Title
Amorphous Silicon Based Radiation Detectors

Authors
Perez-Mendez, V.
Cho, G.
Drewery, J.
et al.

Publication Date
1991-07-01

LBL-30940

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

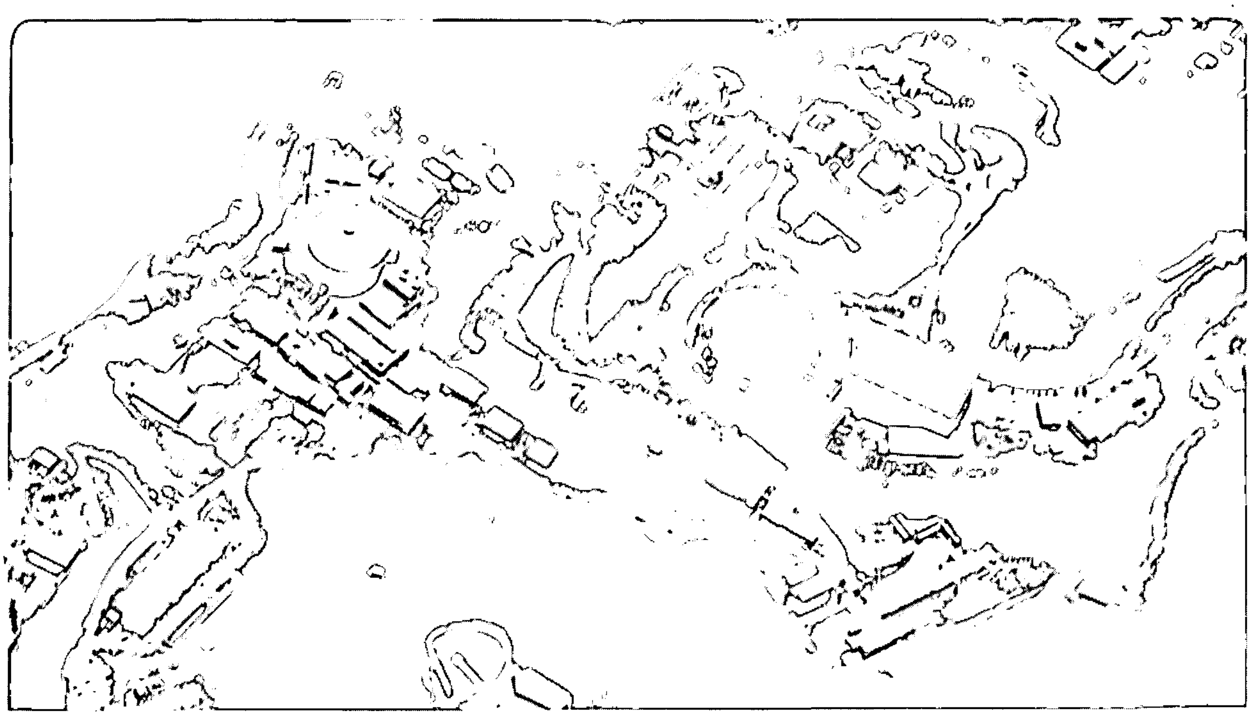
Physics Division

To be presented at the ICAS-14 Conference,
Garmisch-Partenkirchen, Germany,
August 19–23, 1991, and to be
published in the Proceedings

Amorphous Silicon Based Radiation Detectors

V. Perez-Mendez, G. Cho, J. Drewery, T. Jing,
S.N. Kaplan, S. Qureshi, and D. Wildermuth

July 1991



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

DISCLAIMER

AMORPHOUS SILICON BASED RADIATION DETECTORS

V. PEREZ-MENDEZ, G. CHO, J. DREWERY, T. JING, S. N. KAPLAN, S. QURESHI, D. WILDERMUTH

Lawrence Berkeley Lab, University of California, Berkeley, CA 94720

I. FUJIEDA, R. A. STREET

Xerox Parc, Palo Alto, CA 94304

We describe the characteristics of thin(1μm) and thick (>30μm) hydrogenated amorphous silicon p-i-n diodes which are optimized for detecting and recording the spatial distribution of charged particles, x-rays and γ rays. For x-ray, γ ray, and charged particle detection we can use thin p-i-n photosensitive diode arrays coupled to evaporated layers of suitable scintillators. For direct detection of charged particles with high resistance to radiation damage, we use the thick p-i-n diode arrays.

