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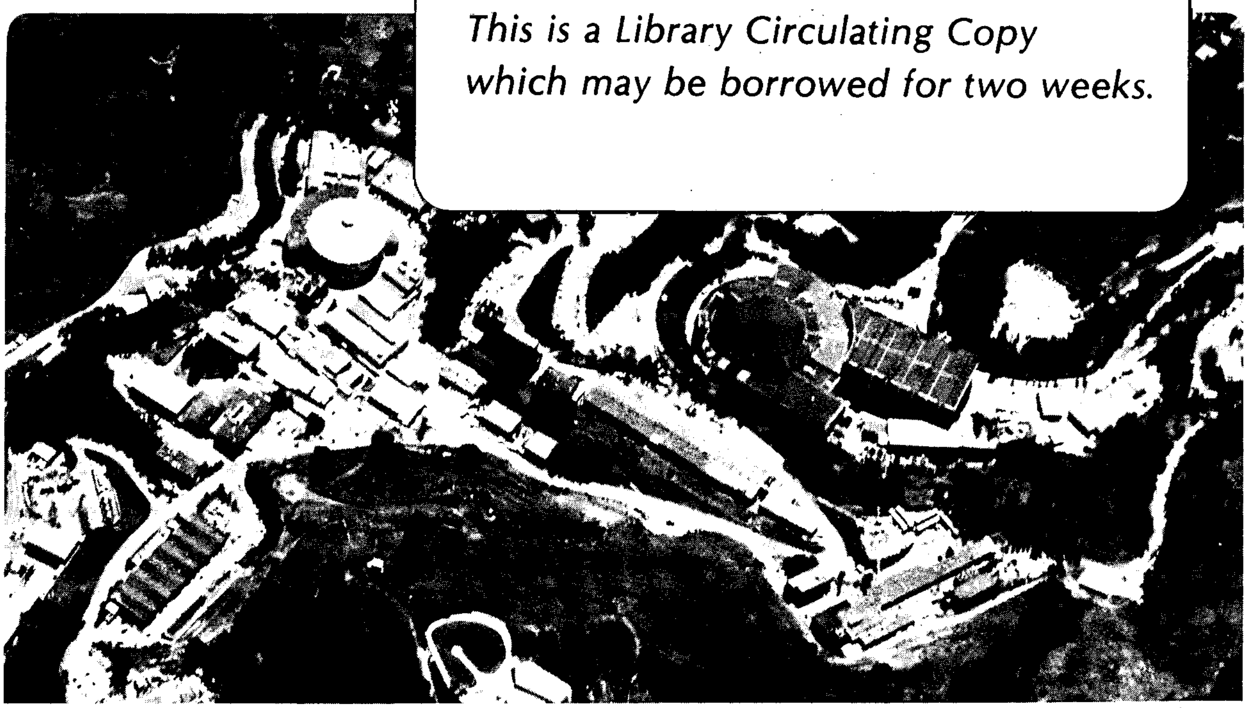

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DISCLAIMER

DETECTION OF CHARGED PARTICLES IN THICK HYDROGENATED AMORPHOUS SILICON LAYERS

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ABSTRACT

We show our results in detecting particles of various linear energy transfer, including minimum ionizing electrons from a Sr-90 source with 5-12 micron thick n-i-p and p-i-n diodes. We measured W (average energy to produce one electron-hole pair) using 17keV filtered Xray pulses with a result W=6.0±0.2eV. This is consistent with the expected value for a semiconductor with band gap of 1.7-1.9eV. With heavily ionizing particles such as 6 MeV alphas and 1-2 MeV protons, there was some loss of signal due to recombination in the particle track. The minimum ionizing electrons showed no sign of recombination. Applications to pixel and strip detectors for physics experiments and medical imaging will be discussed.

