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Miniature Silicon Diode as a Radiation Dosemeter

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§ 1. INTRODUCTION

Semiconductor detectors are solid-state analogs of ion chambers. The operation of these semiconductors as radiation detectors has been extensively discussed (Taylor 1963). Their use as x-ray and γ-ray dosemeters has been investigated by many workers (e.g., Baily and Kramer 1964). These detectors, however, are very expensive. Silicon solar cells and semiconductor diodes have also been studied as radiation dosemeters (Rosenzweig 1962, Whelpton and Watson 1963, Guldbrandsen and Madsen 1962). The advantage of using diodes lies in their small size and low cost. Commercially available miniature silicon diodes (Microsemiconductor Corporation, 11250 Playa Court, Culver City, California) have been investigated by Koehler (1965). In the study presented here these miniature silicon diodes have been investigated, to determine their usefulness at the biomedical facilities of the cyclotrons at Lawrence Radiation Laboratory.

§ 2. APPARATUS

Figure 1 shows a miniature diode mounted on BNC connector; the diode is 0.04 in. in maximum diameter and 0.085 in. long. These are light-sensitive and hence are coated with Kodak dull black brushing lacquer. The short-circuit current generated by radiation is measured by using a digital-type electrometer. There is no need to apply an external potential across the diode.

§ 3. RESULTS AND APPLICATIONS

3.1. 50-kV x rays

These diodes are exposed to 50-kV x rays filtered with 1.75 mm of aluminum, and the radiation-induced charge from the diodes is measured. The typical output from the diodes is 10^{-9} coulomb/R, and the charge is proportional to the x-ray dose and independent of dose rate in the investigated region of 80 to 400 R/min. The sensitivity of these diodes is limited by their size to a minimum of about 1 R/min; one must use larger diodes for greater sensitivity. No radiation damage is observed with 50-kV x rays, i.e., the sensitivity, measured in coulombs of collected charge per roentgen of delivered dose, remains the same.

3.2. High-Energy Protons and α Particles

With high-energy charged particles (910-MeV α and 50-MeV protons), the sensitivity of the diodes (i.e., charge output per unit dose) is found to decrease as the dose increases, as observed by Koehler (1965). The observation that the sensitivity remains the same for 50-kV x-ray doses but is reduced with heavy-particle dose is in agreement with the results of Rosenzweig (1962). Radiation damage due to high-energy γ rays and heavy particles causes the diffusion length of the diodes to decrease. This, however, need not be a limitation on their use as radiation dosemeters (Koehler 1965). If the diode is pre-exposed to higher levels of radiation dose, of the order of 10^6 rads, the sensitivity of the diode is reduced by a factor of the order of three, but the sensitivity does not change significantly thereafter with further radiation exposures. Such a diode pre-exposed to higher levels of radiation dose is found to be independent of dose rate up to the dose rates investigated (910-MeV α or 50-MeV protons) from 25 rad/min to 5000 rad/min. It is hard to investigate at still higher dose levels because of the saturation problems of ion chambers used for comparison. The charge output from the diodes for the unit exposure dose due to 50-kV x rays is found to be higher than for that due to heavy particles. This is because of the high absorption coefficient of low-energy x rays.

3.3. Applications

The small size of this diode is of great help for determining beam profiles and depth-dose distribution of small collimated cyclotron beams where the intensities in general are not uniform.

Figure 2 shows the beam profiles of 50-MeV proton beam degraded by 2 mils of aluminum, 30 mils of graphite and 90 mils of graphite. The profile flattens as the thickness of the absorber is increased. For experiments with irradiation of various biological samples of different sizes, such profiles would be of very great help. Figure 3 shows the beam profile of 910-MeV α beam passing through a 1/4-in. collimator (used for some human pituitary irradiations and also for cat brain lesions). The only way that beam profiles can be obtained over such small regions, other than using these tiny diodes, is by photographic film. The procedure of scanning the photographic film, however, is tedious, and instantaneous readings cannot be obtained.