1. INTRODUCTION

Thin layers of hydrogenated amorphous silicon (a-Si:H) with thickness 0.5-2 μm have found extensive application in solar cells and in thin film transistors (TFT). A well known application of thick > 30 μm layers of a-Si:H is to electrophotography devices. In these devices the usual configuration is that of a p-i-n diode with thin p^+ and n^+ doped layers and the bulk consisting of intrinsic a-Si:H. For radiation detection we use the same general configuration of a reverse biased p-i-n diode. In many of the applications that we propose the spatial distribution of the incident radiation is important: hence we use pixel or strip configurations with appropriately shaped metallic contacts. In some applications single particles are detected. The detector array then requires individual, low noise TFT amplifiers attached to each pixel. Other applications are to radiation flux detection: for these, simple routing electronics may be sufficient. These configurations of detector and TFT arrays are shown in Fig. 1. Charged particle detection - specifically minimum ionizing particles (MIPs) can be accomplished by use of p-i-n diodes with thick i layers in which the charged particle can produce a sufficient number of electron-hole pairs by direct interaction in the depleted i layer. An alternative scheme for MIPs detection is to use pixel/strip arrays of thin a-Si:H diode layers - which function as visible photon sensors - coupled to layers of light emitting (scintillator) material with built in light collimation, such as cesium iodide, gadolinium oxy sulfide and others. For the detection of x-rays or γ rays of energy above a few KeV, the scintillator - a-Si:H array is the only feasible choice due to the low interaction probability of the radiation with a low z element such as silicon. For detection of x-rays in x-ray crystallography applications (E_γ=8 KeV), it is also possible to use moderately thick layers of a-Si:H 90% a-Ge:H (10%) where the germanium is the high z element for the interaction process.

This work was supported by the U.S. Department of Energy under contract #DE-AC03-76SF00098.

2. DETECTION OF CHARGED PARTICLES WITH THICK P-I-N DIODES

A reverse biased diode with a thick i layer requires use of a-Si:H with a low density of dangling bonds (< 3 x 10^{15}/cm^3) for the following reasons: (a) The mean free path of electrons and holes is d=$\mu\tau E$ where μ, τ, are the mobilities and lifetimes of the electrons or holes and E = the electric field of the external bias, therefore a large value of $\mu\tau$ is desirable since $\mu\tau N_d \approx 2.5\times10^8$ (1). (b) When an external bias is applied, a fraction of the neutral dangling bonds $N_d^* \approx 0.3\ N_d$. (2) are ionized and a residual positive charge remains. This fixed charge causes the electric field in the i layer to drop linearly.with distance. Hence, in order to have a fully depleted detector, a minimum bias is needed which increases proportionately to the density of dangling bonds. The electric field peaks at the p-i interface and at high biases enhances breakdown processes for a given thickness of i layer and dangling bond density. We have (3) developed the following schemes to promote full depletion without breakdown as shown in Fig 2. (a) The p layer can be made considerably thicker, i.e., 20-30 nm which places the peak E field further away from the metal contact. (b) A buried thin ~20 nm thick p layer is deposited with a ~1μm spacing to the electrode. (c) One or more thin p layers are deposited in the middle of the i layer whose effect is to decrease the effective slope of the electric field. Schemes (a) and (b) cause little or no loss in the number of charged carriers traversing the i layer.

