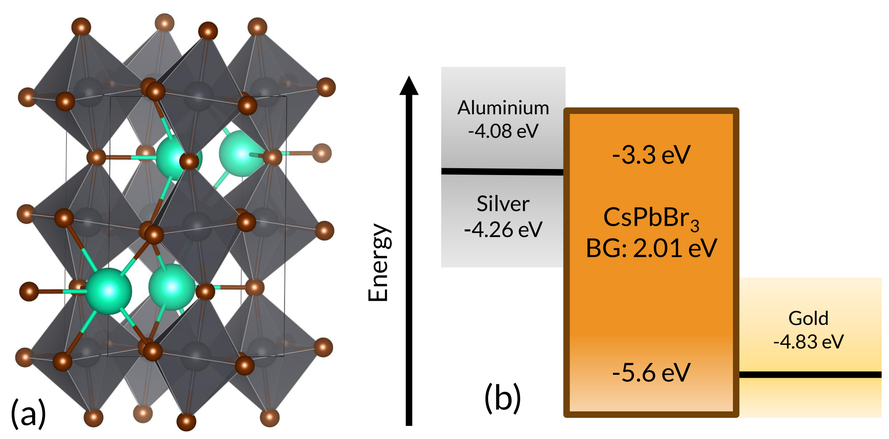

Fig 1. a) $CsPbBr_3$ Perovskite lattice structure
b) Band structure of the electrode interface between Au-$CsPbBr_3$-Al/Ag

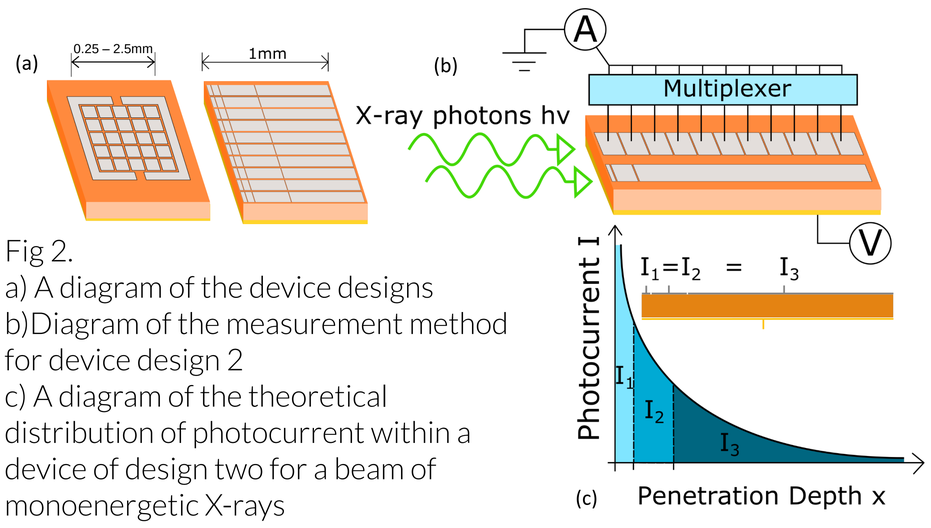

Fig 2.
a) A diagram of the device designs
b)Diagram of the measurement method for device design 2
c) A diagram of the theoretical distribution of photocurrent within a device of design two for a beam of monoenergetic X-rays

