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PLASMA TIME AND RELATED DELAY EFFECTS IN SOLID STATE DETECTORS

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The initial delay in the response of surface barrier detectors to heavily ionizing particles is experimentally studied. Various experimental results are given about this delay in different detectors as a function of electric field and temperature. These results can be of particular interest in experiments requiring a time reference obtained by means of a solid state detector.

1. Introduction

The possibility of obtaining an information about the instant of radiation-detector interaction from the current or voltage signals supplied by a semiconductor detector has been studied by many authors[1–6]). This timing use requires a knowledge of the parameters which influence the rise time of the voltage signal (or the duration of the current signal) in order to be able to evaluate this time and its variations due to changes in bias voltage, temperature, etc. This knowledge enables, for instance, to estimate the delay between the radiation-detector interaction and the reaching of the threshold of a voltage-sensitive fast trigger circuit. The variations of this delay resulting from voltage signal rise time variations[7]) obviously add themselves to the statistical fluctuations due to signal amplitude noise[4]). As an example, fig. 1 shows (broken lines) the switching delay of a trigger circuit as a function of the threshold voltage (expressed as percentage of the maximum value reached by the voltage signal). The calculations refer to 3.5 MeV α-particles incident on a 260 μm thick surface barrier detector made from 40 kΩ·cm n-Si. The two curves refer to two different values of the detector bias voltage, and consequently to two values of the electric field on the centroid of the track[8]). These theoretical previsions are performed by solving the well known equations describing charge collection in overdepleted surface barrier detectors[8]).

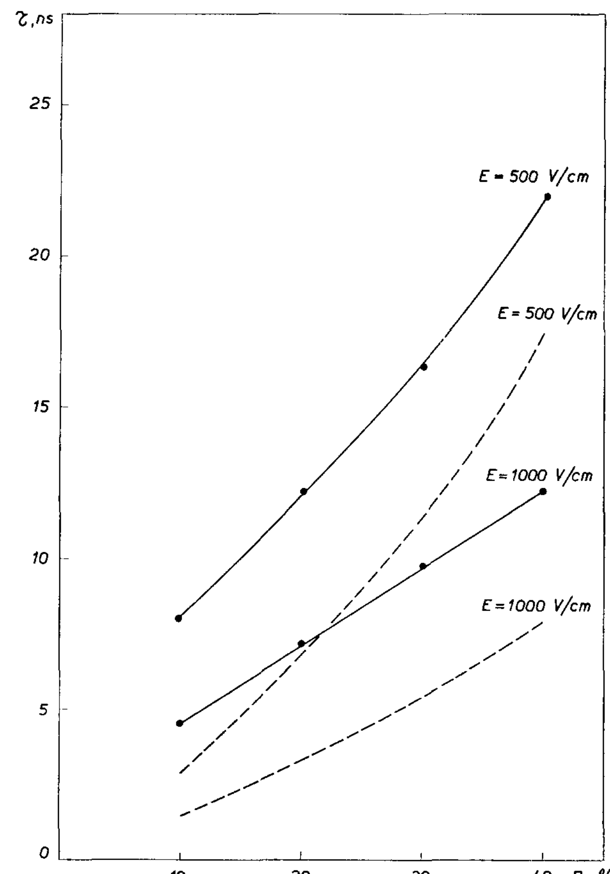

Fig. 1. Switching delay of a trigger circuit as a function of the threshold voltage (expressed as percentage of the maximum value reached by the voltage signal) when the driving signal is supplied by a solid state detector. The theoretical previsions (broken lines) refer to 3.5 MeV α-particles incident on a 260 μm thick surface barrier detector made from 40 kΩ·cm n-Si; they refer to two different electric fields and are performed without taking into account any plasma effect. The solid lines show experimental results for the same detector.

