PFC/JA-92-10

Response of SBDs to MeV protons, tritons and alphas: Evidence that the charged-particle sensitive depth is not generally the depletion depth

D. H. Lo,[†] R. D. Petrasso, K. W. Wenzel,[‡] J. K. Coleman,
C. K. Li, J. R. Lierzer, E. Hsieh* and T. Bernat*

March 1992

Plasma Fusion Center
Massachusetts Institute of Technology
Cambridge, MA 02139

* **Lawrence Livermore National Laboratory**
Livermore, CA 94550

This work was supported by LLNL Subcontract B116798, U.S. DOE Grant No. DE-FG02-91ER54109, SNL Subcontract No. 76363, DOE Magnetic Fusion Energy Technology Fellowship Program(†), and DOE Fusion Energy Postdoctoral Research Program(‡).

Submitted for publication in: *Review of Scientific Instruments*

Abstract

As part of an on-going effort to develop diagnostics for energetic charged particles from laboratory and space experiments, we examined the possibility that particle identification could be expedited by varying the applied bias voltage on silicon surface barrier detectors (SBDs). Using MeV protons, tritons, and alphas, we performed spectroscopy experiments whereby we observed changes of the energy spectrum as a function of the bias voltage. These particles were either generated via a Cockcroft-Walton linac as fusion products, or emitted from radioisotopes. The results indicate that, contrary to commonly held belief, the detector sensitive depth is not generally the depletion depth. Indeed for partially depleted SBDs, the performance is not greatly degraded even for zero bias.

Introduction

Silicon surface barrier detectors (SBDs) have been widely used for the detection of charged particles,[1-3] neutral particles,[4] and x rays.[5-8] As part of an effort to develop diagnostics for energetic charged particles from laboratory and space experiments, we recently performed a series of experiments with SBDs to examine whether charged particle identification could be expedited by varying the bias voltage applied to the SBD. (A surface barrier detector is intrinsically a radiation detector of energy alone.)

When reverse bias is applied to an SBD, a depletion layer is formed on the front of the silicon wafer at the junction. [In fact, an unbiased SBD spontaneously forms a small contact potential (typically ~0.5 volt) across its junction, but the resulting depletion layer is quite thin.] Based on a simple model,[9] it is generally believed that the depletion depth is proportional to the square root of the voltage across the junction (the sum of the contact potential and applied bias). In addition, it is widely accepted that the sensitive depth of an SBD is the depletion depth. Using different charged particles, we performed spectroscopy experiments whereby we observed the energy shift and the spectral shape change as a function of the bias voltage. We found, however, that the depletion depth is not generally the charged-particle sensitive depth, a conclusion also reached for x rays.[7]

Different charged particles have different ranges in the detector. Table 1 lists an array of particles and their ranges in silicon.[10] If a charged particle's range is greater than the sensitive depth of the SBD, the SBD would not be expected to detect the full energy of the particle, since some of this energy is dissipated in a part of the SBD that is beyond the sensitive depth. Consider the detection of a 7.6-MeV α particle with an SBD whose bias voltage is set such that the depletion depth is less than the particle's range (see Table 1). If the detector sensitive depth were indeed the depletion depth, the α particle would contribute less than its full 7.6 MeV to the signal pulse. Therefore, the smaller the depletion depth, the bigger the downshift of the energy spectrum. In fact, when the applied bias approaches zero, the depletion depth due solely to the contact potential will be so small that the spectrum would essentially disappear. If this simple model of the SBD's charged-particle sensitive depth were valid, one could calculate, in principle, the energy shift for any charged particle at any bias voltage with the knowledge of the particle's stopping power. In turn this procedure could allow experimenters to uniquely identify the "ranging" particle.

