



## Description of current pulses induced by heavy ions in silicon detectors

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#### ABSTRACT

The polarization of the electron-hole pairs induced by 80 MeV <sup>12</sup>C ions in a silicon detector was considered and connected to the relative dielectric permittivity. The dissociation of pairs was supposed to take place with a constant probability in a time unit. The exact coordinate dependence of the modified electric field, inside and outside the ion range, was found as the solution of the one-dimensional Maxwell's equation for the electric field in this inhomogeneous medium. The improvement of the current signal simulation with that time-dependent treatment is encouraging, as compared to a prompt carrier collection in an undisturbed electric field.

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### 1. Introduction

The charge and isotopic abundances of the nuclear reaction products in multifragmentation events prepared at Fermi energies are of crucial importance for the present experimental studies concerning phase transition and the isospin degree of freedom. The possibility of charge identification without the energy threshold implied by the classical  $\Delta E-E$  telescope method and the extension of the isotopic resolution from light charged particles (LCP), like protons, to heavy ions (HI), e.g. carbon ions, over a large solid angle, are thus desirable [2–5]. To this aim, we attempt to exploit the sensitivity of the entire current pulse shape in solid state detectors to the carrier density along the ionization track, and thus to the charge ( $Z$ ), mass ( $A$ ) and energy ( $E$ ) of the detected ion. This fact becomes possible with the advent of modern current sensitive preamplifiers, giving access to the nearly undisturbed current flowing inside the detector [3]. The perfect simulation of the time dependence of the experimental signal produced by a given ion ( $Z, A, E$ ) appears thus to be of major interest in relation with Pulse Shape Discrimination (PSD) technique. The first step, approached in the following, is to quantify the extraction and collection of the induced charge

carriers by considering also the eventual electric field distortion due to their presence along the highly ionized track.

The paper is organized as follows. In Section 2, after a brief description of the experimental conditions, the role of the mean linear density of carrier pairs is put forward to explain the failure of a basic simulation of current pulses for heavy ions. A new simulation based on a dielectric polarization and a constant rate of pair dissociation is described in Section 3; the proposed scenario and equations are presented and applied to <sup>12</sup>C ions. Conclusions of the work done and prospects are given in Section 4.

### 2. Current pulses and concentration of carrier pairs along the track

The neutron transmutation doped (n-TD) silicon detector [1] used in this work is of the passivated implanted planar silicon (PIPS) type with an overdepleted abrupt p–n junction, a 310  $\mu\text{m}$  n-type bulk and an extremely thin p-type zone. The experimental conditions, the detector and the current preamplifier used for the LCP and <sup>12</sup>C ions are detailed in Ref. [3]. Energy measurements using the charge output of the same preamplifier show a good linearity and do not put in evidence any significant pulse height defect for the <sup>12</sup>C ions, within the resolution limits of 0.3%. On the other side, current pulses delivered by the current preamplifier

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output and induced by protons and  $^{12}\text{C}$  ions of a few MeV/nucleon impinging on the n-type rear side have very different shapes [3]. Mean current pulses (averaged over about a thousand) digitized at 4 Gsamples/s—8 bits are used to validate or not the simulations. The homogeneously doped n-TD detector used here is suitable for the PSD technique, but the following description has to be valid for other type of ionizing particle detectors in which high charge carrier concentrations appear, e.g. the classical surface-barrier ones.