Fig. 1 shows a remarkable discrepancy between theoretical previsions and experimental results: the measured delays, in fact, are systematically longer than the calculated ones. This discrepancy comes from the fact that the above mentioned theoretical approach completely disregards the so-called "plasma effect" [8]), which, on the contrary, is very important in the situation considered in fig. 1. The electron-hole pairs

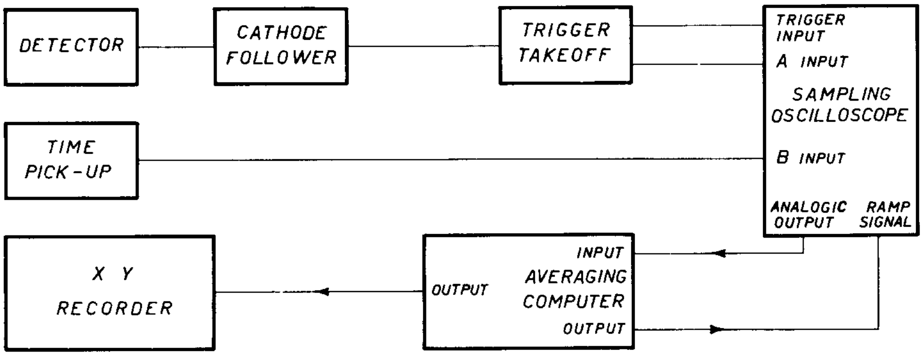

Fig. 2. Block diagram of the experimental apparatus.

generated by a strongly ionizing particle inside the space charge region have in fact such a high density that, as soon as collection takes place (under the action of the electric field due to the bias voltage), a counter electric field is generated. Charge collection is then substantially blocked, until, owing to transverse diffusion, the density falls to lower values. Also after this time, however, charge collection is slowed down by the influence on the electric field of the density of the charges to be collected.

This model for the plasma effect has been already successfully used to predict the slowing down of the (10–90%) rise time of the voltage signal[9]). We can also expect plasma effect to be particularly relevant at the beginning of collection, giving rise to a delay connected with the dissolution of the ionized column generated by the incident radiation. This means that the data on plasma time[8]) are not sufficient for timing previsions, since they give no information about the initial delay.

In this paper an experimental investigation is then made about this delay effect, which can be a relevant one, particularly at low electric fields* and high ionization densities.

* A low field region exists inside all surface barrier detectors near the back contact where the applied voltage is lower than the depletion voltage; the collection time can therefore be delayed when the incident particle loses some energy in this region.

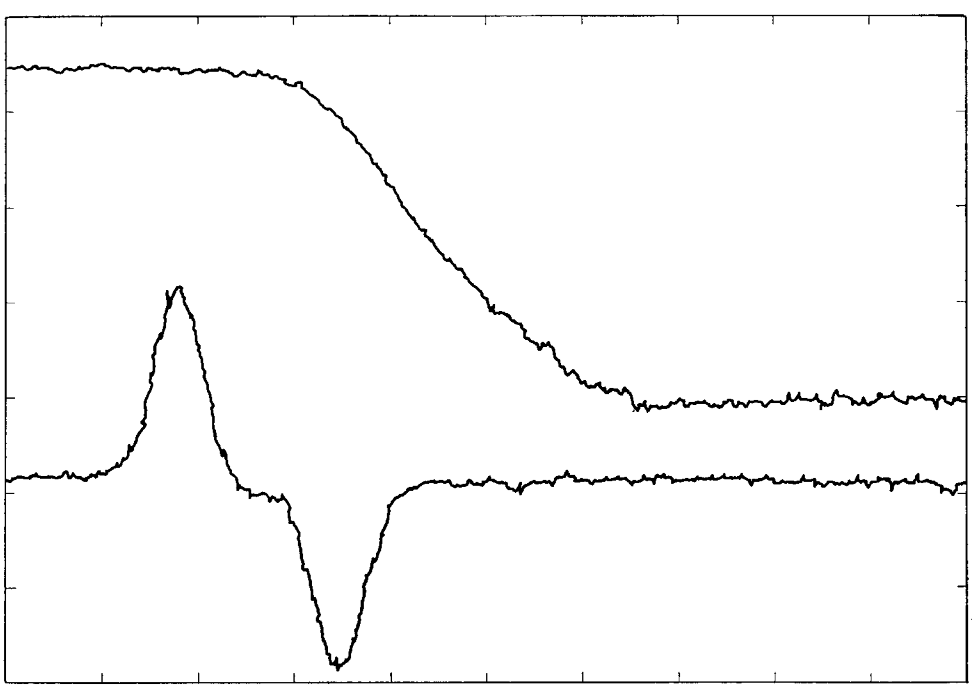

Fig. 3. Typical record of voltage signal supplied by detector and time reference current signal supplied by the time pick-up.