Apparatus and Sources of Charged Particles

Numerous SBDs, all manufactured by EG&G Ortec, were used in this study. (See Table 2.) SBD #30-020A, which is n-type, is fully-depleted when operated with maximum bias. All the other SBDs, henceforth to be referred to collectively as the Group, are "ruggedized" p-type and partially-depleted when maximum bias is applied. Each SBD was irradiated in vacuum. The electronics included an ORTEC 142 preamplifier, an ORTEC 590 amplifier, and a PC-based pulse-height analysis system.

We report here on studies done with two sources of MeV charged particles. First, 3 MeV protons and 1 MeV tritons were produced via beam-target D-D fusion using a Cockcroft-Walton accelerator.[11] The SBD viewed a deuterated-erbium target at 120° relative to the incident direction of the 150 keV deuteron beam. A 1.5 μm mylar filter in front of the SBD stopped accelerated deuterons from back scattering into the SBD. Consequently, the D-D protons and tritons suffered small energy losses ($\approx$30 keV and $\approx$120 keV respectively), while the 0.8-MeV D-D ^{3}He particles were ranged out. [This accelerator is also routinely being used for fusion γ ray generation[11,12] and particle-induced x-ray emission (PIXE).[13]] The second particle source was ^{226}Ra which provides four well-resolved alpha lines.

Results and Discussion

Fig. 1 shows a series of spectra of D-D protons and tritons obtained with SBD #16-662D as the applied bias was varied from -75 V (providing $\approx$100 μm of depletion depth) to 0 V. The fusion products incident on the SBD do not have their full energies because of kinematic effects and ranging through mylar. This agrees well with our prediction. The double peaks due to D^+ and D_2^+ species in the accelerator beam are observable in Fig. 1a. In general, for all the particles investigated (i.e. protons, tritons, and alphas), the response exhibited in Fig. 1 is representative of the SBDs in the Group. There is always a gradual energy downshift and a degradation of the resolution as the bias is lowered. At zero bias, the energy downshift for the various SBDs in the Group ranges from $<5\%$ to $\sim50\%$; and the change in energy resolution, as measured by the change in spectral width, varies from practically none to $>300\%$ increase. A striking feature is that the spectrum nonetheless remains intact even at 0 V. From the practical point of view, this could be important since it indicates that counting experiments are possible without applied bias, though spectroscopy may be precluded or at least made difficult. Also, based on the simple model for the SBD, this result is unexpected.

Analogous to Fig. 1, Fig. 2 shows the response of SBD #30-020A to particles as the applied bias was varied from +355 V (depletion depth of 2000 μm) to +50 V. At 0 V, the spectrum had totally disappeared. The spectrum immediately begins to degrade when the applied bias is not close to maximum. This behavior with varying bias for SBD #30-020A is observed for all the charged particles of Table 1, including the longer-range 14.6-MeV protons (1300 μm) from D-^{3}He fusion. Nevertheless, the energy shift does not quantitatively follow the prediction ascribed by the simple model. Obviously, the charged-particle response of this SBD and of the SBDs in the Group are markedly different; we do not understand this difference.

Thus, we arrive at the conclusion that the charged-particle sensitive depth of SBDs is not generally the depletion depth. *It is important to emphasize that this result is contrary to what is commonly believed.* Also, this result is completely analogous to the conclusion reached about the x-ray sensitive depth.[7] In order to clarify these charged-particle results, it would be useful to do comprehensive studies using various SBDs with different characteristics, such as thickness, type (p or n), resistivity, and so on.

Acknowledgments

We are very grateful to Dr. Ramon Leeper and Dr. Carlos Ruiz at Sandia National Laboratory and Dr. Lynn Provo at General Electric for fabricating several deuterated-erbium targets. We appreciate Dr. Fredrick Séguin and Ms. Cristina Borrás for their careful reading of the manuscript.

