Title

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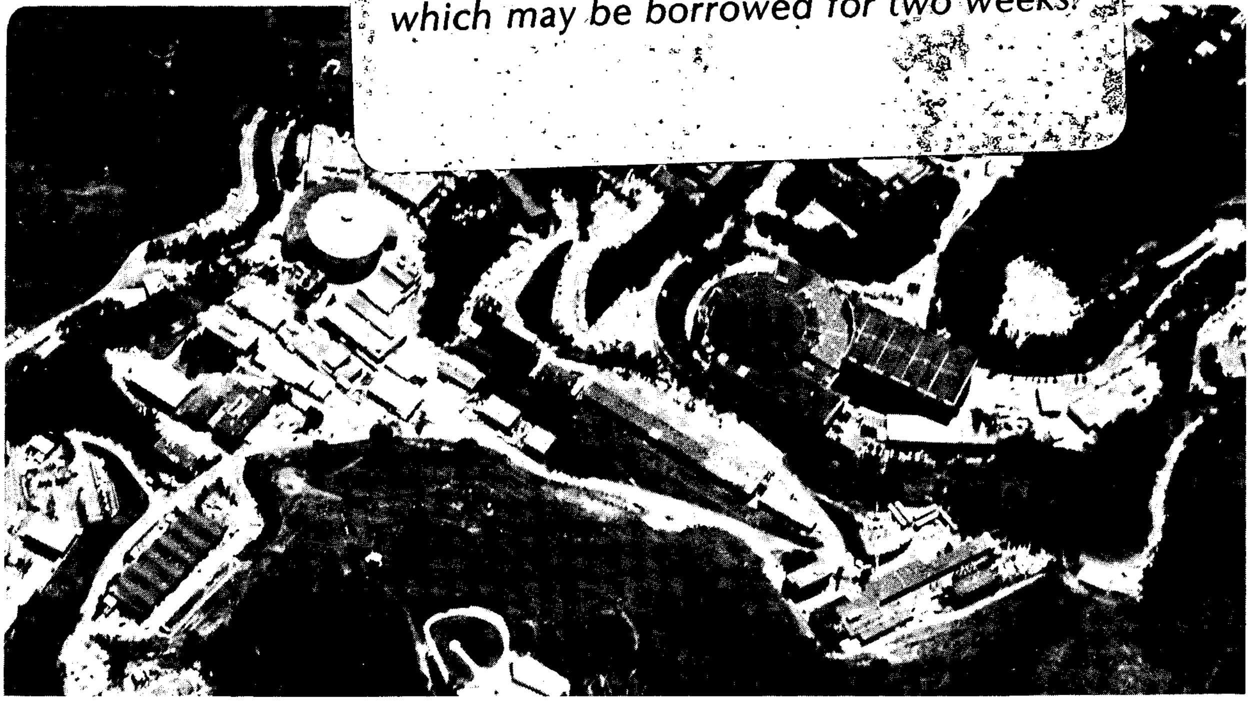

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Hydrogenated Amorphous Silicon
as a
Large Area Position Sensitive Detector for Photons and Charged Particles

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Abstract

Hydrogenated Amorphous Silicon can be easily deposited in large areas to form p-i-n diodes. When back biased with suitable stripe contacts, they can function as position sensitive detectors for visible light photons and for charged particles.

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I General Propeties

Hydrogenated Amorphous Silicon is a relatively new silicon alloy whose good electronic properties were discovered by Spear and Lecomber in 1976.(1) They showed that the partial attachment of Hydrogen reduced the $10^{19}/cm^3$ dangling bonds as traps for electrons and holes in pure Amorphous Silicon by factors of 10^3—10^4. This allowed the doping of the resulting a-Si:H by boron and phosphorus to produce p and n regions, thereby laying the foundation for a technology utilizing a-Si:H as a semiconductor capable of fulfilling some of the electronic properties of conventional crystalline silicon devices.