For routine use of the diode either for beam profile measurements or depth-dose distribution, the charge output of the diode at consecutive positions can be stored in the consecutive channels of a pulse-height analyser and an instantaneous display of either beam profile or depth-dose distribution can be obtained. This type of automatic display of beam profile or depth-dose distribution is extremely useful, especially in connection with cyclotrons, where beam time is very valuable. Such an automatic beam-profile detector system is being made at Lawrence Radiation Laboratory.

Figure 4 shows the Bragg curve data of 910-MeV α beam in copper obtained by using both ion chambers and diode normalized at zero absorber thickness. The response of the diode near the Bragg peak region is higher than that of the ion chamber. Part of this increase is due to positioning of the diode behind the second ion chamber. The diode sees the particles after they have passed through the copper absorber, the ion chamber and the coating on the diode. The increased response of the diode at the Bragg peak region in comparison with the ion chamber, is in conformity with the results of Koehler (1965). This difference may be due to the secondaries' escaping through the ion chamber whereas the diode, being a solid, stops them or slows them down significantly. There is need to confirm this difference in behavior near the Bragg peak region between gas ion chambers and solid-state devices; such work is being done by the author.

The diode can be mounted inside a plastic capillary needle so that it can be inserted in any region for measurement of the dose without appreciably perturbing the tissue medium. As the atomic number of silicon is very close to that of bone, the diode would be ideal for measuring the depth-dose distribution or dose buildup in bone.

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SUMMARY

The use of commercially available miniature silicon diodes as dosemeters, with particular reference to their application to biomedical facilities at cyclotrons, is discussed. They are simple and convenient, and their small size makes them ideal to use as beam profile detectors or to measure depth-dose distribution of small collimated beams.

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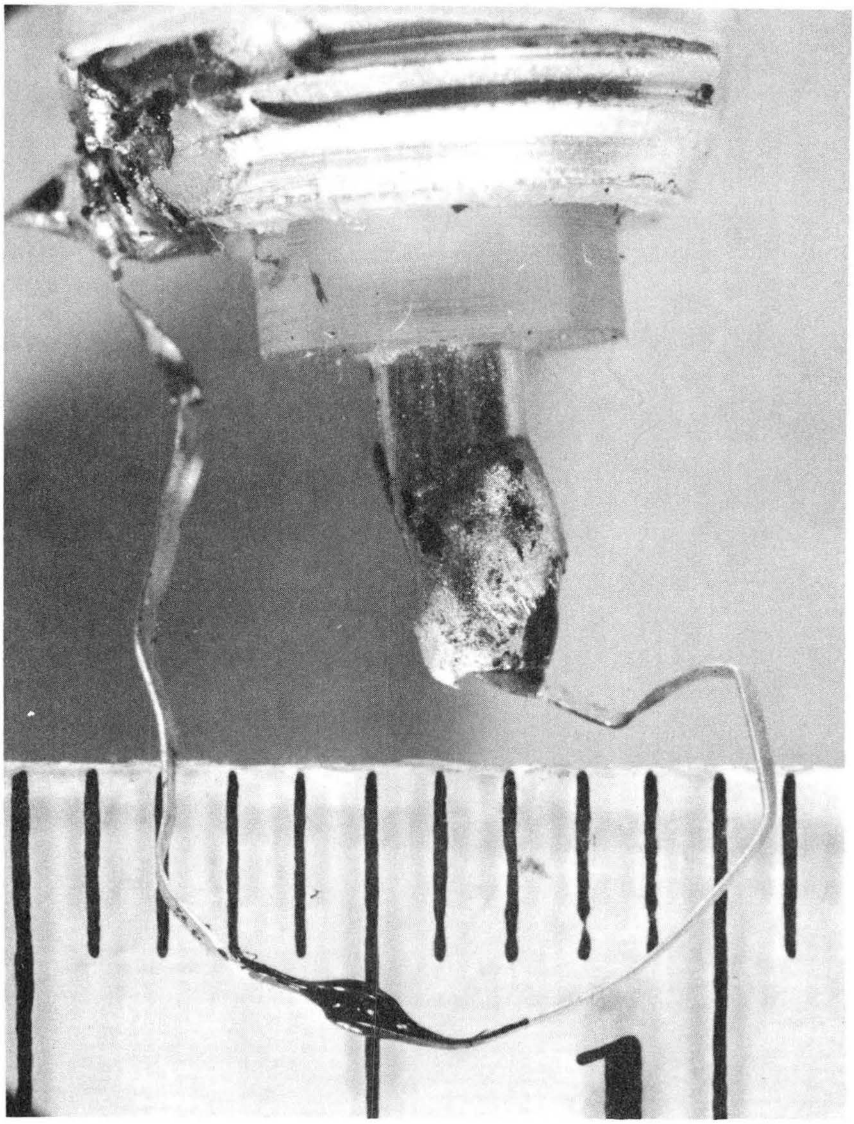
FIGURE CAPTIONS

