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FIELD PROFILE TAILORING IN a-Si:H RADIATION DETECTORS

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ABSTRACT

The capability of tailoring the field profile in reverse-biased a-Si:H diodes by doping and/or manipulating electrode shapes opens a way to many interesting device structures. Charge collection in a-Si:H radiation detectors is improved for high LET particle detection by inserting thin doped layers into the i-layer of the usual p-i-n diode. This buried p-i-n structure enables us to apply higher reverse-bias and the electric field is enhanced in the mid i-layer. Field profiles of the new structures are calculated and the improved charge collection process is discussed. Also discussed is the possibility of field profile tailoring by utilizing the fixed space charges in i-layers and/or manipulating electrode shapes of the reverse-biased p-i-n diodes.

INTRODUCTION

Hydrogenated amorphous silicon (a-Si:H) has been investigated as a possible alternative for radiation detector material for high energy physics experiments, medical imaging, material and life science studies [1,2]. Since a-Si:H is prepared by decomposition of SiH_4 gas in glow discharge on low temperature substrates, large area detectors can be easily fabricated at low cost. The disordered Si-Si network makes the material less sensitive to radiation-induced damage, which can be annealed at low temperature subsequently. Doping is done by mixing a boron or phosphorus containing gas such as B_2H_6 or PH_3 to SiH_4 during the glow discharge deposition; under these condition, abrupt composition changes are possible.

To detect charged particles directly, thick a-Si:H layers are required so that the incident radiation can deposit enough energy in the material to give a signal size above noise. 10-50 µm thick detectors with simple structures such as Schottky or p-i-n diodes have been fabricated and tested with charged particles, X-rays and γ rays. Positive fixed space charges in the i layer after depletion of free carriers result in a non-uniform field profile. Due to this non-uniform field and low carrier mobility and lifetime, a high bias must be applied to an a-Si diode in order to ensure good charge collection efficiency. The highest reverse bias applicable to these diodes is limited to 10-20 V/µm by the onset of a low-frequency "pop-corn" type noise possibly due to micro-plasma breakdown [3] in the vicinity of the diode-metal surface or at the p/i interface where the field strength becomes maximum. Moreover, there was a wide variation in this highest bias even among the samples made in a single run. This poses a serious problem of nonuniformity for large area applications.

Charge collection efficiency and uniformity over a large area will be improved if this partial breakdown noise is suppressed and/or if the field inside a diode is made more uniform. In this paper, two methods of tailoring the field profile to achieve these objectives, via doping and electrode geometry, will be described. We have fabricated "buried p-i-n" structures [4]and their characteristics will be described in detail. The ideas for field profile tailoring by other means will also be discussed in the following sections.

FIELD PROFILE TAILORING BY DOPING

Buried p-i-n structure

Intrinsic layers and lightly-doped layers were successively deposited to make a structure consisting of glass substrate/Cr/0.03-n^+/0.3-i/0.03-n/5-i/0.03-p/0.3-i/0.03-p^+/Cr as shown in Fig.1. Numbers are thickness of each layer in µm; the top Cr electrode is a disk 3 mm in diameter and it forms a parallel plate electrodes together with the bottom Cr layer. Deposition parameters and gas mixture concentrations were adjusted to give the smallest value of the fixed positive space charge density in the i layers under reverse bias ($7x10^{+14}$ cm^{-3}) [5] and the active dopant density of $3x10^{+17}$ cm^{-3} in doped layers [6]. These densities will be used in field profile calculations for various structures discussed in this paper. The electric field profile is calculated by solving the Poisson equation for each layer with a fixed charge density under the depletion approximation. An example is shown in Fig.1 for the case of this buried p-i-n structure under a reverse-bias of 25V/µm. The maximum field occurs at the p-i boundary away from the surface and this is effective in suppressing the partial-breakdown noise as shown below.