The main advantage of a-Si:H is that it can be easily produced in large areas by the decomposition of Silane (SiH_4) on a heated substrate. Fig. 1 shows schematically a three stage production device used by solar cell manufacturers to produce continuous lengths of a-Si:H on metal coated plastic or on a thin foil of stainless steel passing through roller vacuum interlocks. The intrinsic a-Si:H is deposited by the decomposition of silane (SiH_4) on the heated metallic substrate (250 °C). The addition of small amounts of diborane (B_2H_6) in the first tank and phosphine (PH_3) in the third tank is for the purpose of producing p or n layers in addition to the intrinsic layer in the center tank. Typical deposition rates are 1-5 microns/hour regulated by the R.F. power, substrate temperature and gas pressure in the decomposition process.(2)

Crystalline semiconductor detectors are basically back biased p-n, p-i-n or Schottky (M-i-M) barrier diodes. The same is true in a-Si:H diodes with some differences. First the mobilities of the electrons and holes are much smaller. For intrinsic a-Si:H with dangling bond density $\sim 10^{15}/cm^3$,(3) the corresponding mobilities and lifetimes are:

Electrons	$\mu = 2\ cm^2/Vsec$	$\mu\tau = 1 \times 10^{-6} cm^2/V$
Holes	$\mu = \sim 10^{-2}\ cm^2/Vsec$	$\mu\tau = 2 \times 10^{-7} cm^2/V$

The mean free paths are $d = E\mu t$ and for $\bar{E} = 10^5$ V/cm are $d_e = 1$ m.m. and $d_h = 200$ micron respectively, which are considerably longer than the thickness of the detectors that we propose. The addition of boron or phosphorus to form p or n type material in addition to forming acceptor and donor bands, also forms additional trapping levels. Hence the most common configuration for solar cells and for our work is a p-i-n diode with thin (50 nm) p and n layers and the bulk of the material is intrinsic with a minimum of dangling bonds. Forward and reverse currents are shown below in Fig. 2 for various of our diode types.(4)

II a—Si:H Photodiodes for Scintillation Light

A p-i-n diode with layer thickness of 1.5-2 microns as in solar cells forms an excellent scintillation light detector. For wave lengths in the visible [350-650 nm], the absorption mean free path of the light in a-Si:H is less than 1μ. Hence the detection efficiency is $\sim 70\%$,(5) allowing for 30% light reflection from the surface and some absorption in the front contact. These efficiencies are very similar to the commercial crystal silicon photodiodes.(6)

III Charged Particle Detection in a–Si:H Layers

Charged particles passing through a back biased p-i-n or Schottky [M-i-M] diode generate a number of electron hole pairs which produce a voltage signal on the electrodes, which can be readily detected above noise by a charge sensitive amplifier. Position sensitivity is produced by making the metallic contacts [Chromium, Palladium] form a crossed grid configuration. This is shown below in Fig. 3.(7) In Fig. 4 below(4) we show results of our measurements on alpha particles of various energies and on 1,2 MeV protons. In the case of these heavily ionizing particles there is a significant signal loss due to charge recombination.(4) However, the trend with dE/dx and recent measurements with a pulsed x-ray machine show that this charge recombination will be minimal for minimum ionizing particles. The charge signal depends on the energy deposited by the charged particle in the depletion region of the diode and on W, the average energy to produce an electron hole pair. For crystalline silicon with a band gap of 1.1 eV, W = 3.62 eV. For a-Si:H with a band gap of ~ 1.8 eV, our preliminary measurements indicate a higher W ~ 5-6 eV. This is consistent with the reported proportional relationship between gap width and W for various semiconductors.(8) We have made measurements on diodes up to a maximum thickness of 15 microns. Assuming a noise figure of ~ 2500 electrons (FWHM), typical for a charge sensitive amplifier at room temperature attached to a diode of capacity ~ 100 p.f., a detector thickness of 120-150 microns would be adequate for the detection of minimum ionizing particles. Layers of a-Si:H 40 microns and thicker with good electrical quality have been made in research laboratories.(9) The simple solution for minimum ionizing particle detection is to make stacked detectors to add up to the desired thickness.

a-Si:H devices are also considerably more radiation resistant than comparable x-tal Si devices. Preliminary measurements that we made on some of our detectors exposed to fast neutron fluxes indicated a factor of 10 or more in radiation resistance to signal deterioration compared to the crystal Si detectors.

IV Summary

Hydrogenated Amorphous Silicon is a semiconductor that can form Schottky and p-i-n diodes. It is readily made in large areas for solar cells. Solar cell type diodes can be used as unity gain position sensitive detectors for scintillation light in calorimeters.

With presently available material we have made fully depleted p-i-n diodes 15 microns thick. We have measured x-ray pulse signals in these and thinner diodes and estimate that W(a-Si:H) ~ 5-6 eV. We have also used these layers as detectors for 1,2 MeV protons and various energy alpha particles. From our measurements we estimate that stacked layers ~ 120 microns will be needed for minimum ionization particle detection. High quality a-Si:H layers 40 microns or thicker have been made and we expect to use them for further measurements before making the stacked arrays. Lastly, there is considerable industrial development of a-Si:H transistors (bipolar and F.E.T.). We expect these could be incorporated in future detectors to produce integrated detector amplifier systems.