2. Description of the experimental apparatus

Fig. 2 shows a block diagram of the experimental apparatus. The ionizing particles are supplied by a pulsed accelerator (the Padua University Van de Graaff). The ion bursts have a duration less than 2 ns (fwhm) and a repetition rate of 1 Mc/sec. Each burst passes through a time pick-up coaxial electrode, which is connected by means of a 50 Ω cable to sampling oscilloscope input. A time reference current signal (lower signal in fig. 3) is then produced. A small fraction of the ions contained in each burst is then elastically scattered by a thin gold foil (set at 45° with respect to beam axis) and after passing through a collimator with a 2° acceptance angle impinges on the detector. By means of a convenient choice of beam intensity it is possible to get at most one ion per burst to reach the detector. This avoids the large dispersion in the voltage signal amplitudes which could result from variations in the number of incident particles. The sampling oscilloscope must then be triggered by the detector signal, since its average repetition rate is lower than burst repetition rate. The signals from the detector and from the pick-up electrode are fed to the two vertical channels of the sampling oscilloscope and are then recorded on the same sheet of an XY recorder. The Average Computer drastically reduces the noise, so that a typical record looks like the one shown in fig. 3.

The delays which can be read from the records have no absolute meaning. This obviously depends on the fact that the two signals are differently delayed by the coaxial cables; the most important reason, however, is the fact that the pick-up signal does not give the instant of radiation-detector interaction, but the instant of passage of the burst through an electrode set at a certain distance from the detector. It will then be necessary, for a correct interpretation of experimental results, to consider delay variations with respect to a value assumed as reference delay.

Moreover, as we said in the introduction, delay measurements are meaningful only if they follow the choice of the voltage level at which the delays themselves are to be measured. Since our experimental results are obtained by means of particles of one energy, the choice of this level can be done in terms of percentage of voltage signal maximum amplitude. In particular we chose, as a definition of delay, the time interval between the positive maximum of the pick-up signal and the 10% of the detector signal maximum amplitude. The choice of the last value is suggested by conflicting requirements. On the one hand, in fact, it is necessary to choose low amplitude values in order to enhance the delay effect due to the first collection stage; on the other hand, however, at low amplitude values reading difficulties can arise, due to noise and to a "rounding off" effect introduced by electronic circuitry.

3. Experimental results

Delay measurements were made on five different n-Si surface barrier detectors, whose characteristics are reported in table 1. The measurements were made at

TABLE 1

Detector	Width (μm)	Resistivity ($\Omega\cdot$cm)
1	260	40 000
2	260	40 000
3	260	40 000
4	190	18 000
5	190	18 000

300, 185 and 77° K using 3.5 MeV α-particles, deuterons and protons. Since our purpose is the study of delays due to a plasma effect, we can assume as reference delay the value corresponding to protons at high electric fields and low temperature. In this case the measured delays are practically independent of electric field and temperature, and plasma effect can be supposed to be negligible[8,9]). In order to obtain the reference delays for deuterons and α-particles it is obviously necessary to take into account the different transit times between the pick-up electrode and the detector. This is easily done, since the energy and the distance are precisely known.

Fig. 4 shows the dependence of the instant the voltage signal reaches 10% of its maximum value (measured with respect to reference delay) on the electric field on the centroid of the ionized track; the data shown refer to 3.5 MeV α-particles and to 300 and 185° K.

The procedure followed to obtain the theoretical previsions shown in fig. 1 can also give the complete time behaviour of the voltage signals induced at the detector leads by the motion of charge carriers inside the space charge region without considering any plasma effect[8]). On the other hand, plasma time values previously published[8]) were obtained by considering this effect as an "integration" of the voltage signal, which slows down collection time. This approach permits to obtain a prevision of the instant the voltage signal reaches a given percentage of its maximum value by means of a simple integration of the signal itself with a "plasma time constant" whose value is taken from plasma time data.