A basic approach can be used to start the comparison. If  $d$  is the detector thickness,  $e$  the electron charge magnitude,  $N_D$  the bulk concentration of donors and  $\varepsilon = \varepsilon_r \varepsilon_0$  is the silicon dielectric permittivity, written as the product of its relative dielectric permittivity  $\varepsilon_r$  (for silicon  $\varepsilon_r = 11.7$ ) by the vacuum permittivity  $\varepsilon_0$ , the expression of the depletion bias voltage of the junction is  $V_d = eN_D d^2 / (2\varepsilon_r \varepsilon_0)$ . When the applied bias voltage  $V$  is higher than the depletion one ( $V > V_d$ ) and for  $x$  considered from the rear side, the electric field established in the detector volume reads  $F(x) = 2V_d x / d^2 + (V - V_d) / d$ . For the present study the detector has a resistivity of  $2500 \Omega \text{ cm}$  ( $N_D \approx 1.9 \times 10^{12} \text{ atoms/cm}^3$  and hence  $V_d = 128 \text{ V}$ ) and is overbiased at  $V = 190 \text{ V}$ . An ionizing LCP induces a rather low concentration of carriers along the particle path. Driven by this electric field, they drift, with mobilities depending of the field strength [6,7], towards the electrodes. According to the Ramo's theorem [8], every moving charge, electron (e) or hole (h), contributes to the electric current [9]. Just after the ionization ( $t = 0$ ), their local linear density in an infinitesimal slice  $dx$  is  $N_0(x) = N(x, t = 0) = (1/w)|dE/dx|$ , where  $w = 3.62 \text{ eV}$  is the energy per e-h pair creation and  $|dE/dx|$  is the local energy loss provided by Ref. [10]. The current pulse of, e.g., 5 MeV protons is very well reproduced by this basic approach [3]. Conversely, the same simulation completely fails in case of 80 MeV  $^{12}\text{C}$ —Fig. 1.

The question arises why the basic approach fails in reproducing current pulses from  $^{12}\text{C}$ . The answer is the following: the mean stopping power  $E/l$  ( $l$  being the range of the particle), and hence the mean linear density of carriers:  $\langle N_0 \rangle = (1/w)(E/l)$  greatly varies as shown in column 4 of Table 1. As a consequence, the mean bulk concentration of e-h pairs is at least one order of magnitude higher in case of carbon (a cylinder of radius  $r_c$  [11] may be used as approximation to estimate the ionized track volume), but still far below the free electron concentration in a conductor, of the order of  $\approx 10^{22} \text{ cm}^{-3}$ .

Historically, this difference, associated to a slower carrier collection for HI, was quantified as a plasma delay. This would be

**Table 1**

Ranges and mean values of the linear density of carrier pairs  $\langle N_0 \rangle$  for 5 MeV protons and 80 MeV  $^{12}\text{C}$  (see text for explanations).

Ion	$E$ (MeV)	$l$ ( $\mu\text{m}$ )	$\langle N_0 \rangle$ (pairs/ $\mu\text{m}$ )
p	5	215	$6.5 \times 10^3$
$^{12}\text{C}$	80	131	$1.7 \times 10^5$

one of the main components (besides the preamplifier characteristics) of the current signal rise-time,  $\tau_r$ , which relationship measured experimentally is:  $\tau_r^{\text{HI}} > \tau_r^{\text{LCP}}$  [11–16]. The present current preamplifier and the digitizing technique allow to investigate the influence of the impinging particle energy and nature on both, the rise time (mainly related to the plasma delay) and the fall time (accounting for the carrier drift), i.e. on the entire induced signal.

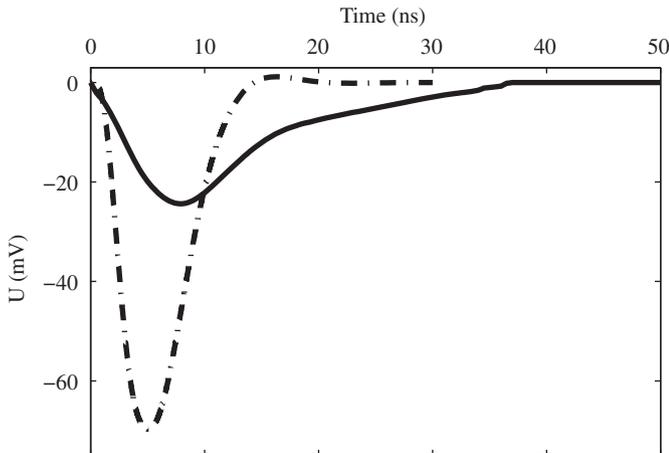
Traditionally, the plasma delay scenario is based on the analogy with a conductor placed in an external electric field, or eventually with an electronic tube. The separated negative and positive charges in the ionization track are prompted towards its extremities under the action of the electric field. This polarized plasma is supposed to act as an electric shield: inside, the electric field cancels out ( $F = 0$ ), which is equivalent to an infinite dielectric permittivity ( $\varepsilon \rightarrow \infty$ ). Then, the plasma undergoes an erosion mainly due to the radial diffusion of the carriers. The electric field is finally restored and the carriers may start their drift towards the electrodes. But, the delay time involved by the diffusion process is two or three orders of magnitude longer [17] than the experimentally measured rise times. To overcome these short-comings, one had to resort to artifices as, for example, to allow the penetration of the external electric field into a thin sheet of plasma, in order to speed up its erosion [18].