Fig. 1. Photograph of diode mounted on BNC connector (millimeter divisions in background).

Fig. 2. Beam profile of 50-MeV proton beam.

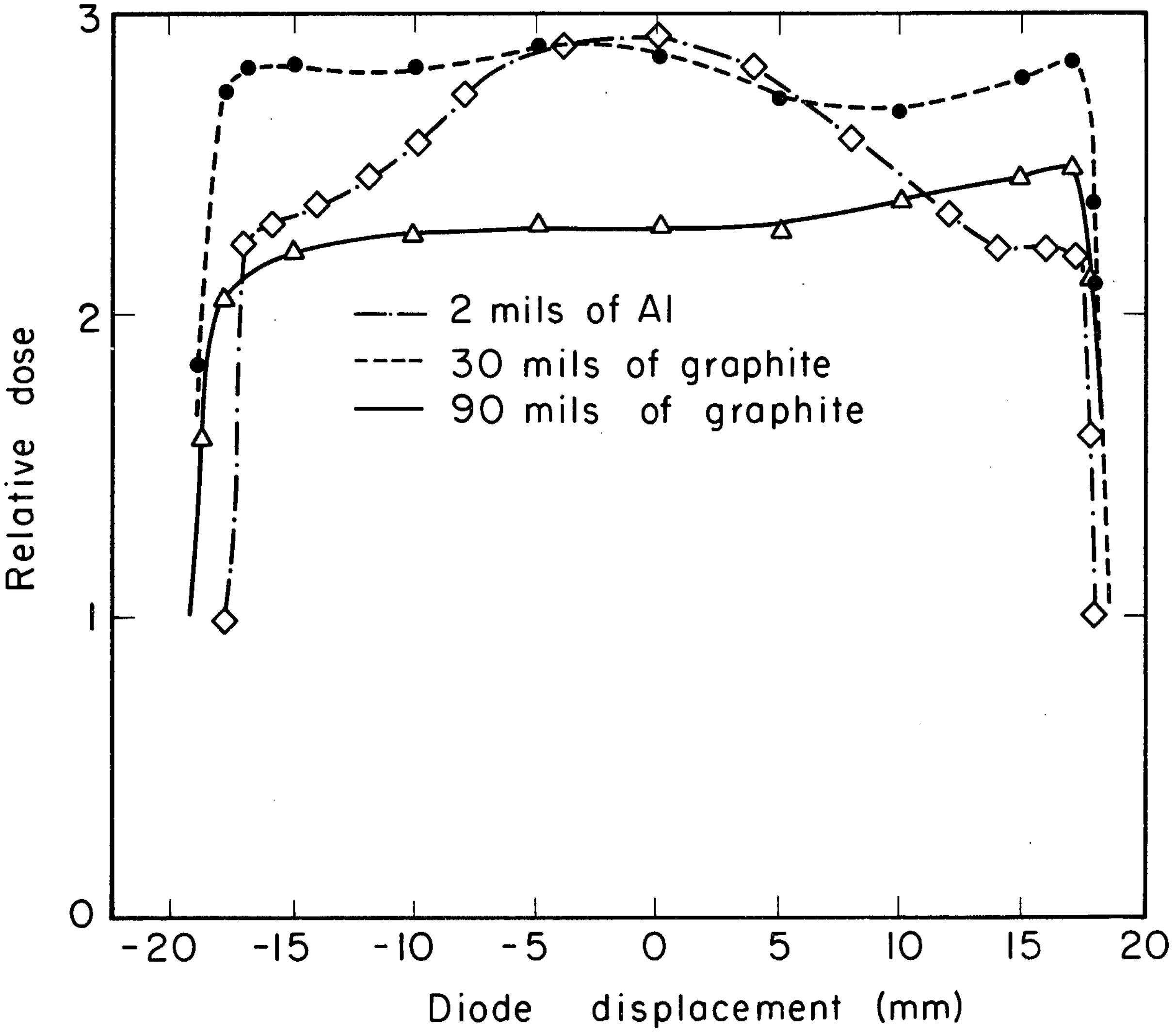
Fig. 3. Beam profile of 910-MeV α beam passing through a 0.25-in. collimator.