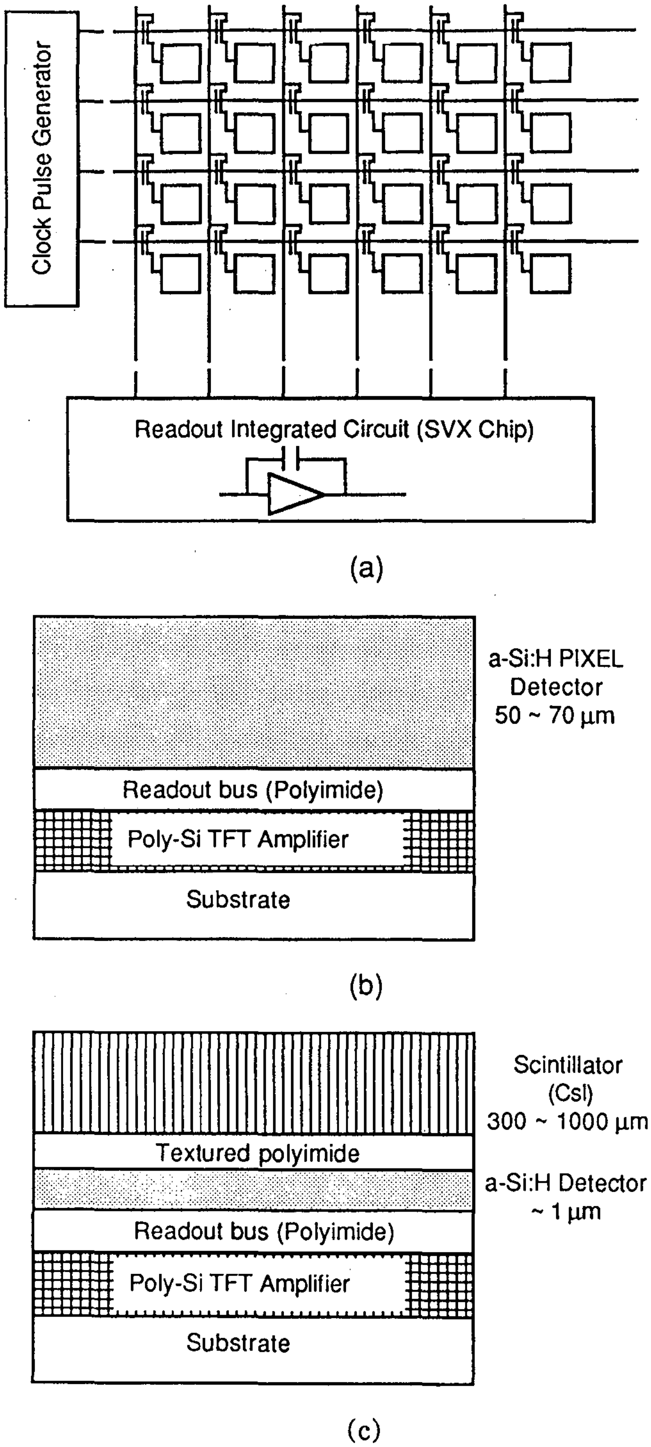


Fig. 1. Detector and TFT configurations (a) 1 TFT routing electronics (b) polysilicon amplifier coupled to thick PIXEL detector (c) polysilicon amplifier coupled to thin PIXEL detector/ scintillator

Scheme (c) causes some electron loss due to trapping because of the lower mean free path in the p layer whereas the hole loss is minimal (4). An important quantity in evaluating the interaction of charged particles with an a-Si:H p-i-n diode is W = average energy used in producing 1 e, h pair. We measured W using an 860 MeV alpha particle beam - essentially MIPs (5) and found W = 4.8± 0.3 eV. This corresponds to a production rate by MIPs of ~80 e, h pairs/μm of a-Si:H.

The noise produced in a reverse biased p-i-n detector together with that of a typical readout amplifier should be small. In Fig. 3 we show the noise in a 26 μm diode as a function of reverse bias, measured by a charge sensitive amplifier with a 1.5 μsec CR-(RC^2) shaping time. The flat portion of the noise graph, at low biases, is the sum of (a) the amplifier noise when loaded by the capacity of the detector, and a mostly resistive (Nyquist) noise generated by the contact resistance, and the p layer resistance. The noise contribution of the p layer resistance can be reduced by annealing (~ 2 hours at 150°C) under bias (6). At higher biases when the reverse current increases, the contributing shot noise - which has a flat frequency spectrum and is proportional to the current is observed. At still higher biases with larger reverse current, 1/f noise, which has the 1/f spectral response and is proportional to I^2 becomes the predominant contribution. All of these noise components are proportional to the area of a pixel detector (7).