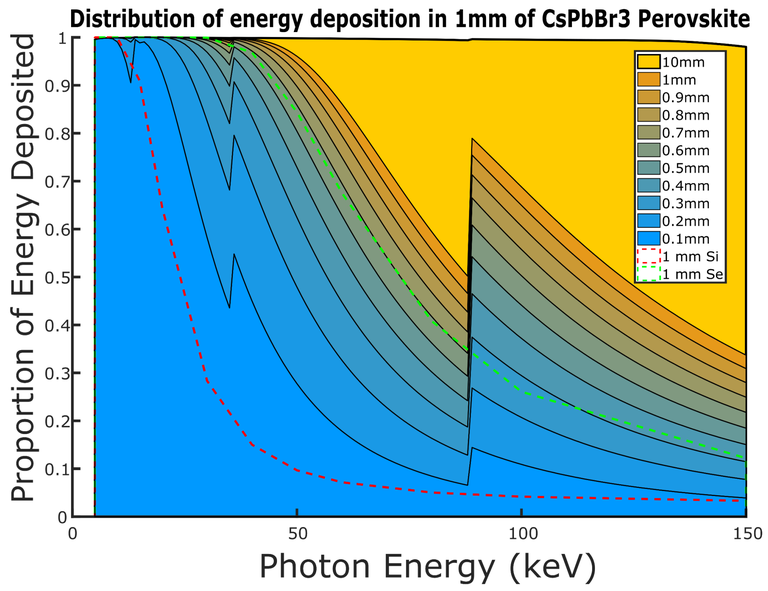

Fig 3. A graph from GEANT4 simulations comparing the attenuation efficiency of multiple thicknesses of $CsPbBr_3$ for X-ray energies from 5 to 150 keV, with Silicon and Selenium included for comparison

Aims

The aim of this research project is to explore the capabilities of $CsPbBr_3/I_3$ as an X-ray detecting material and to consider the possible applications. A combination of device construction/testing and monte carlo simulation is needed to understand their full potential.

The detector designs being explored are of two types, shown in Fig 2. a): 2D pixel arrays of varying pitch, from 50 μm to 500 μm and a 1D pixel distribution of either equal or varying pitch. 2D pixel arrays are a well established means for spatially imaging an orthogonal beam of photons and the performance of such arrays in $CsPbBr_3$ must be tested, through which it's application to the most common uses of X-ray imaging can be determined.

The second design, of 1D pixels is more experimental, where the focus is to extract the photoexcited charge carriers to electrodes that are placed at set distances along the path of the incoming photons. The intention is for photons to enter the detective area of the material from a lateral direction. The pixel distances are placed to correspond with depths within the perovskite that the photon is absorbed, which can function as an indirect measure of the energy of the photon, as higher energy photons will travel further before complete absorption. Another advantage to this design is that the only dictated dimension is the attenuation length of the material, which is approximately 1mm for most energies below 100 keV as shown in Fig 3, leaving the thickness of material and width of electrodes to be optimised for efficiency or resolution.

These designs have yet to be produced in the lab, but we have carried out preliminary studies to test the methodology as it is set up.

Results

Figure 4 shows an array of results from preliminary tests carried out on samples of multiple manufacture methods. The most promising result is shown in Fig.4a) where at maximum X-ray exposure we observed a I_{ON}/I_{OFF} ratio of 86.2, and 1.6 at minimum X-ray exposure, with a dark current of 0.7 nA at 5V bias. This sample was produced from crushing the ground crystal powder together into a 10mm pellet and deposition of silver contacts. Fig.4b) shows the responses of a single crystal based device. This single crystal was produced by furnace heating and gradual cooling to form the lattice structure. The dark current here is much greater, but this device was not set up with any charge blocking layers, so this could easily be reduced for the next batch of samples. Fig.4c) shows the response of a 1mm thick crushed powder sample, through a bias sweep. The response here is only about 4 nA. Fig.4d) shows a much greater response from the same sample after being soldered into the circuit.