Fig. 4. Bragg curve of 910-MeV α beam in copper.



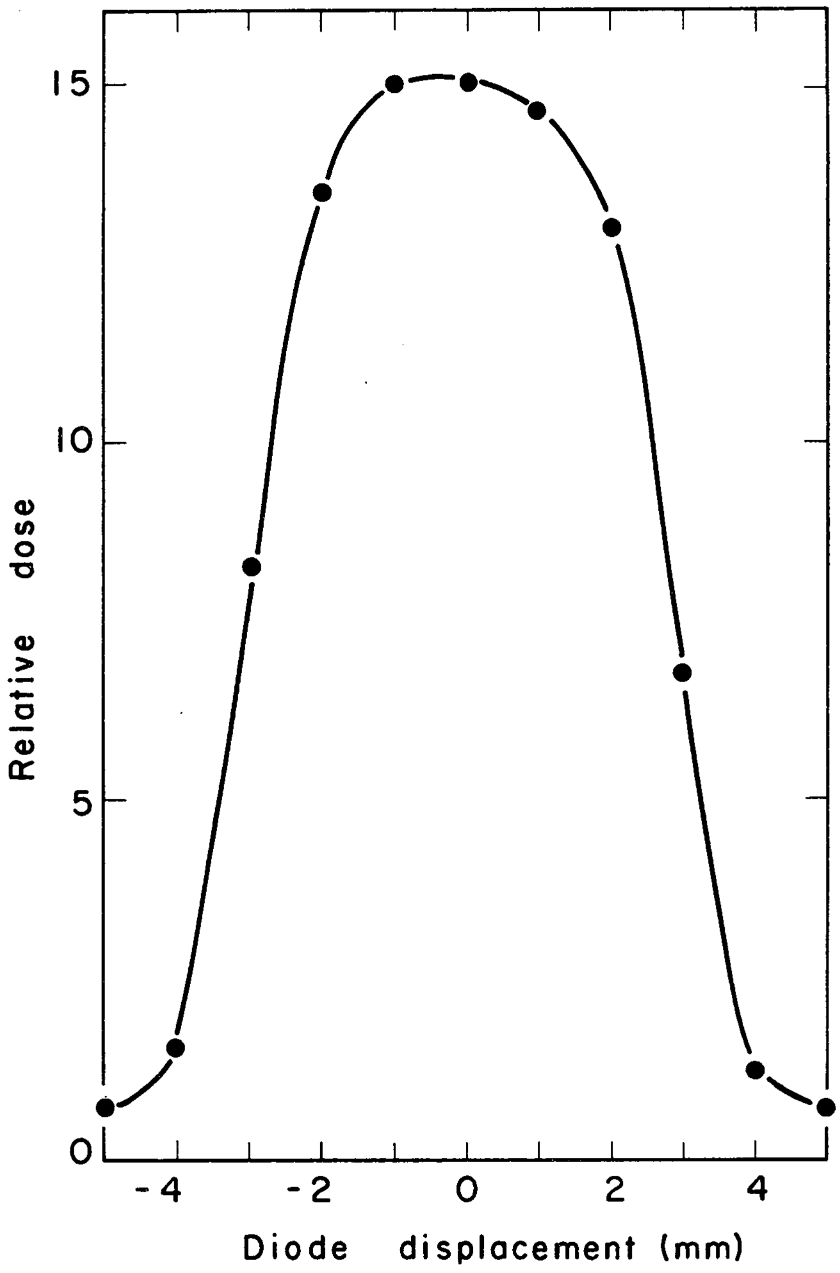
ZN-5266

Fig. 1



MUB-8548

