Theoretical calculation of a charged particle detector's response fabricated by Semi Insulating (SI) GaAs

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Abstract

In the present work we have conducted theoretical calculations of the transient response of SI GaAs radiation detectors. The detector under consideration is a typical reverse biased Schottky diode of high purity undopped GaAs or compensated material. The electrical characteristics of the "dark" equilibrium state, derived by the Poisson and continuity equations, indicate that in the compensated detector is established a wider active region [1]. We considered that the detector operates in pulse or current mode. In pulse mode, a single charged particle (i.e. proton, a–particle) incidents the detector on either the Schottky or ohmic contact, whereas in current mode the detector is irradiated by a short-lived particle beam.

1 Ionization of the detector – C.C.E and Energy Resolution

The effect of the charged particles interaction with the detector's material is the ionization of the detector. This ionization (direct and due to recoils) is calculated by the use of Monte Carlo simulation (IBM SRIM v.2000.39)[2] and consists of e–h pairs. The electric field applied to the detector by the reverse bias, forces the generated carriers to the collecting contacts.

1.1 Energy deposition – Bragg curves

The plot of specific energy loss along the track of a charged particle is known as a Bragg curve. For most of the track the charge of an a–particle is two electronic charges and the specific energy loss increases roughly as 1/E (E: a–particle energy). Near the end of the track, the charge is reduced through electron pickup and the curve falls off. The Bragg curves for a single a–particle track and for the average behavior of a parallel a–particle beam, are somehow different because of the energy straggling phenomena. Figure 1 represents the Bragg curves of a 100 protons and a–particle parallel beams incident on a bulk GaAs detector.

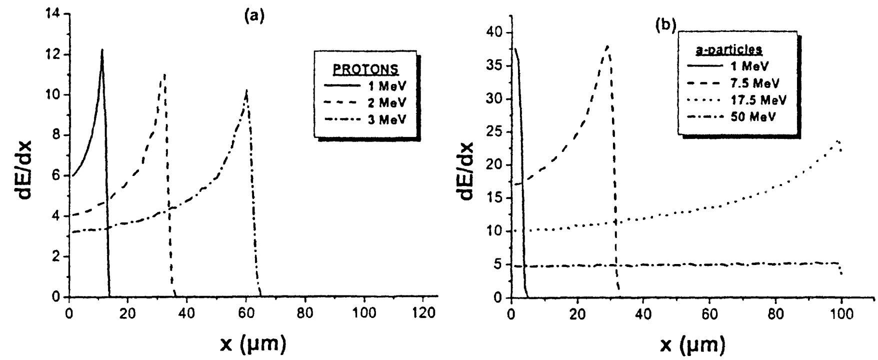

Fig. 1. Bragg curves indicating the energy deposition of (a) protons in a 125μm thick bulk GaAs detector, (b) a–particles in a 100μm thick bulk GaAs detector. The ionization of the detector is proportional to the particle's energy loss dE/dx.

1.2 Detector's charge collection efficiency and energy resolution

The c.c.e achieved by the detector is calculated by the Ramo's theorem and the evaluation of energy resolution is based on the calculation of the mean value of the "induced charge" to the detector's contacts and it's typical deviation. The results of these calculations are illustrated in Figure 2. We concluded that there is a difference in the results for c.c.e and energy resolution when the detector is irradiated from the front (Schottky) and the back (ohmic) contact, especially when the incident a-particle energy is in the range of 1 to 60 MeV.

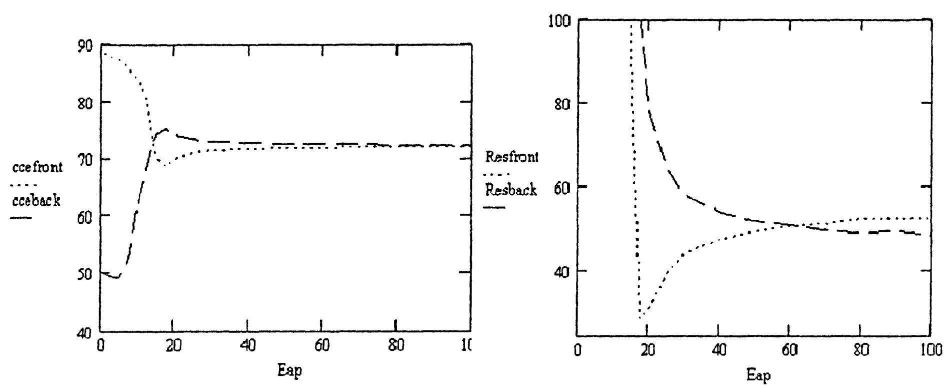

Fig. 2. Energy dependence of the c.c.e (left) and energy resolution (right) calculated for a bulk SI GaAs 100μm thick detector irradiated by a–particles with energy range 1–100MeV.

The difference is significant in this energy range, due to the dissimilar distribution of the photo-carriers within the detector (Fig.1) and the width of the specific active region established. The best results are accomplished when the detector is irradiated by 17.5MeV a–particles (detector's width 100μm, V_{bias}=100V, active region 66μm), hence the choice of the irradiated contact is meaningless for particle energies grater than 60 MeV. In this specific energy the c.c.e achieved during the back irradiation is better than the one achieved during the front irradiation, hence the energy resolution behavior is adverse.