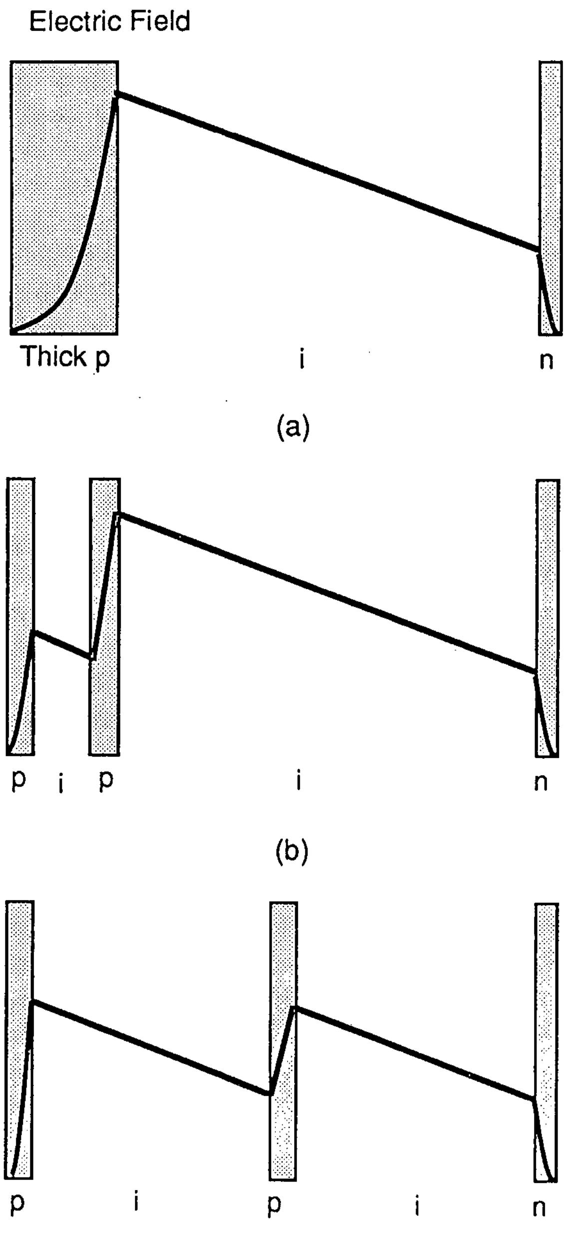


Fig. 2. Full depletion schemes (a) thick p layer (b) buried p layer (c) central p layer

The signal response as a function of shaping time can be calculated from the mobility - typically $\mu_e \sim 1\ cm^2/Vsec$, $\mu_h \sim 0.005/cm^2/Vsec$, and the E field in the i layer at a given bias. Fig. (4) shows the signal from electrons and holes for a 5 μm and a 50 μm thick detector diode. For the thick diode, fast timing can be achieved by collecting the electron signal only.