References

1. R. A. Langley, Nucl. Instrum. Methods **113**, 109 (1973).
2. W. W. Heidbrink and J. D. Strachan, Rev. Sci. Instrum. **56**, 501 (1985).
3. H.-S. Bosch, Rev. Sci. Instrum. **61**, 1699 (1990).
4. T. Elevant, H. W. Hendel, E. B. Nieschmidt, and L. E. Samuelson, Rev. Sci. Instrum. **57**, 1763 (1986).
5. R. Petrasso, M. Gerassimenko, F. H. Seguin, R. Krogstad, and E. Marmar, Nucl. Fusion **21**, 881 (1981).
6. R. D. Petrasso, D. J. Sigmar, K. W. Wenzel, J. E. Hopf, M. Greenwald, J. L. Terry, and J. Parker, Phys. Rev. Lett. **57**, 707 (1986).
7. K. W. Wenzel and R. D. Petrasso, Rev. Sci. Instrum. **59**, 1380 (1988).
8. K. W. Wenzel and R. D. Petrasso, Rev. Sci. Instrum. **61**, 693 (1990).
9. G. F. Knoll, *Radiation Detection and Measurement*, 2nd ed., Wiley, New York (1989).
10. U. Littmark and J. F. Ziegler, *Handbook of Range Distributions for Energetic Ions in All Elements*, Pergamon, New York (1980).
11. K. W. Wenzel, D. H. Lo, R. D. Petrasso, J. W. Coleman, C. K. Li, J. R. Lierzer, C. Borrás, T. Wei, E. Hsieh, T. Bernat, submitted for publication in Rev. Sci. Instrum. (1992).
12. K. W. Wenzel, R. D. Petrasso, D. H. Lo, C. K. Li, J. W. Coleman, J. R. Lierzer, E. Hsieh, T. Bernat, submitted for publication in Rev. Sci. Instrum. (1992).
13. C. K. Li, K. W. Wenzel, R. D. Petrasso, D. H. Lo, J. W. Coleman, J. R. Lierzer, E. Hsieh, T. Bernat, submitted for publication in Rev. Sci. Instrum. (1992).

Table 1: Energetic particles (column 1) from differnet sources (column 2), and their energies and ranges in silicon.[10]

Particle	Source	Energy (MeV)	Range (μm)
^{1}H	D-D	3.0	91
	D-^{3}He	14.6	1300
^{3}H	D-D	1.0	9.8
^{3}He	D-D	0.82	2.7
^{4}He	D-^{3}He	3.7	15
	^{226}Ra	4.7	22
		5.4	26
		5.9	30
		7.6	44

Table 2: The SBDs used in this study are listed with maximum applied bias voltage, the corresponding depletion depth at that bias, the nominal physical thickness of the silicon, and the resistivity of each SBD. Note that SBD #30-020A is fully-depleted at +355 V.

I.D. #	Max. Bias (V)	Depletion Depth (μm)	Silicon Thickness (μm)	Resistivity (Ω-cm)
26-454B	-100	$\approx$100	530	15700
16-662D	-75	$\approx$100	335	3000
18-312C	-100	$\approx$100	484	3000
17-380F	-150	$\approx$100	461	4400
18-365E	-100	$\approx$100	292	3500
16-848A	-75	$\approx$100	328	3000
16-821D	-75	$\approx$100	544	3500
17-381G	-100	$\approx$100	321	4000
18-748A	-100	$\approx$100	334	4400
30-020A	+355	2000	2000	75000