INTRODUCTION

Various devices have been used for radiation detection in physics experiments and medical imaging. Gas filled chambers have the longest history and semiconductor detectors are relatively new. Scintillation detectors are intermediate. Each of these devices satisfies different requirements specific to each application. For physics experiments, there is a need for large area, position-sensitive detectors which are also radiation-resistant. Its performance should not be affected by unusual environment such as strong magnetic fields. When these conditions are not met by a single type of radiation detector, we turn to new materials or a combination of existing devices. It is our belief that amorphous silicon (a-Si) offers an interesting alternative that satisfies these requirements. The same argument applies to medical imaging although some conditions are less stringent. To summarize advantages of a-Si:H are: (1) large area position-sensitive detectors can be fabricated easily; (2) the material is radiation-resistant and induced radiation damage can be annealed; and (3) relatively low cost. The challenging questions are whether the material can be made thick enough to achieve sufficient signal to noise (S/N) ratio, and to have adequate transport of the charge carriers created by the radiation.

We have obtained relatively thick a-Si:H diodes grown on glass substrates by Plasma Enhanced Chemical Vapor Deposition (PECVD) from Xerox (5-12μm p-i-n, n-i-p) and from Glasstech Solar (G.S.I.) (12, 27 μm p-i-n diodes). The dangling bond density of the thick i layer of these diodes is kept as low as possible with state-of-the-art technology ($< 1 \times 10^{15}/\mathrm{cm}^3$). These diodes are reverse-biased, and connected to standard electronics for solid state radiation detectors, i.e. charge-sensitive preamplifier followed by a shaping amplifier. We have exposed these diodes to several kinds of radiation, such as photons, Xrays, and charged particles. The discussion on experiments and results follows.

I-V, NOISE CHARACTERISTIC

Fig. 1 shows a typical I-V characteristic and noise of a 27 μm thick sample with contact area 0.32 cm^2 made by G.S.I. Also shown is the noise when the detector is replaced by an equivalent capacitor (130pF) which simulates the Nyquist noise of the amplifier and a current source equal to the reverse current of the detector to simulate the shot noise. The remaining noise at lower voltages is the 1/f noise which is generated by the a-Si:H [1]. The noise of the p-i-n diodes starts increasing more rapidly than we expect from the shot

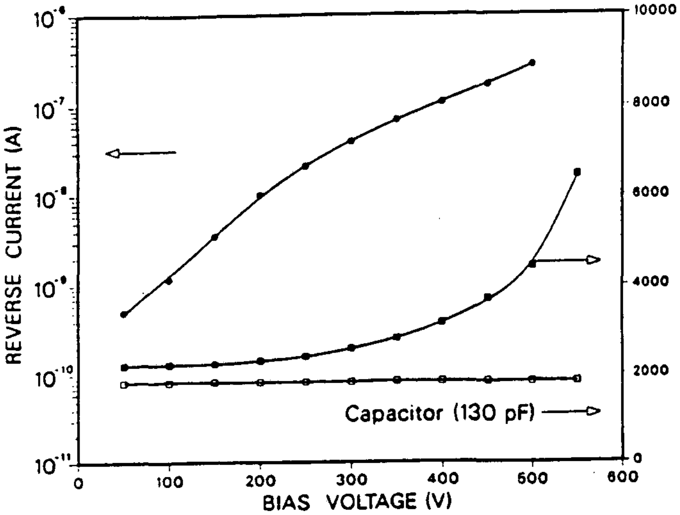

Fig. 1. Typical I–V and noise characteristic of p-i-n diode (27 μm thick). Also shown is the Nyquist noise and the step noise from the equivalent capacitor plus current source.

noise increase. One possible explanation for this additional "noise" may be the partial breakdown at weak spots where foreign dust particles sit on the substrate [2].

