CONVERTING FILMS FOR X-RAY DETECTORS, APPLIED TO AMORPHOUS SILICON ARRAYS.

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ABSTRACT

This paper presents results from our on-going efforts to characterize semiconductor thin films for direct x-ray conversion. We deposit these thin films on to an amorphous silicon (a-Si:H) readout array with the overall goal of developing a large area x-ray detector for protein crystallography, and for other x-ray imaging fields.

INTRODUCTION

There are a number of applications for large area x-ray detectors. For the purposes of this work we have concentrated on developing large area x-ray detectors for protein crystallography, and applying such detectors at x-ray synchrotron beam lines. Protein diffraction studies are carried out to determine the three dimensional structure of a protein molecule. Because of the need of high atomic resolution of large crystal unit cells, there is a requirement that the detector be highly sensitive to 8 - 20 keV x-rays, physically large (tens of centimeters on a side) with high dynamic range (14 bits and up) with minimal image lag from one frame to the next (a few seconds).

We present in this paper results from our on-going efforts [1] to characterize semiconductor thin films for direct x-ray conversion, and the readout of the generated signal charge by an array of amorphous silicon field effect transistors (FET's). While we have investigated several candidate thin films, we have concentrated our efforts on lead iodide (PbI_2). This material seems to have low leakage current and high x-ray sensitivity. We have measured the characteristics of this material both as a thin film deposited on test substrates (indium-tin-oxide covered glass), and as an x-ray converter deposited onto an amorphous silicon readout array.

EXPERIMENT and RESULTS.

All of the lead iodide films discussed in this paper were deposited by Radiation Monitoring Devices, Inc. of Watertown MA, as part of our on-going collaboration [2]. The amorphous silicon readout array was provided as a "sample" by Xerox, Palo Alto Research Center. Thin film and X-ray characterizations were performed at our electronics test facility, at the Argonne Structural Biology center's rotating anode laboratory, and at their synchrotron beamline at Argonne's Advanced Photon Source (APS).

Lead iodide has a theoretical band gap of 2.3 eV, an electrical permittivity of 21. It has a theoretical stopping power of 310 cm^{-1} for 20 keV x-rays, and 1600 cm^{-1} for 8 keV x-rays. We measured the leakage current of a lead iodide thin film as a function of bias voltage, at various temperatures. (FIG 1). The film behaves in an ohmic fashion, and is

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hence is used in a photo-conductive mode. We compute then that for a typical pixel area of 127 x 127 microns, we would have 20K dark current electrons per second, at -40 C, and 20 volts bias -- a minute fraction of the theoretical full well. Fitting conductivity data to an expression for conductivity

$$(eq\ 1) \sigma = \sigma_0 * \exp(-E_a/KT)$$

we compute a activation energy E_a of 0.68 eV.

We measured the sensitivity of these films to 8 keV x-ray photons using a rotating anode source. We compared the signal current generated by such x-rays photons to the photon flux measured by a scintillator plus photomultiplier tube (PMT), and multi-channel analyzer (MCA) to integrate the spectrum. We estimate that 1200 +/- 400 electron hole pairs were created per 8 keV x-ray photon, with a bias of greater than 20 volts on the 85 micron thick PbI₂ film. We have begun studies of the time response behavior of this film by pulsing bright visible light or x-rays and noting the time decay of signal. While first results are encouraging (a time decay of 4 orders of magnitude of signal resulting from a pulse of light less than 10's of milliseconds), we plan to do additional circuit tests to properly construct an "equivalent circuit".

We made a preliminary measurements of the effectiveness of a lead iodide coating on an amorphous silicon readout array. (FIG 2 -- photo) The array consisted of 256 x 256 readout FET's on a 127 micron pitch. Xerox PARC has estimated that this array had a storage capacitance of about 2-3 pF, and that the ON resistance of the a-Si:H TFT was several megohms. Xerox has begun characterization another copy of this array for applications to medical imaging. [3].

We show that relative signal increases with lead iodide bias (FIG 3), and that the integrated signal increases with x-ray exposure time (FIG 4). The initial non-linearity of this latter curve is believed to be a function of our readout electronics which were developed for an earlier a-Si:H array. We are currently repeating our sensitivity measurement relative to the PMT/MCA standard. The detected signal on the array saturates within 10 seconds or so when illuminated with an expanded rotating anode x-ray beam.

CONCLUSIONS

There are a number of measurements remaining before we can conclude that the combination of a lead iodide x-ray conversion layer and an amorphous silicon readout electronic structure will produce a high quality detector for protein crystallography. However initial results have been encouraging. The leakage current of the film with high bias is low, especially at modestly low temperatures. At such a bias, the dynamic range of the amorphous silicon FET should be high. Our first attempt at combining these technologies produced a system capable of taking imaging, and is providing us with a first look at overall sensitivity.

ACKNOWLEDGEMENTS.

This work has been supported by a National Institute of Health Contract 1 R01 GM51488-01A1.

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Fig. 1. Bias current density through a $85\text{ }\mu\text{m}$ thick lead iodide sample as a function of bias voltage, for several temperatures.

FIG 2
Amorphous Silicon Array,
Coated with PbI_2 film

FIG 3

X-ray
Response
vs
bias

FIG 4

X-ray
Response
vs
time