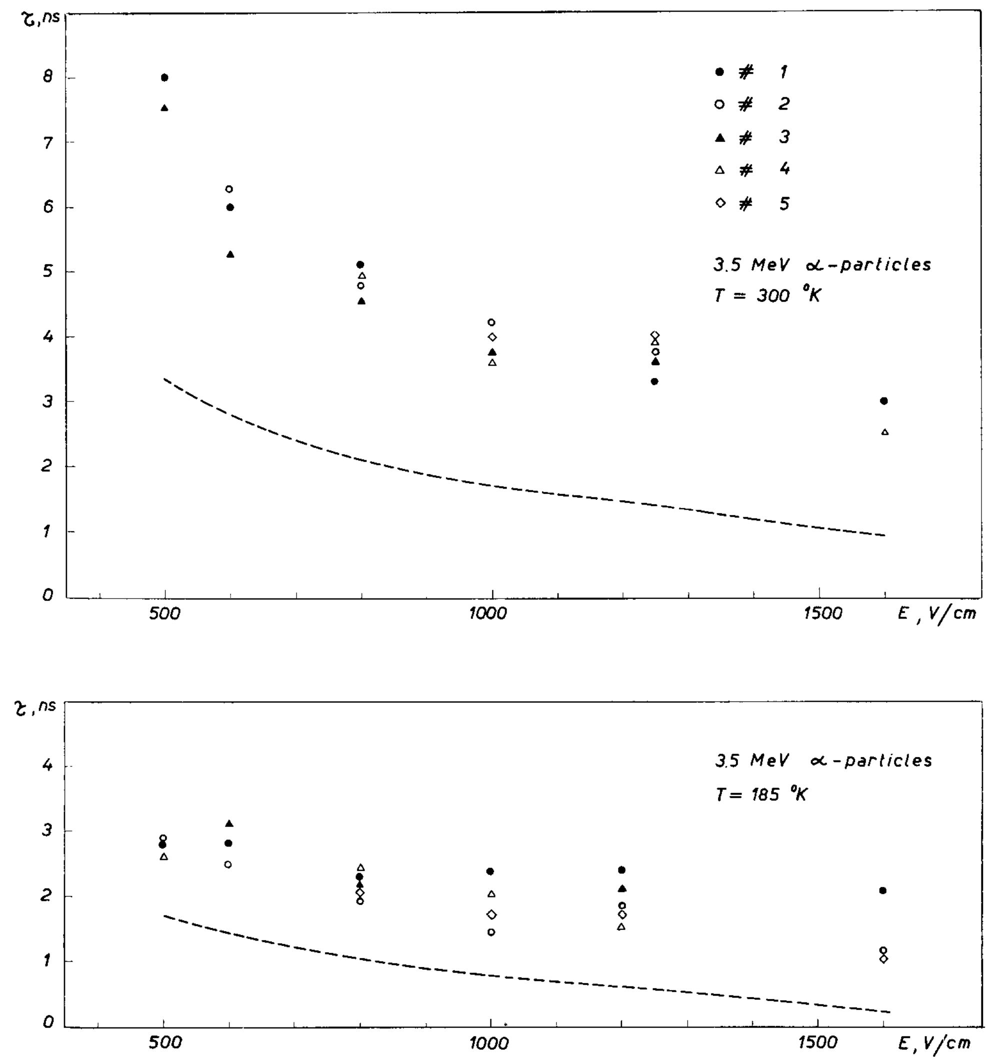

Fig. 4. Experimental results on the dependence of the instant the voltage signal reaches 10% of its maximum value (measured with respect to reference delay) on the electric field on the centroid of the ionized track for 3.5 MeV α-particles incident on five different detectors at two temperatures.

As it can be seen in fig. 4, the experimental results are remarkably higher than the predictions obtained in this way (broken lines). This clearly shows the presence of an initial delay, which is not predicted in the previous oversimplified approach where the only source of delay was the plasma slowing down effect. This initial delay is particularly important at ambient temperature and low electric fields.