PULSED LIGHT MEASUREMENT

When these diodes are biased (DC), the electrons at the dangling bond sites are swept away by the field, leaving the Si atoms ionized. These ionized dangling bonds represent fixed charges and cause the electric field to drop down linearly until a low critical potential is reached at some distance inside the material near the end of the depletion region [3, 4]. Since the signal is obtained only when radiation-induced charges are drifted by the field, it is important to have this field extended through the material (full-depletion). To test if our thick diodes can be fully depleted, we observed the response to short light pulses (<100nsec wide) from LEDs at wavelength 665nm and 760nm. Fig. 2 shows output signal size from a 27μm thick p-i-n diode as a function of bias. With 760nm light (mean free path in a- Si:H $\sim$ 100μm), electrons and holes are created almost uniformly inside the diode, and electrons move to the n side and holes to the p side. Thus both carriers contribute to the output. With 665nm light (mean free path in a- Si:H $\sim$ 1μm), the electron-hole pairs are created close to the input surface; one type of carrier is collected by the nearby electrode and the other charge carriers are drifted toward the other electrode. Hence only one type of carrier contributes to the output. The curve denoted as 665nm (hole) in Fig. 2 corresponds to the situation when the n side is exposed to the 665nm light pulse. Since the i layer is slightly n type, the depletion layer develops from the i-p junction. At low bias, it does not reach the n side and charges do not move, so there is no signal output.

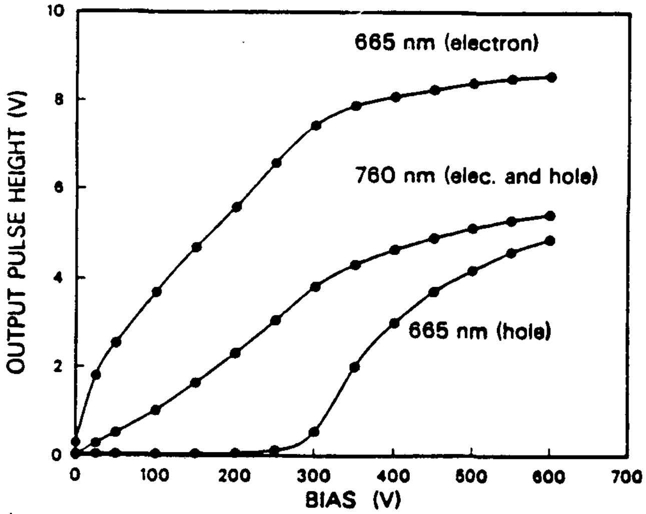

Fig. 2. Plateau curves with 655nm and 760nm light pulse (27 μm sample, shaping time = 9μsec)

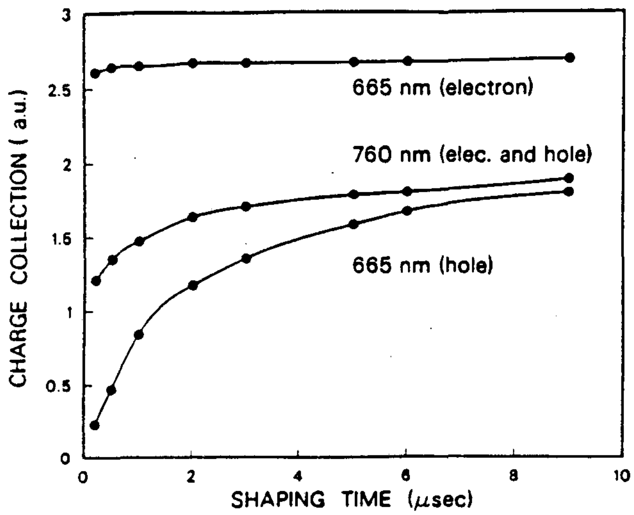

Fig. 3. Signal size as a function of shaping time for 655nm and 760nm light pulse detection. (27 μm (sample, bias = 600V)

When the bias is increased to ~300V, the field just extends to the n side so that holes can move and contribute to output. However, since the field is still low, some holes are lost during the transit to the n side, or they do not complete the transit during the charge collection period determined by the shaping time. In both cases, the actual signal size is still smaller than in the complete collection case. If the field is high enough and no carriers are lost during the transit, saturation of signal is expected because the further increase of bias does not further improve the signal development. As shown in Fig. 2, we can achieve over 95% charge collection for electrons. Hole collection is lower in this example due to the dispersive nature of the hole transport. The 760nm light simulates a high energy particle traversing the detector, and its collection as a function of shaping time is shown in Fig. 3 which also shows signal response times for the 665nm light pulse. Electrons can be fully collected in less than 200nsec, but hole collection is much slower. The relative magnitude of these three curves in Fig. 2 and Fig. 3 is not significant because the transmission and reflection at the two contacts are not known.