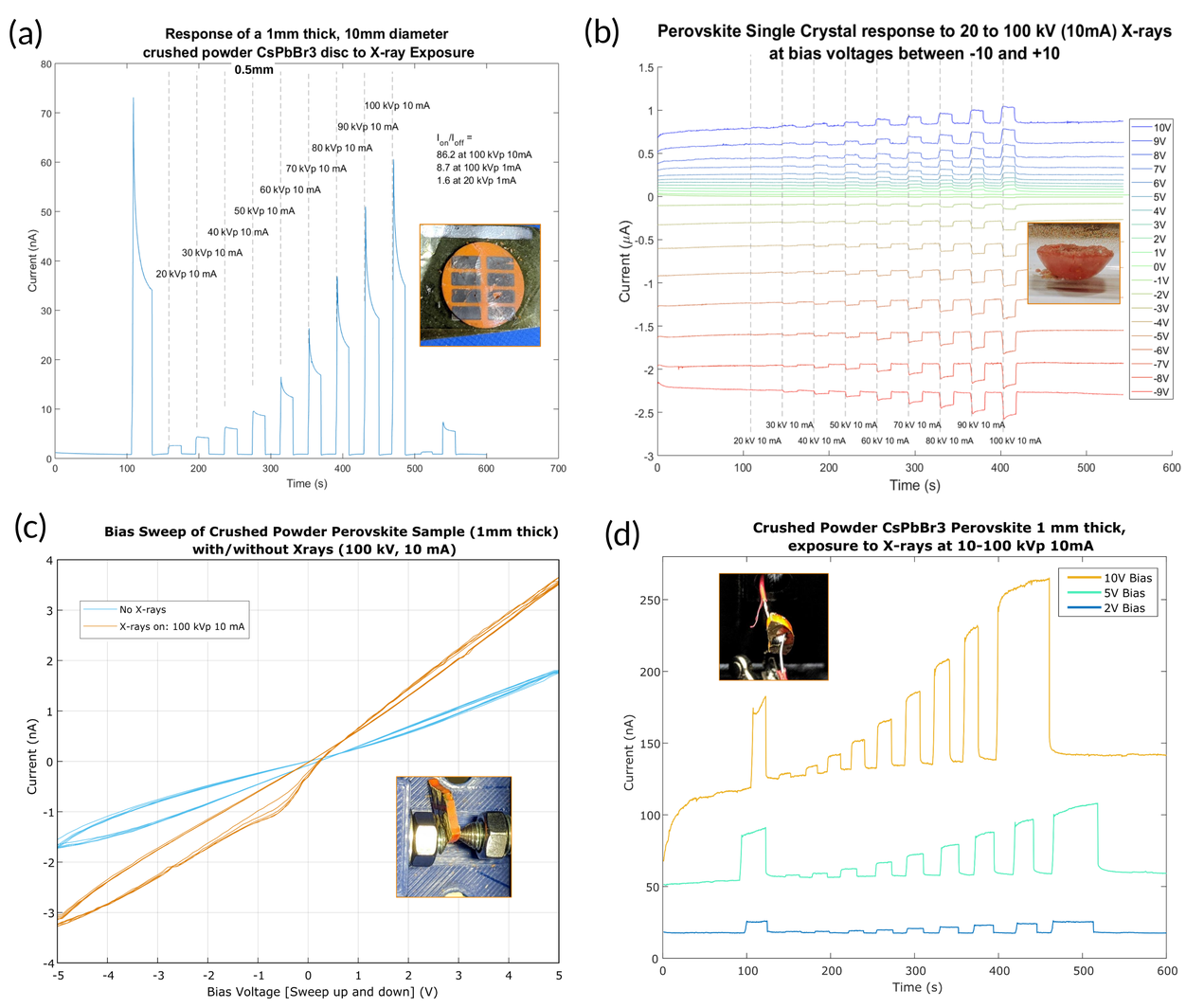

Fig 4. Direct X-ray exposure response of 3 $CsPbBr_3$ samples with inset images of each sample
a) 500 μm thick sample featuring a maximum I_{ON}/I_{OFF} ratio of 86
b) 5 mm single crystal biased at -9 to +10V, produced from a furnace melt
c) Bias voltage sweep from -5 to +5 V for a 1mm thick sample
d) 1mm sample from c) soldered for a more direct connection

Conclusions

The simulations in combination with these preliminary results indicate that these device designs are promising and once produced could offer unique applications for security and medical science. Further development could involve Boron-10 being incorporated into the material to detect neutrons simultaneously with X/γ-rays.

[1.] Wang, R. *et al.* A Review of Perovskites Solar Cell Stability. *Advanced Functional Materials* **0**, 1808843
[2.] He, Y. *et al.* Resolving the Energy of γ-Ray Photons with MAPbI3 Single Crystals. *ACS Photonics* **5**, 4132–4138 (2018).