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Figure Captions

Fig. 1 Continuous roll glow discharge reactor for producing p-i-n a-Si:H diodes for solar cells.

Fig. 2 Forward and reverse currents as function of voltage in a-Si:H diodes.

Fig. 3 Double layer p-i-n position sensitive detector.

Fig. 4 Charge-collection efficiency vs. dE/dx for a 5 μm p-i-n diode.

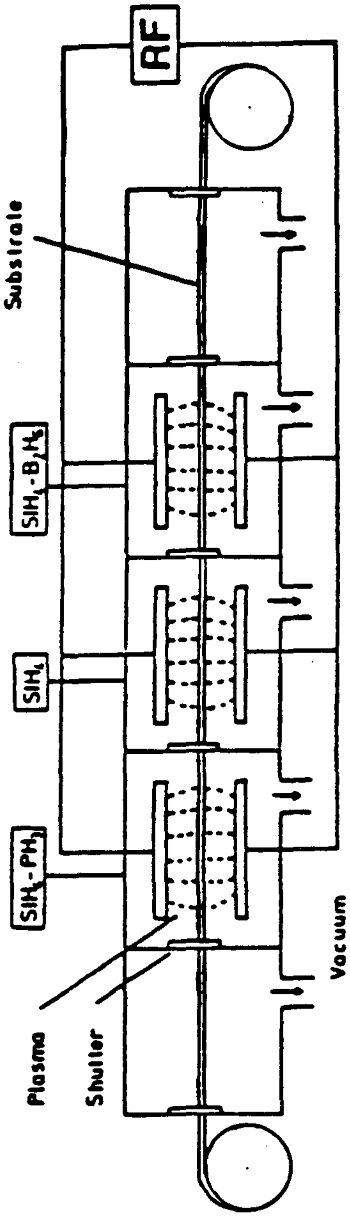

Fig. 1

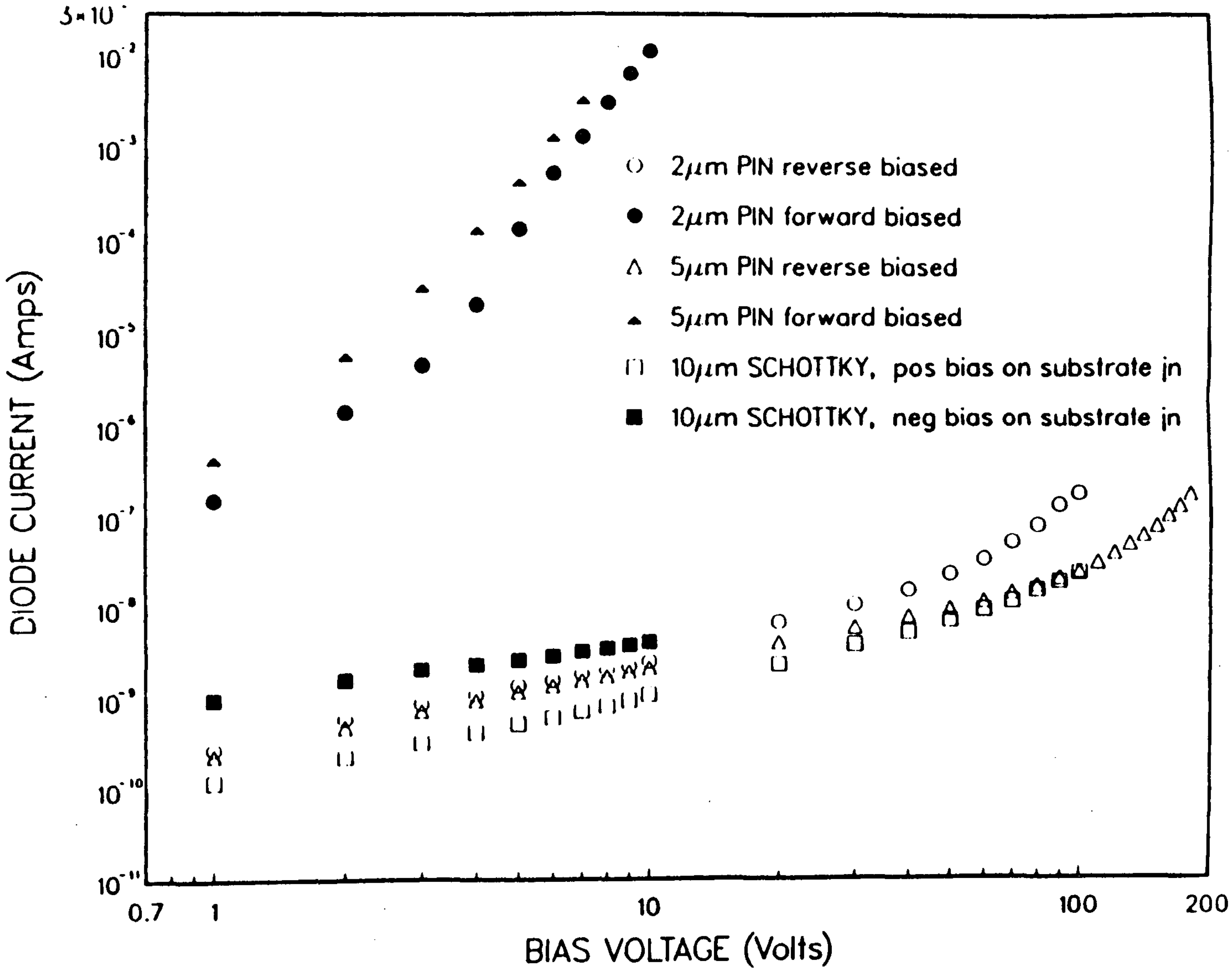

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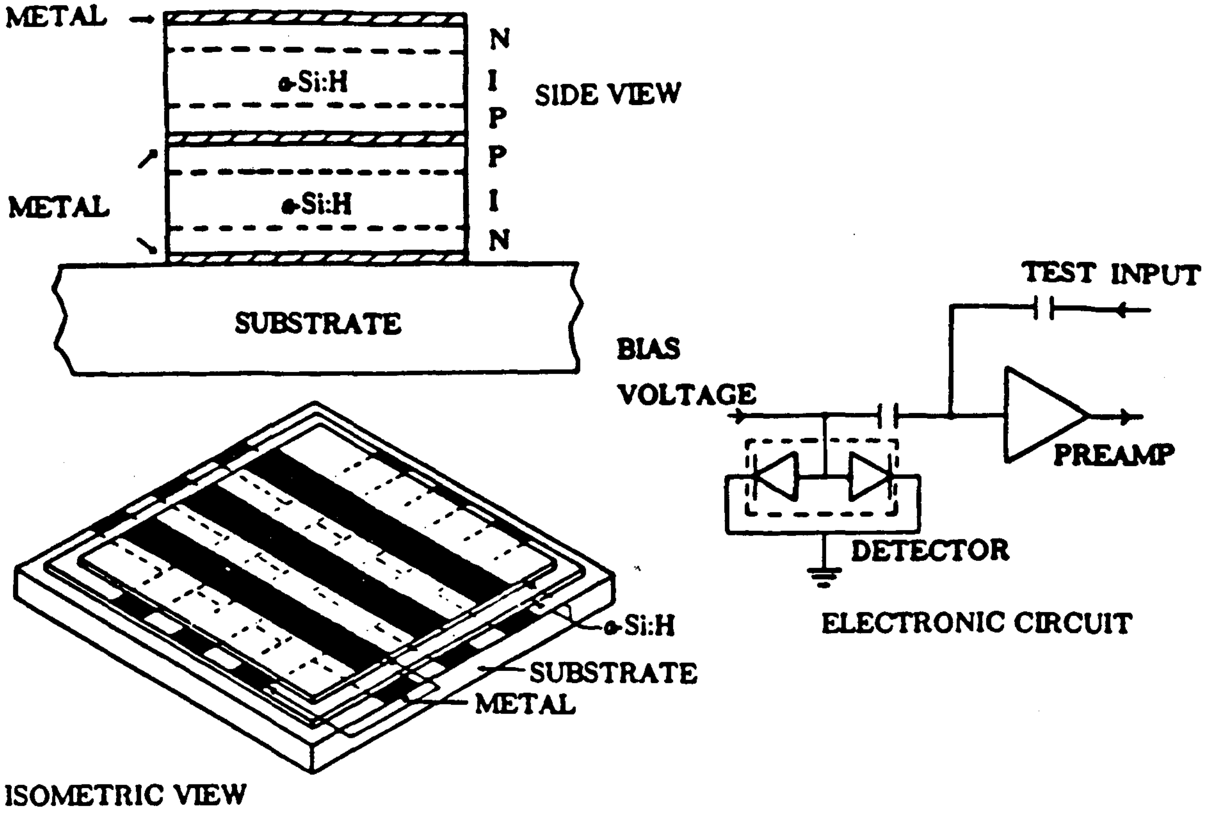
Fig. 2