XRAY MEASUREMENT

The average energy to create one electron and hole pair (known as W or ϵ value) is an important number for semiconductors detectors. We measured this W value for our a-Si diode by using a filtered pulsed 17keV Xray source and comparing the signal size of a-Si diodes and crystalline-Si diodes whose W is 3.6eV. Fig. 4 shows the signal size from 5μm thick p-i-n diode relative to the signal from the equivalent thickness crystalline Si as a function of the a-Si bias. From this measurement and that of thicker diodes, we conclude W of a-Si is 6.0 ± 0.2eV. This number is consistent with the empirical relation of W to band gap reported by Klein [5].

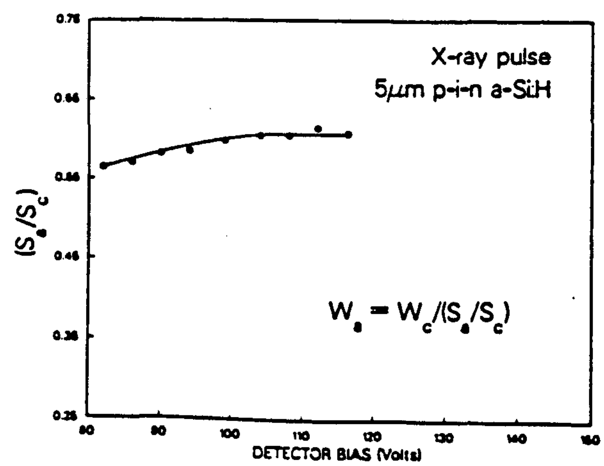

Fig. 4. a-Si signal size relative to the equivalent thickness c-Si signal as a function of a-Si bias, or 17KeV Xray pulses.

ALPHA PARTICLE AND PROTON DETECTION

Fig. 5 shows the result of 4.6 MeV α particle detection with a 5μm diode when it is tilted at an angle θ against the beam path so that the effective thickness of the detector is increased by a factor of $1/\cos\theta$. The signal is normalized to the case of normal incidence ($\theta = 0°$). Instead of a 2-fold increase in signal size in the case of $\theta = 60°$, there is an almost 4-fold increase [6]. Not only does the signal size increase more rapidly than $1/\cos\theta$, but the fractional excess increases with applied bias. This behavior suggests signal saturation caused by direct recombination within the ionization column produced by the particle transit. That is, the electrons and holes recombine along the beam track, which is also the field axis when $\theta = 0°$. When the beam axis is tilted with respect to the field, it becomes much easier for electrons and holes to escape this column (Fig. 6). Similar behavior is observed for 1-2 MeV protons from a Van de Graaf accelerator.