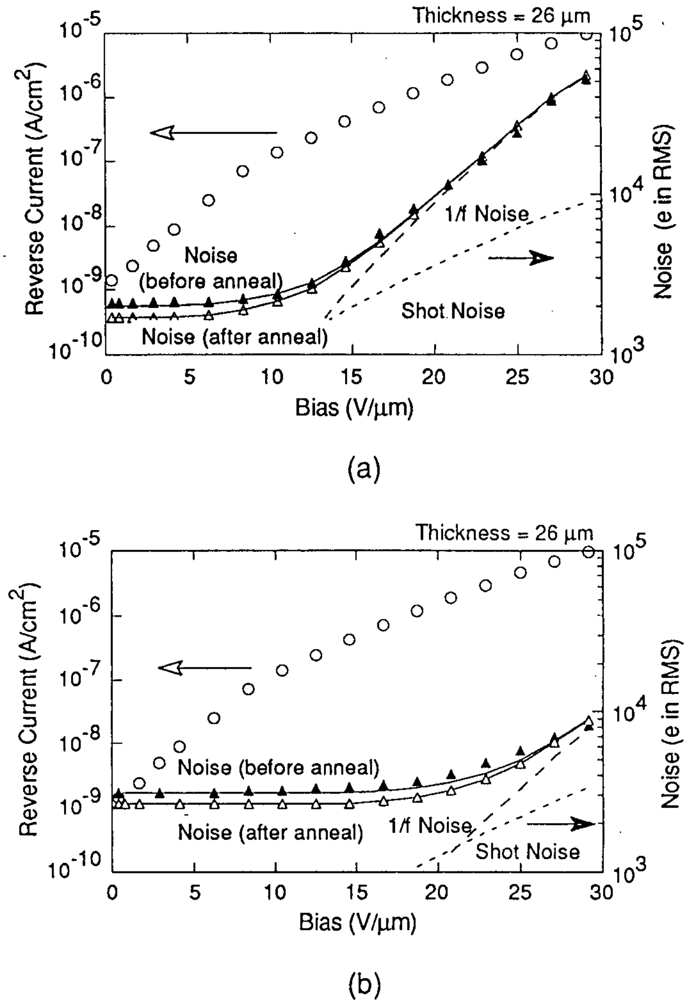
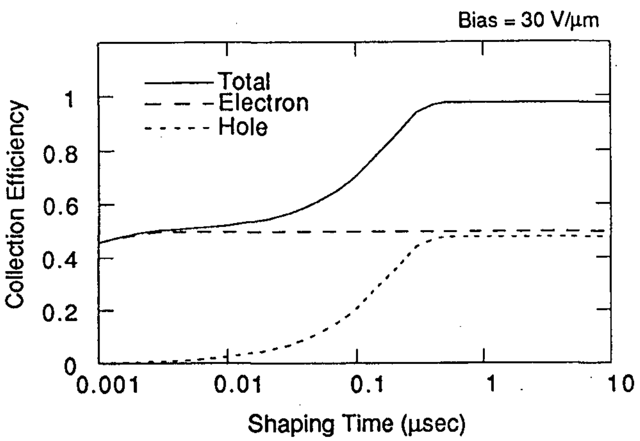


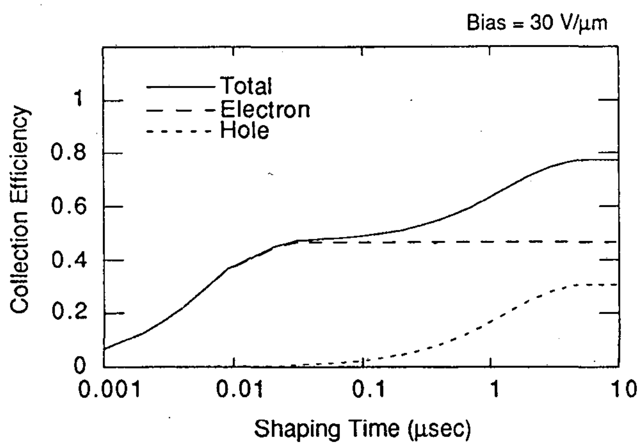
Fig. 3. Resistive, shot and 1/f noise in a-Si:H p-i-n detector (a) shaping time 2.5 μsec (b) shaping time 0.5 μsec

3. DETECTION OF RADIATION BY THIN A-SI:H DIODES COUPLED TO SCINTILLATOR LAYERS

For this case we assume that the signal is produced predominantly by the interaction of the radiation with the scintillator and that the scintillation light is then detected by the a-Si:H through a transparent ITO contact. A further requirement - if good position accuracy in a pixel or strip detector is desired - is that the scintillation light be suitably collimated. Fiber optic plates loaded with terbium or cerium scintillating material are available (8) for this purpose. We have worked primarily with evaporated layers of CsI activated with thallium or sodium. The CsI(Tl) has been measured (9) to produce ~ 50,000 visible light photons/MeV of radiation interaction - charged particles, x-rays or γ rays. The spectral response of CsI(Tl) , CsI(Na) and the response of a 2 μm thick a-Si:H diode is shown in Fig (5). For the CsI(Tl) the light to e, h pairs yield is > 70%. CsI(Tl) has the advantage that it is considerably less hygroscopic than CsI(Na). CsI(Na) in layers ~ 300 μm thick is routinely used as the sensitive layer for x-ray image intensi-