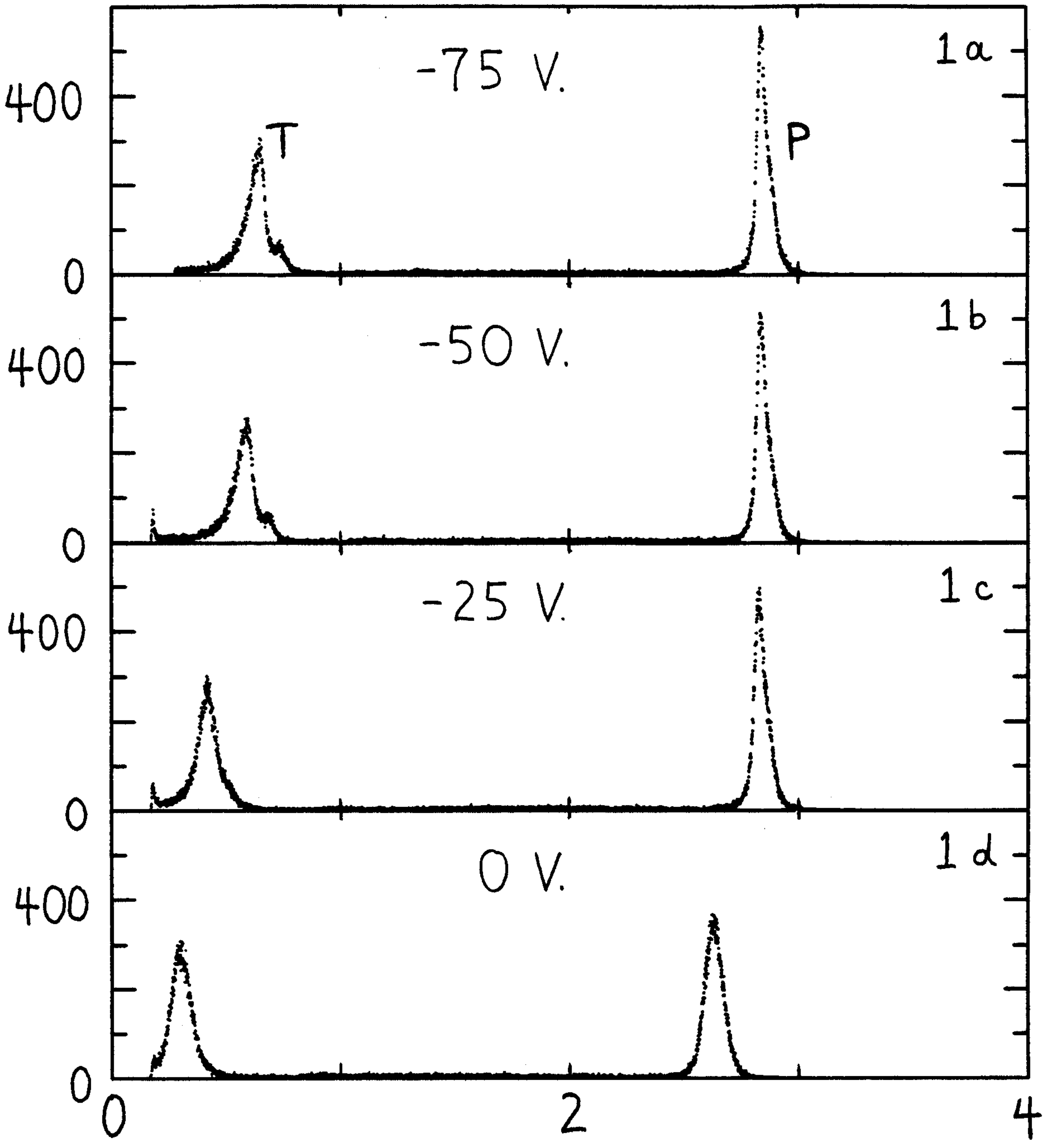

Figure 1 : A series of spectra of D-D protons (P) and tritons (T) collected with SBD #16-662D at different applied bias. The presence of double peaks, due to D^+ and D_2^+ species in the accelerated beam, is especially noticeable in the triton peak. It is surprising that the spectrum stays intact even at zero applied bias.