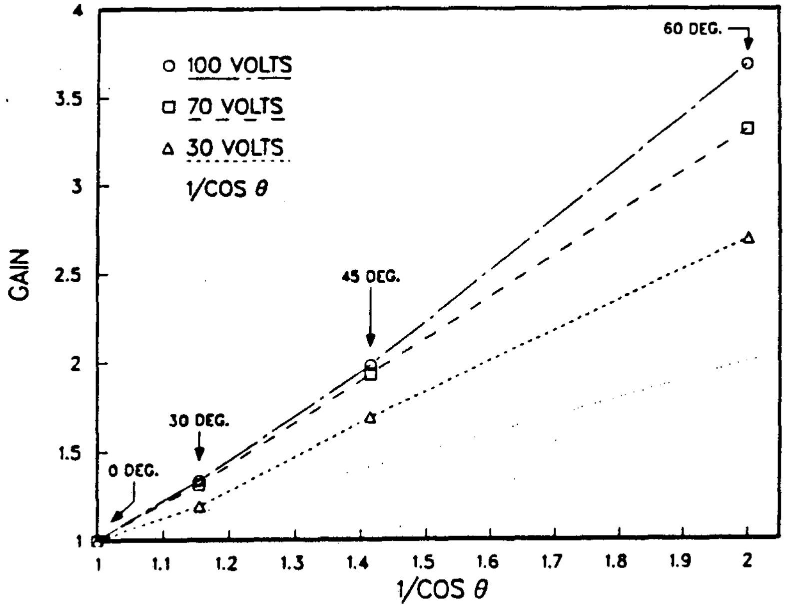

Fig. 5. 4.6 MeV α particle signal from a 5 μm diode as a function of $1/\cos\theta$, where θ is the α particle incidence angle.

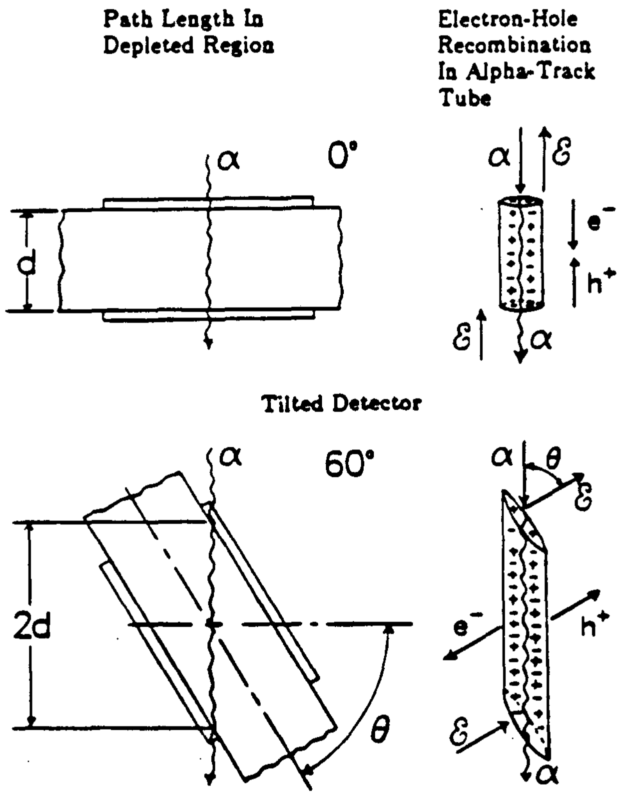

Fig. 6. Schematic diagram of factors affected by detector tilting: (a) path length in depleted region, and (b) electron-hole recombination in α-track.

It is expected that this columnar recombination effect becomes less significant as the LET is decreased so that the carrier concentrations in the track are smaller. The expected signal is smaller than the noise level, which is high [7] due to the large capacity of our 0.32 cm^2 area diodes (C = 130pF). Therefore, we used an averaging noise reduction technique. A schematic of the system is shown in Fig. 7. The signal from the c-Si detector is used to trigger the sampling scope which adds 256 signals from the a-Si detector and divides by 256. This process reduces the noise by a factor of 16 and the signal produced by β particles from Sr-90 source (average energy $\sim$ 1 MeV) becomes larger than the noise. A plateau curve similar to the 760nm light (Fig. 2) is obtained for β particle detection with a 27 μm p-i-n diode (Fig. 8). The signal ratio for $\theta = 58°$ and 0° is almost equal to 1/cos 58°, suggesting no columnar recombination effect.