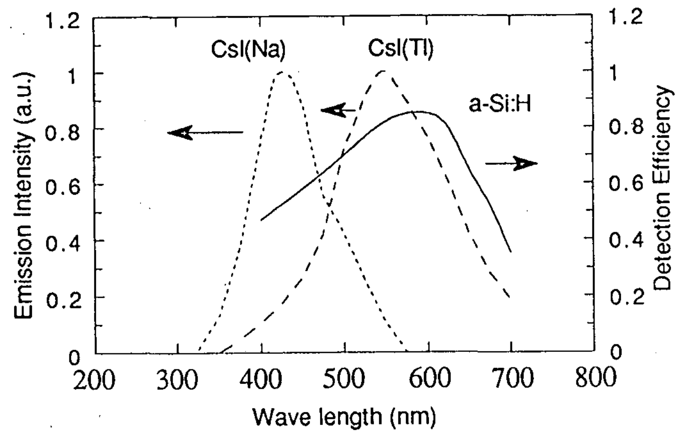
(a)



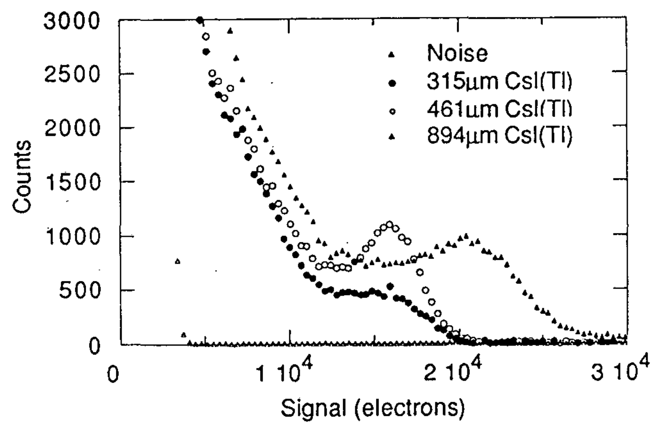
(b)

Fig. 4. Signal response at 30 V/μm bias (a) 5 μm thick detector (b) 50 μm thick detector

fiers as used in medical imaging (angiography and digital radiography). The light collimation is achieved by inducing columnar cracks to develop through the CsI(Na) layer by controlling the cooling rate of the substrate in the evaporation process (10). We have obtained better light collimation - hence better spatial resolution by evaporating CsI(Tl) on to an etched patterned substrate of Polyimide (11) deposited on the a-Si:H surface or on a glass/aluminum substrate.



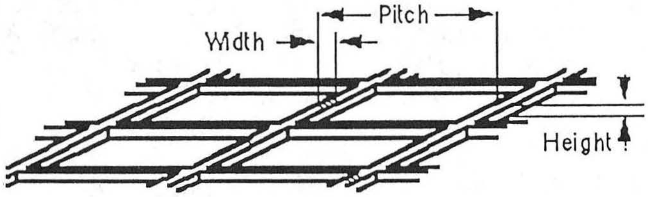
(a)



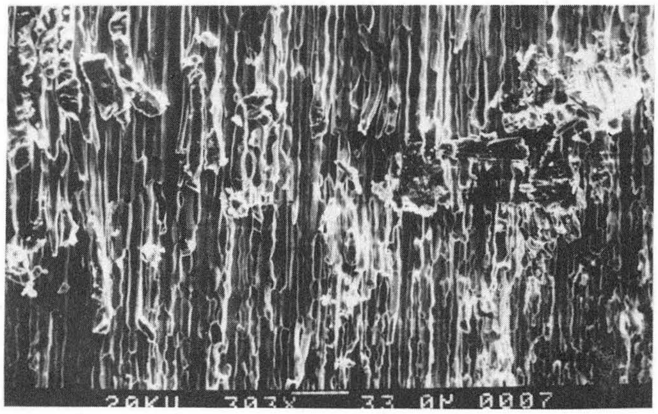
(b)

Fig. 5. Signal from a-Si:H-CsI combination (a) emission spectra of CsI and detection efficiency of a-Si:H (b) signal produced by Bi-207 beta source on a-Si:H-CsI combination