Fig. 2



MUB-8547

Fig. 3

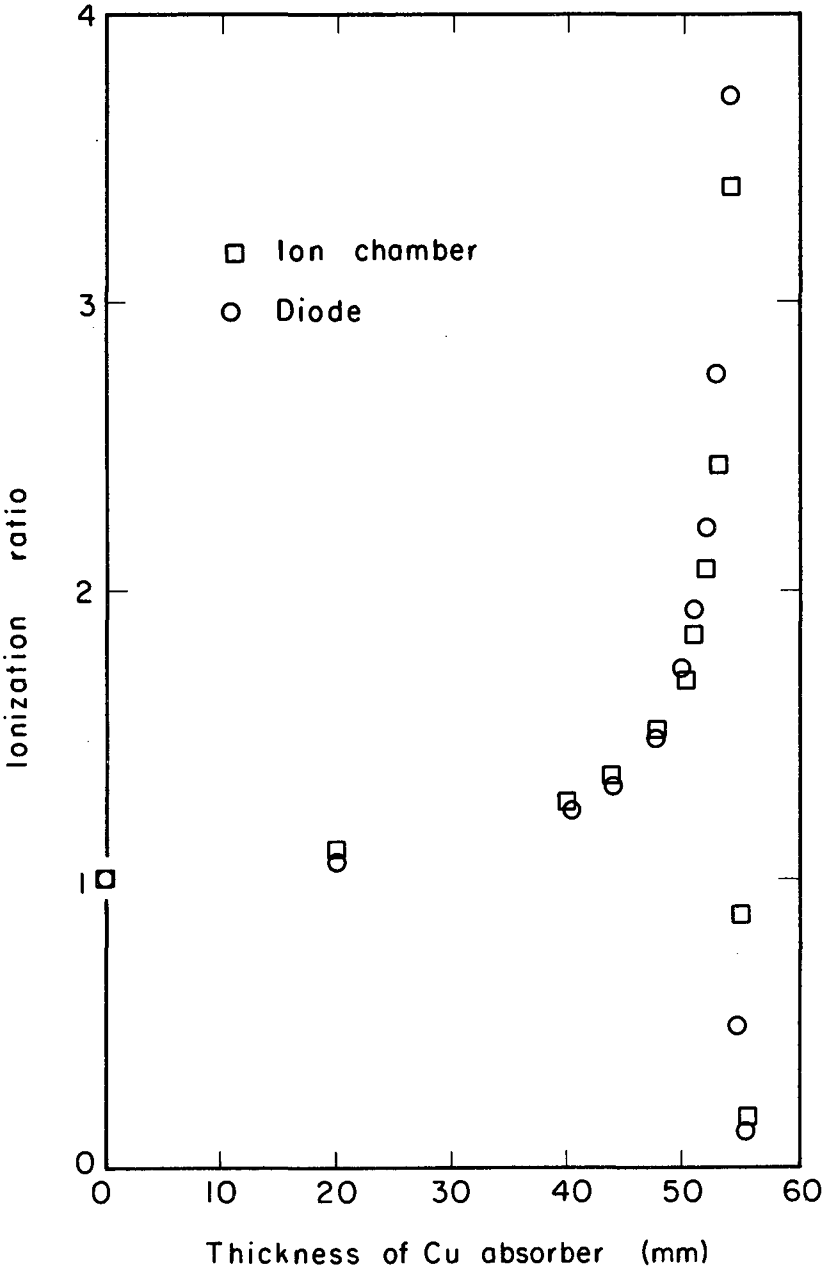


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Fig. 4