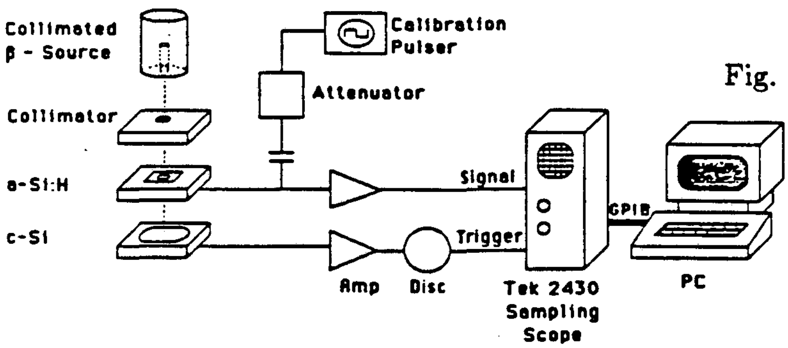

Fig. 7. The system for detecting β particles from the Sr-90 source. The sampling scope adds signal from the a-Si detector only when the c-Si detector detects β particles.

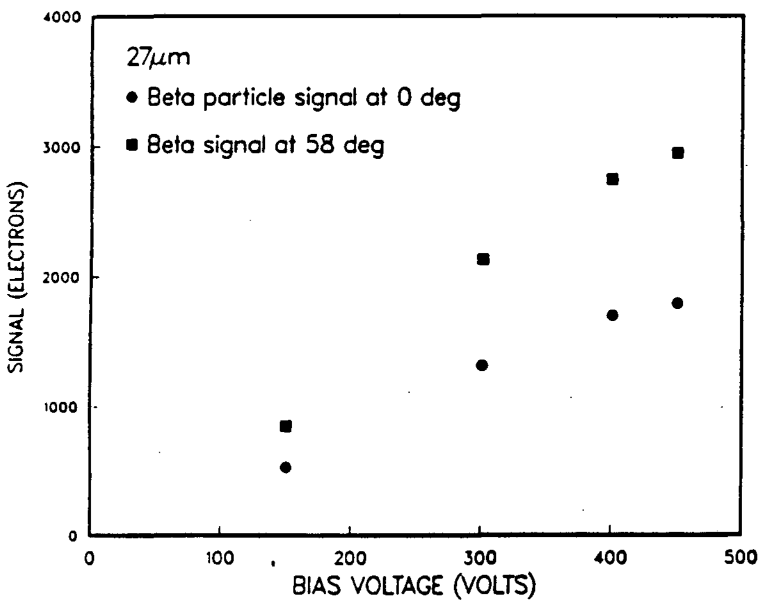

Fig. 8. Plateau curve with a 27μm sample for normally and obliquely incident β particle detection. ($\theta = 0°$ and 58°)

CONCLUSION

It has been demonstrated that thick a-Si p-i-n diode can detect charged particles with a wide range of LET. The W value is measured to be 6.0±0.2 eV from the Xray pulse technique. For physics experiments and medical imaging, a pixel or strip a-Si:H detector with readout electronics on each picture element can be used to detect charged particles directly, and Xrays and even gammas when it is coupled with high light-yield scintillators like CsI($T\ell$). The noise of these devices with a small pixel size ($\leq 300\mu m \times 300\mu m$) will be sufficiently low to allow us to detect single minimum ionizing particles directly with signal levels appreciably larger than noise. The small pixel size also has the advantage of good spatial resolution.

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REFERENCES

1. F.Z. Bathaei and J.C. Anderson, Phil. Mag. *B55*, 87 (1987).
2. A. Madan, Glasstech Solar, Wheatridge, CO. (private communication).
3. J.D. Cohen, *Hydrogenated Amorphous Silicon, Part C*, edited byJ. Pankove (Academic Press, Orlando, Florida, 1984), p. 9.
4. V. Perez-Mendez, J. Morel, S.N. Kaplan and R.A. Street, Nucl. Inst. and Method, *A252*, 478 (1986).
5. C.R. Klein, J. Appl Phys. *39*, 2029 (1968).
6. V. Perez-Mendez, S.N. Kaplan, W. Ward, S. Qureshi and R.A. Street, Nucl. Instr. and Method, *A260*, 195 (1987).
7. F. Goulding and D. Landis, IEEE Trans. Nucl. Sci. *NS-29*, 1125 (1982).

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