2 Dynamic behavior

The dynamic behavior of the detector was obtained by the use of finite element analysis, taking under consideration the generation – recombination processes, the drift of the carriers to the collecting contacts and their collection. We divided the detector's volume into a considerable large number of thin strips and calculated the amount of carriers contained in each strip for a specific time step. The time step was taken considerably low, in order to ensure that the maximum drift of the carriers contained in a strip is limited to the next strip and that the recombination process will be practically negligible in this time. The detector's current pulse response is obtained by integrating the charge of all the strips, for a time interval greater than the irradiating beam duration. Figure 3 illustrates the calculated current pulse produced by a 100μm thick bulk GaAs detector when operating in pulse and current mode, irradiated by 17.5MeV a-particles.

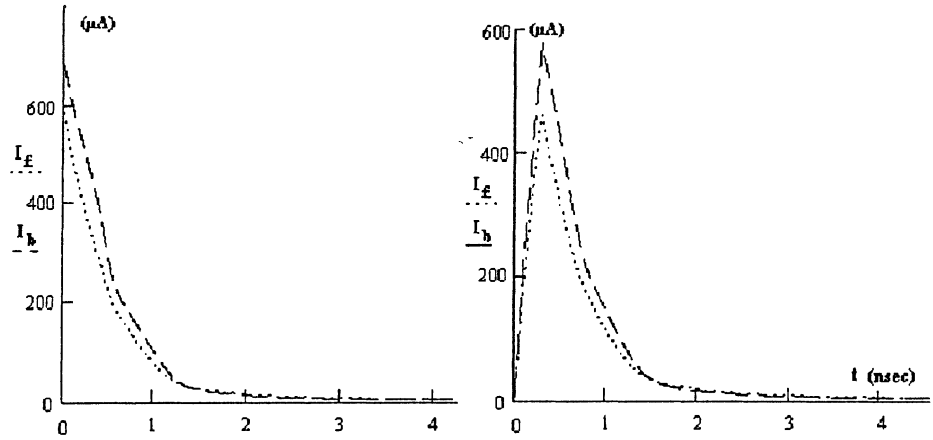

Fig. 3. Calculated current pulse produced by a GaAs detector when irradiated from the Schottky contact (doted) or the ohmic contact (dashed) when operating in pulse mode (left) and current mode (right).

In this calculation we considered the contribution of all the generated carriers to the "induced charge", because the formation of the current pulse is not only due to the collected charge but is also due to those carriers that never reach the contacts because of the trapping and recombination phenomena.

The pulse formation illustrated above explains the adverse behavior of the detector's c.c.e and energy resolution during irradiation by 17.5 MeV a-particles. During front irradiation c.c.e is worst but the photo-carriers collection rate is better resulting a lower amplitude current pulse but sufficiently narrower than the one achieved during back irradiation.

The current pulse shaping dependence is explained in Figure 4. The pulse rise is due to (faster) electrons and the abrupt fall shape indicates the collection of the electrons generated near the ohmic contact. The "knee" that follows is due to the lateness collection of the electrons generated away from the collecting contact and those that have been trapped and re-emitted by the native GaAs traps. Finally the slow current component is due to the hole drift and collection to the Schottky contact.

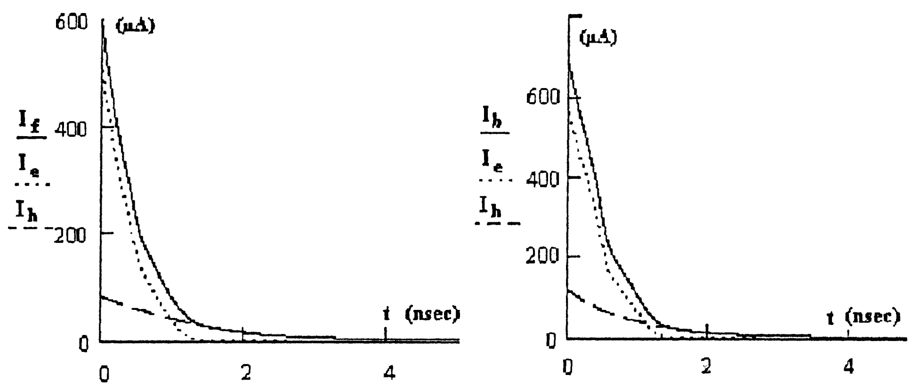

Fig. 4. Simulated current pulse during the 17.5 MeV front (left) and back (right) irradiation of a 100μm thick bulk GaAs detector operating in pulse mode. The electron (dot) and hole (dash) current components resultant is the total current (solid).

The current pulse shape and amplitude are significant information for both pulse and current mode operation. In pulse mode, this information is useful to derive the pulse height spectra i.e. the energy of the incident particle. In current mode operation this information is useful to derive the transient characteristics of the incident particles.

References

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