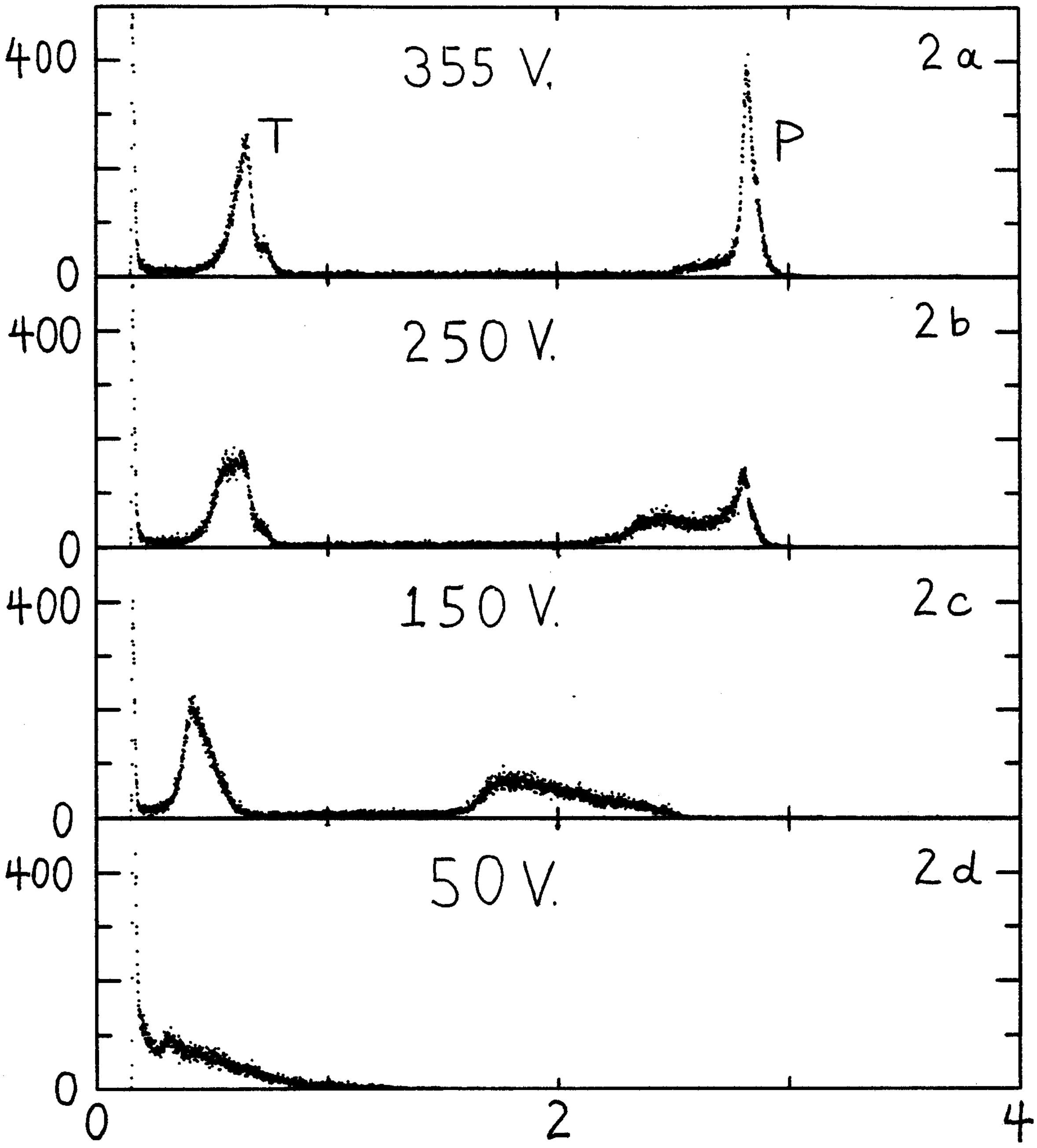

Figure 2 : A series of spectra of D-D protons (P) and tritons (T) collected with SBD #30-020A at different applied bias. The changes of the spectrum with decreasing applied bias cannot be explained quantitatively (based on the simple model that SBD's sensitive depth is its depletion depth).