Fig. 5 shows the dependence on the electric field of the instant the voltage signal reaches 10% of its maximum value for 3.5 MeV deuterons and protons at ambient temperature. In these cases, and then also at lower temperatures, it is impossible to see clearly any delay effect other than the one due to slowing down. On the other hand, it is obvious from a physical point of view that the delay must decrease when the initial density of the ionized column is decreased.

Let us finally briefly comment upon experimental errors. Since the reading error is less than 0.5 ns, the indetermination due to burst time width is the main cause of error, so that we must expect, at most, a time spread of about 2 ns. On the other hand, the averaging computer is effective in reducing the error, so that, as it can be seen in the figures, the time spread is generally not larger than 1 ns.

4. Conclusions

Our experimental results have evidenced an initial

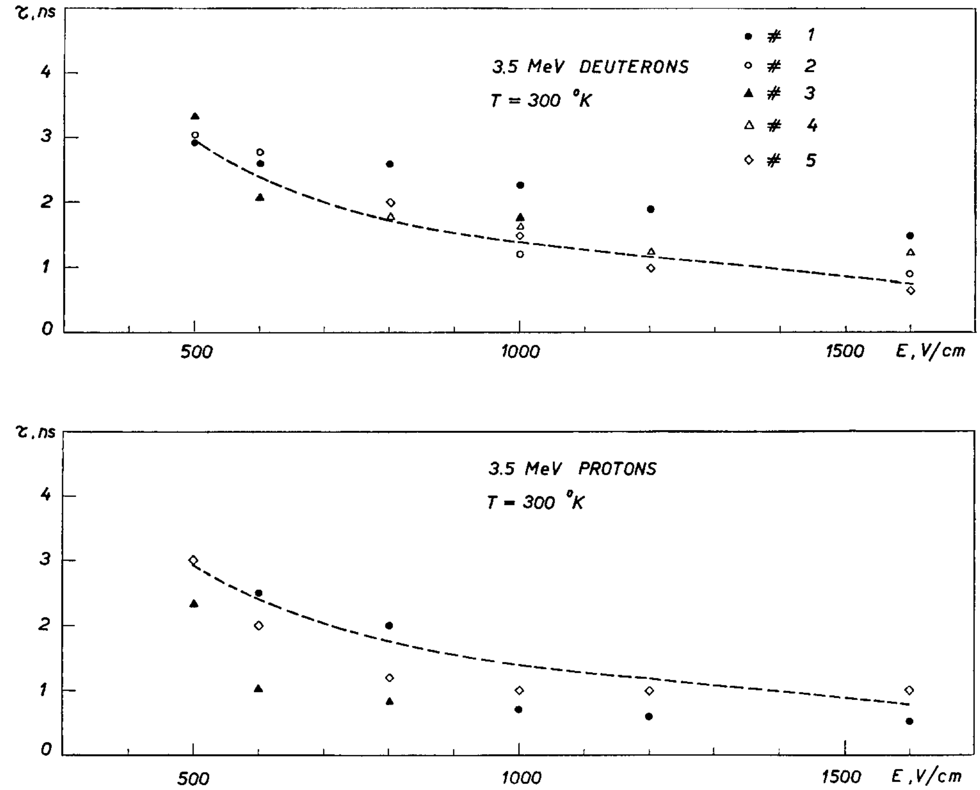

Fig. 5. Experimental results on the dependence of the instant the voltage signal reaches 10% of its maximum value (measured with respect to reference delay) on the electric field on the centroid of the ionized track for 3.5 MeV deuterons and protons incident on different detectors at 300°K.

delay effect in the collection of the charge carriers generated by a strongly ionizing particle entering the space charge region of a surface barrier detector. It has been shown that, while this delay obviously comes from a plasma effect, it cannot be predicted simply on the ground of a slowing down model, particularly when high ionization rates and low electric fields are considered.

Various experimental results have been given about the delay in different detectors as a function of electric field on the centroid of the ionized track and of temperature. These results can be of particular interest for the design and the interpretation of experiments requiring a time reference obtained by means of a solid state detector.

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