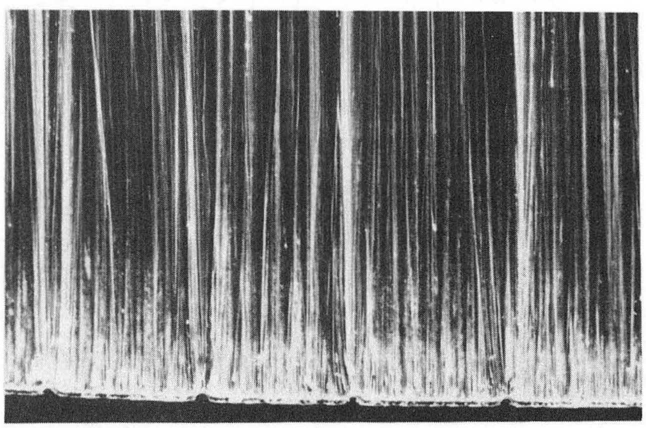
The point spread function produced by an x-ray beam incident through a 70 μm aperture and measured by a linear detector array is shown in Fig.7. The better columnar structure produced by the patterned substrate compared to the thermally induced pattern allows for the improved point spread functions seen in the figure. We measured that the overall efficiency of a CsI(Tl) layer directly coupled to the a-Si:H diode is > 35,000 e, h pairs/MeV of energy deposited in the CsI(Tl). Another quantity of interest is the resistance of the device to radiation.



(a)



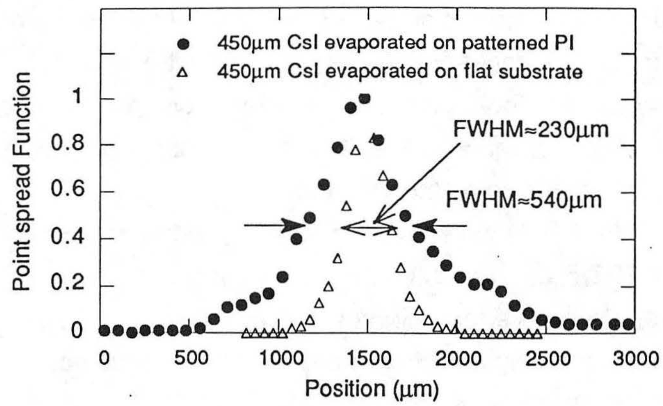
(b)



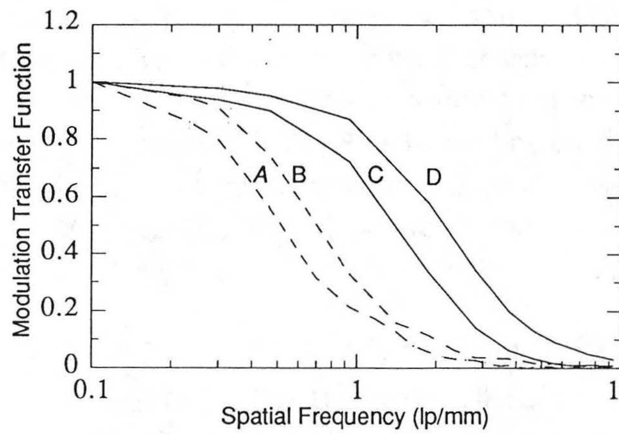
(c)

Fig. 6. Position accuracy of CsI/polyimide/a-Si:H combination. (a) Polyimide pattern on a-Si:H (b) SEM picture of thermally induced column of CsI on flat substrate (c) SEM picture of polyimide pattern induced column of CsI

As noted previously, the a-Si:H diodes and TFT are very radiation resistant. CsI(Tl) crystals are considerably more susceptible to loss due to radiation damage. In general it has been shown that the main loss is due to decrease of light transmission through the bulk of a crystal. We confirmed this by measuring the signal decrease for a CsI(Tl) crystal and an evaporated layer 300 μm thick and we show that the thin layer has a radiation resistance ~100 higher than a 1 cm crystal (12). We measured the signal produced by electrons (MIPs) from a Sr-92 beta source as



(a)



(b)

Fig. 7. Spatial response of a-Si:H-CsI combination (a) point spread function of CsI films evaporated on flat and patterned substrates (b) modulation transfer function of CsI films ; A & B : 450 μm & 300 μm CsI on flat substrate, C & D : 450 μm & 300 μm CsI on patterned substrate respectively

shown in Fig (8). This signal, > 30,000 e,h pairs is more than sufficient for the detection of individual particles in a pixel/strip array with simple, low noise, routing electronics.