The above image has a basic difficulty: total electric shielding and hence infinite permittivity are compatible with a conductor, in which the valence band and the conduction band are partially superimposed, while the silicon is, in the framework of the electrodynamics, a dielectric, having a gap of 1.12 eV between the valence and conduction bands at room temperature.

### 3. A new simulation

#### 3.1. Scenario and equations

Actually, the alternative to this “conductor” scenario is the “dielectric” one; we make the following ansatz: (i) the charge carriers created by an ionizing HI may remain bound for a few instances due to their high concentration and the implied electrostatic forces and (ii) the probability to extract the carriers is the same, irrespective of their sign. This may be equivalent with electrons paired with their nearest neighbour holes in, let us say, exciton-like couples [19]. We shall consider them as “dipoles” distributed in the whole plasma column and oriented by the initial electric field. The barycentres of the negative and positive charges inside the ion track  $l$  are thus slightly shifted, introducing the bulk dielectric polarization. Consequently, as we shall show in the next section, the electric field strength at any position  $x$  inside the plasma column  $F_{in}(x, t)$  will be, for a while, lower than the undisturbed value  $F(x)$  at the same point, but not completely suppressed:  $0 < F_{in}(x, t) < F(x)$ . At the same time, the probability of dipole dissociation is not null and, via a mechanism which is disregarded here, it starts at once. Albeit diminished,  $F_{in}(x, t)$  may immediately drive a part of the carriers towards the two electrodes of the detector. The diffusion is no more seen as a



**Fig. 1.** Mean experimental current signal induced by 80 MeV  $^{12}\text{C}$  ions impinging on the rear side of a silicon detector [3]—full line; the simulation using undisturbed electric field—dashed-dotted line—completely fails.

stage sine qua non before setting in the charge collection. It is not considered in the following approach.

The “dipole” dissociation hypothesis, allowing equal release rates for electrons and holes, facilitates the calculation algorithm. We propose a constant dissociation probability  $\lambda$  in the unit time:  $(-1/n(x,t))dn(x,t)/dt = \lambda$  for the unstable ensemble formed by these “dipoles” and the electric field. Here  $n(x,t)$  is the instantaneous bulk concentration of one type of carriers at the coordinate  $x$ , and  $n_0(x) = n(x, t=0) = (1/(\pi r_c^2 w))|dE/dx|$ . A constant dissociation rate is a direct consequence of the Fermi's Golden Rule coupling the initial states to the final ones and having a high degree of generality. We have already used the same type of equation, completed with a quadratic term accounting for the light quenching in mineral scintillators or for pulse height defect in silicon junctions, to describe the integral of the signal in solid state detectors [20,21].

By using the linear density of carriers  $N(x,t) = \pi r_c^2 n(x,t)$  one may write the first equation of our treatment:

$$-\frac{1}{N(x,t)} \frac{dN(x,t)}{dt} = \lambda \quad (1)$$

containing the constant  $\lambda$  as a first parameter. The e-h pairs contained in an infinitesimal slice are progressively dissociated and the resulting free carriers are carried out, concomitant with a progressive restoration of the electric field. The extraction of the carriers is thus controlled as long as  $N(x,t) < N_{th}$ ; when the threshold value  $N_{th}$ , our second parameter, is reached, all the remaining carriers are allowed to drift towards the electrodes.