DOUBLE LAYER DETECTOR

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Fig. 3

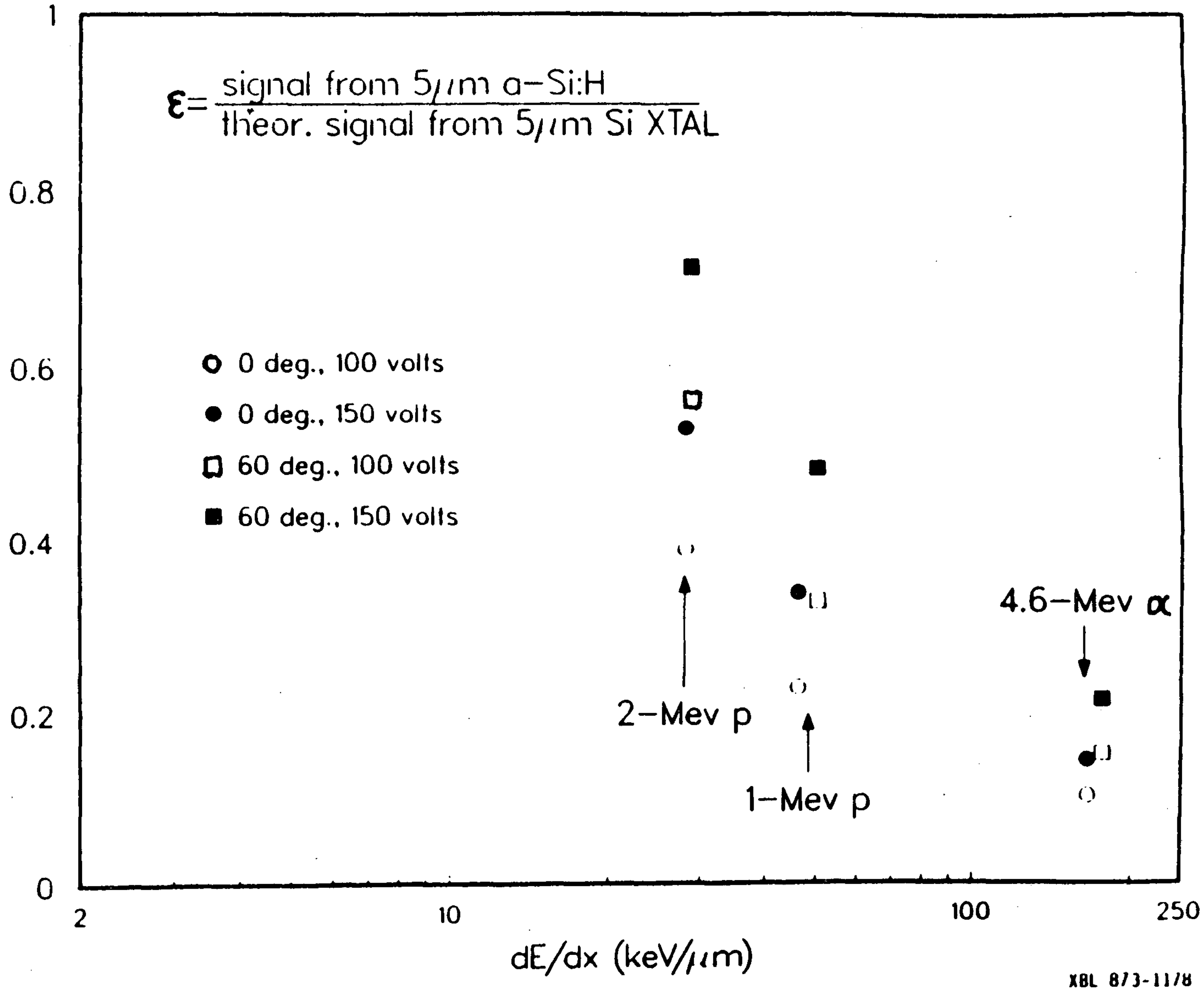
ε = signal from 5μm a-Si:H / theor. signal from 5μm Si XTAL
○ 0 deg., 100 volts
● 0 deg., 150 volts
□ 60 deg., 100 volts
■ 60 deg., 150 volts
2-Mev p
1-Mev p
4.6-Mev α
1
0.8
0.6
0.4
0.2
0
2
10
100
250
dE/dx (keV/μm)
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Fig. 4

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