4. SUMMARY AND CONCLUSIONS

At present the technology which is ready for use is the thin photosensitive p-i-n diode array coupled to an evaporated layer of CsI(Tl) deposited on a patterned substrate to produce good spatial resolution. Furthermore, the larger signals obtained from MIPs from this combination compared to those from a 50 μm direct interaction p-i-n diode simplify the electronic array necessary for readout of both flux distributions and single particles. The main disadvantage of this configuration is that it is less radiation hard than the monolithic a-Si:H detector.

In Fig (1) we showed a simple readout logic with 1 TFT/pixel. For full charge collection it is convenient to couple the columns of the rectangular array to a linear array of gated charge sensitive amplifiers such as the SVX chip developed at LBL (13). This gives good signal to noise characteristics when recording fluxes of x-rays for medical imaging, as an example. For recording single events it is necessary to have individual low noise, amplifiers connected to each pixel as shown schematically in Fig 1. We have designed and tested an 8 TFT polysilicon CMOS amplifier with a charge sensitive front end for this purpose which has a band gain product of ~400 MHz.

ACKNOWLEDGEMENTS

We would like to thank C. C. Tsai, M. Hack and S. Nelson from Xerox Parc for their assistance. We acknowledge the contribution of R. Hollingsworth, J. Xi from the Materials Research Group (formerly Glasstech-Solar, Wheat Ridge, Co.) for making thick p-i-n detectors. We thank Dan Wyman from DuPont Electronics, North Billerica, MA for acquainting us with the properties of the DuPont polyimide and giving us a large sample Also, Gene Weckler from EG&G Reticon for the use of various linear readout diode arrays.

REFERENCES:

1. R. A. Street, Phys. Rev. B 27 (1983) 4294.
2. S. Qureshi, V. Perez-Mendez, S. N. Kaplan, I. Fujieda, G. Cho, R. A. Street, Mat. Res. Symp. 149 (1989) 649-654.
3. I. Fujieda, G. Cho, J. Drewery, S. N. Kaplan, V. Perez-Mendez, S. Qureshi, D. Wildermuth, R. A. Street, Mat. Res. Symp. 192 (1990) 399-404, T. Pochet, J. Dubeau, L. A. Hamel, B. Equer, A. Karak, Mat. Res. Soc. 149 (1989) 661.
4. R. A. Street, J. Zesch, M. J. Thompson, App. Phys. Letters 43 (193) 672-676.
5. V. Perez-Mendez, Chapter 8 in "Physics and Applications of Amorphous and Microcrystalline Semiconductor Devices", J. Kanicki, Ed., Artech House Pub., Boston, MA (May 1991).
6. S. Qureshi, G. Cho, J. Drewery, T. Jing, S. N. Kaplan, A. Mireshghi, V. Perez-Mendez, D. Wildermuth, R. A. Street, to be published in IEEE Trans. Nuc. Sci. NS 39 (1992).
7. G. Cho, J. Drewery, I. Fujieda, T. Jing, S. N. Kaplan, V. Perez-Mendez, S. Qureshi, D. Wildermuth, R. A. Street, Mat. Res. Soc. 192 (1990) 393-398.
8. Synergistic Detector Design, 2438 Wyandotte St., Mountain View, CA 94043, Collimated Holes, 460 Division St., Campbell, CA 95008.
9. L. Holl, E. Lorenz, G. Mageras, IEEE Trans. Nuc. Sci NS 35 (1988) 105-109.
10. C. W. Bates, Adv. Electronics and Electron Physics 28A (1968) 451-459, A.L.N. Stevels and A.D.M. Schrama de Pauw, Phillips Res. Rpts. 29 (1974) 340-362.
11. DuPont Photosensitive Polyimide Resin Pyralin PD PI 2722.
12. I. Fujieda, G. Cho, J. Drewery, T. Gee, T. Jing, S. N. Kaplan, V. Perez-Mendez, D. Wildermuth, R. A. Street, IEEE Trans. Nuc. Sci. NS 38 (1991) 255-262.
13. S. A. Kleinfelder, W. C. Carithers, R. P. Ely, C. Haber, F. Kirsten, H. Spieler, IEEE Trans. Nuc. Sci. NS-35 (1988) 171.