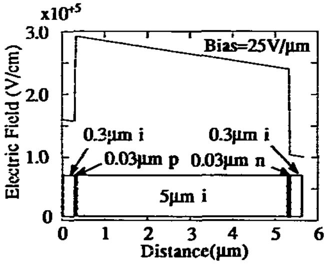

Fig.1 Calculated field profile of the 5.7 µm buried p-i-n diode described in the text.

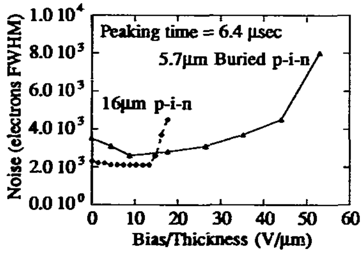

Fig.2 Noise characteristics of a 16 µm p-i-n diode and the 5.7 µm buried p-i-n diode.

Figure 2 compares the noise characteristics of a 16 µm thick p-i-n diode and this 5.7 µm thick buried p-i-n diode as measured with a low noise charge-sensitive preamplifier connected to a quasi-Gaussian shaping amplifier (6.4 µsec peaking time). Both the p and n layers at the end of these diodes are 30-40 nm thick and heavily doped as in the case of a solar cell. The rapid noise increase of the buried p-i-n diode occurs at an average field of 55 V/µm which is three times larger than the case of the 16 µm p-i-n diode. There are a few other observations to make in this comparison. The minimum noise level for the 5.7 µm diode is larger than that of the 16 µm diode. This fact and the initial noise decrease with bias for the 5.7 µm diode indicate that the main contribution to the measured noise in this bias range is due to delta noise [7] which is proportional to the diode capacitance. The slow noise increase at intermediate bias for the 5.7 µm diode may be due to the leakage current through the diode known as shot noise [7]. For the 16 µm diode, these characteristics are less apparent since the total noise level is already low. However, the noise increase at high bias for both diodes is more rapid and cannot be explained by these two known noise components. The burst-like behavior of this noise on oscilloscope observation suggests that it is caused by the microplasma breakdown as found earlier in crystalline silicon [3].

The onset of the breakdown varies even among samples made from a single deposition run for both the p-i-n and buried p-i-n structures. We defined the breakdown bias somewhat arbitrarily as the bias at which the noise exceeds three times the minimum noise level, and conducted a systematic study of the breakdown bias. Results are shown in Fig.3. The p-i-n diodes are all 16-17 μm thick, made from a single deposition run and have a 3 mm diameter Cr top electrode. This distribution for p-i-n diodes is a representative one for samples with different thickness. The buried p-i-n diodes are the ones described above. This comparison clearly shows that the new structure is effective in suppressing the onset of the low frequency noise.

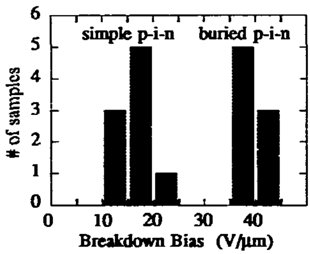

Fig.3 Breakdown bias for simple p-i-n diodes and the 5.7 μm buried p-i-n diodes.

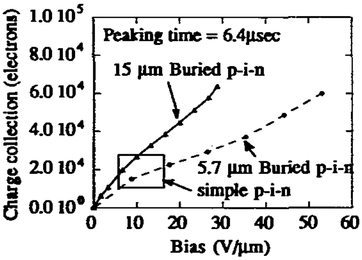

Fig.4 5.8 MeV α particle detection with the 15 μm and 5.7 μm thick buried p-i-n diodes.

The 5.7 μm and a 15 μm thick buried p-i-n diode were exposed to normally-incident 5.8 MeV α particles from a Cf-249 source in vacuum. Signal size was recorded as a function of the bias across the unit diode thickness and is plotted in Fig.4. The 5.7 μm buried p-i-n diodes are the ones described above. The structure of the 15 μm buried p-i-n diode is glass/Cr/0.03-n+/0.3-i/0.06-n/15-i/0.1-p/0.3-i/0.03-p+/Cr. Numbers are thickness of each layer in μm. The contact size and the doping concentrations are the same as with the 5.7 μm buried p-i-n diodes. The signal size from the conventional p-i-n diodes are also indicated in the box in the figure. In all diodes, the collected charges increase with bias. Charge collection efficiency never reaches unity at least in this range of field. This is attributed to the recombination loss of carriers in the plasma column created by the α particle passage [4]. The recombination loss is reduced by a higher field. The larger signal size from the buried p-i-n diodes confirms the presence of the high field.

Thick p layer

It has been reported that making the heavily-doped p layer thicker in the conventional p-i-n structure permits the application of high bias on a-Si:H diodes [8]. It is likely that a thick p layer works as a buffer layer to move the maximum field point away from the metal contact as in the case of the buried i-p layer. The field profile inside a p-i-n diode with a thick lightly-doped p layer is calculated as before and is shown in Fig.5.

Buried p layer

Thicker a-Si:H p-i-n diodes require higher bias to be fuly-depleted since the field inside a diode drops down with distance at a constant rate determined by the ionized defect density in the intrinsic layer. This field drop can be reversed by inserting a thin p layer which leaves fixed negative space charges under depletion of free carriers. A sample calculation of the field profile of this buried p layer is shown in Fig.3. The thin i-p structure is added at the end of this i-p-i structure in order to decrease the field strength in the vicinity of the surface.

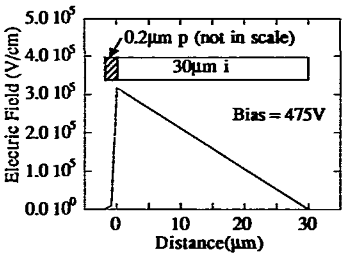

Fig.5 Calculated field profile for a p-i-n diode with a thick p layer. Assumed charged center densities are $7\times10^{+14}cm^{-3}$ in the i layer and $3\times10^{+17}cm^{-3}$ in the p layer.

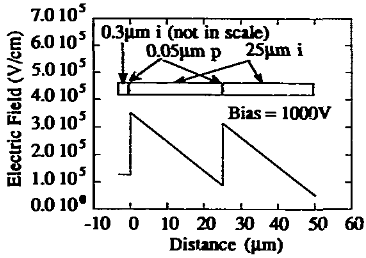

Fig.6 Calculated field profile for a diode with thin p layers buried in the thick i layer. The same charge densities are assumed as in Fig.5

FIELD PROFILE TAILORING BY ELECTRODE SHAPING

To improve charge collection efficiency of thick a-Si:H diodes, it is advantageous to have a uniform electric field profile. Using thick doped layers is not desirable for good efficiency since the carrier lifetime and mobility are strongly affected by doping [9]. Field profiles can also be controlled by changing the shape of the electrodes. In the parallel plate configuration, the field changes linearly due to the fixed space charge in the intrinsic layer under bias. When one of the plates is made smaller than the other, the field in the regions close to the smaller electrode is enhanced roughly by the ratio of the electrode widths. This is because the number of field lines landing on the two electrodes are the same. With both of these effects present, we can make the field profile more or less uniform or, if desired, can make a very non-uniform field profile, by the proper choice of electrode geometry and the right bias polarity.

To illustrate the possibility of field compensation by the electrode geometry, a simple case of a 50 μm thick a-Si i layer (the fixed space charge density $7\times10^{+14}cm^{-3}$) sandwiched between one continuous electrode and one discrete electrode is treated below. The code "POISSON" [10] was used to solve the resultant 2D-Poisson equation with suitable boundary conditions. Figure 7(a) shows the cross section of this diode and the calculated equipotential lines. Only one half of the unit cell is shown here. The other half is mirror-symmetrical to this half along the y axis. The bottom electrode is continuous and biased at -2000V whereas the top electrode is discrete and grounded. The width and pitch of the top electrode are 4 μm and 30 μm, respectively. The field strength along the diode depth direction at x = 0, 2, 7.5, 15 μm are plotted in Fig.7(b). The field drops linearly with depth in the region close to the continuous electrode and it increases in the region close to the discrete electrode. The geometrical field enhancement compensates the field drop due to the fixed space charge in the i layer to some extent. It is apparent that a low field region exists at the upper right corner of Fig.7(a). This region should not have a significant effect on charge collection process for the following reasons: (i) most of the carriers generated in the bulk and drifting along field lines don't pass this region and (ii) as for the carriers created in this region, electrons, with their superior transport characteristics, have to drift only a small distance to the top electrode. The hole contribution to the signal is often lost anyway due to its low mobility and the limited collection time required by some applications. This structure has an additional advantage over the parallel plate configuration, namely, a reduced capacitance and, therefore, smaller delta noise.

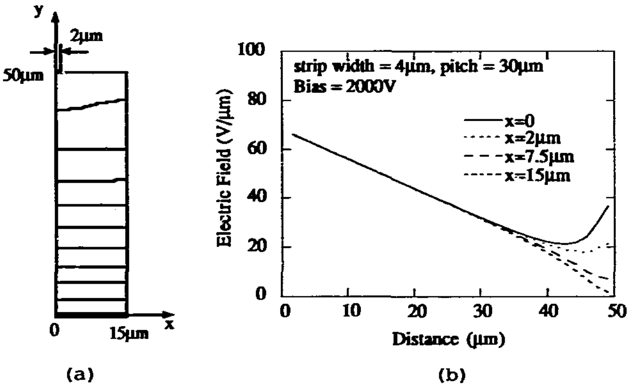

Fig.7 Calculated field profile of a diode with a continuous bottom electrode and a discrete top electrode. (a) The cross-section of the diode. The bottom electrode is continuous whereas the top electrode is a strip of 4 μm width and 30 μm pitch. Only one half of the unit cell is shown here. Equipotential lines are drawn every 200V when the bottom electrode is biased at -2000V. (b) The field strength along the diode depth direction at x=0, 2, 7.5 and 15 μm.

CONCLUSION

The capability of tailoring the field profile in a-Si:H radiation detectors is demonstrated by the buried p-i-n structure. This structure improves the charge collection process by allowing one to apply higher bias while suppressing the near-surface breakdown phenomenon. It also gives a solution to the uniformity problem, i.e., a bias safety margin before breakdown for each element of a large area detector is provided by this structure. Some other schemes for tailoring the field profiles and their calculation results show that thicker a-Si:H layers can be fully-depleted with a non-uniform field profile.

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REFERENCES

[1] V. Perez-Mendez, G. Cho, I. Fujieda, S.N. Kaplan, S. Qureshi and R.A. Street, Mater. Res. Soc. Symp. Proc. 149, 621 (1989) and see references therein.

[2] I. Fujieda, G. Cho, M. Conti, J. Drewery, S.N. Kaplan, V. Perez-Mendez, S. Qureshi and R.A. Street, J. Non-Cryst. Solids 115, 174 (1989).

[3] D.J. Rose, Phys. Rev. 105, 413 (1957).

[4] I. Fujieda, G. Cho, M. Conti, J. Drewery, S.N. Kaplan, V. Perez-Mendez, S. Qureshi and R.A. Street, to be published in IEEE Trans. Nucl. Sci. NS-37 (1990).

[5] S. Qureshi, V. Perez-Mendez, S.N. Kaplan, I. Fujieda, G. Cho and R.A. Street, Mater. Res. Soc. Symp. Proc. 149, 649 (1989).

[6] M. Stutzmann, D.K. Biegelsen and R.A. Street, Phys. Rev. B35, 5666 (1987).

[7] F. Goulding and D. Landis, IEEE Trans. Nucl. Sci. NS-29, 1125 (1982).

[8] T. Pochet, J. DuBeau, L.A. Hamel B. Equer and A. Karar, Mater. Res. Soc. Symp. Proc. 149, 661 (1989).

[9] R.A. Street, J. Zesch, M.J. Thompson, Appl. Phys. Lett. 43, 672 (1983).

[10] POISSON/SUPERFISH Los Alamos Accelerator Code, LA-UR-87-126, (1987).