As a consequence of the bulk dielectric polarization, the local instantaneous dielectric permittivity  $\varepsilon'(x,t)$  inside the ionization track will increase in comparison with the usual silicon dielectric constant  $\varepsilon$ :  $\varepsilon'(x,t) > \varepsilon$  for  $x \leq l$ . This enhancement is in fact connected to the local energy loss in this exact, infinitesimal treatment. A change of the dielectric constant was already considered in the early nineties [22], but always in the ancient “conductor+diffusion” vision, and by assuming a same constant value of the modified permittivity all along the range of the incident ion.

The electric field is related to the free charge density  $\rho_{free}$  in a dielectric by the third equation of Maxwell:

$$\nabla \left( \vec{F} + \frac{\vec{P}}{\varepsilon_0} \right) = \frac{\rho_{free}}{\varepsilon_0} \iff \nabla \vec{F} = \frac{\rho_{free} + \rho_{pol}}{\varepsilon_0}. \quad (2)$$

Here  $\vec{P}$  is the dielectric polarization vector and the term  $\rho_{pol} = -\nabla \vec{P}$  is the polarization charge density given by the product of the dipole electric charge  $e$  and the dipole bulk concentration  $\mathcal{N}$ :  $|\rho_{pol}| = \mathcal{N}e$ . The physical meaning of  $P = \mathcal{N}e\mathbf{r}$  is that of dipolar moment of the volume unit,  $\mathbf{r}$  being the mean relative distance between individual dipole charges.

In the first order approximation:  $\vec{P} = \chi \varepsilon_0 \vec{F}$ ,  $\chi$  being the dielectric susceptibility and hence  $\mathbf{r}$  is proportional to the electric field strength too; as  $\varepsilon_r = 1 + \chi$ , the above equation becomes

$$\nabla(\varepsilon_r \vec{F}) = \frac{\rho_{free}}{\varepsilon_0}. \quad (3)$$

To fix the ideas,  $\mathcal{N}$  corresponds to the intrinsic dipoles induced by the electric field in the silicon lattice and equals the atom concentration. The ionization due to the impinging HI creates the concentration  $n(x,t)$  of supplementary “dipoles”, its value starting from  $n_0(x)$  and diminishing in time as supposed by Eq. (1). When the bulk concentration of dipoles, at the coordinate  $x$ , varies in time from the initial value  $\mathcal{N}$  to the instantaneous value  $\mathcal{N}'(x,t) = \mathcal{N} + n(x,t)$ , the polarization varies from  $P$  to  $P'(x,t) = \mathcal{N}'e\mathbf{r}' + n(x,t)e\mathbf{b}'$ . We have supposed here different mean relative distances  $\mathbf{b}' \neq \mathbf{r}'$ , both of them proportional to the electric field, for the supplementary  $n(x,t)$  and the previous  $\mathcal{N}$  dipoles in

the volume unit, respectively. Some algebra leads to the relation between the relative permittivities in the two cases:  $\varepsilon_r'(x,t)/\varepsilon_r = 1 + Kn(x,t)$ , which connects the new permittivity in the ionized column to the bulk carrier concentration  $n(x,t)$  by means of the constant  $K$ .

For the rear side entrance, the charge distribution  $\rho(x) = \rho_{free}$  in the overdepleted reverse biased junction reads

$$\rho(x) = \begin{cases} eN_D, & 0 < x \leq x_n \\ -eN_A, & x_n < x \leq x_n + x_p \end{cases} \quad (4)$$

where  $N_A$  is the acceptor concentration in the thin p-type part of thickness  $x_p$  and  $x_n$  is the thickness of the n-type zone. In a cylindrical, longitudinal geometry, the Maxwell's equation (3) may be considered in one dimension  $x$  at any moment  $t$ :

$$\frac{d(\varepsilon_r(x,t)F(x,t))}{dx} = \frac{\rho(x)}{\varepsilon_0} \quad (5)$$

with the boundary conditions for the electric potential  $\varphi$ :  $\varphi(0) = V$  and  $\varphi(x_n + x_p) = 0$ ; the relation between the field and the potential is  $F(x,t) = -d\varphi(x,t)/dx$ . In fact, this simplifying hypothesis allows to overcome the calculation of the radius  $r_c$  and to connect the changed relative permittivity  $\varepsilon_r'(x,t)$  directly to the linear carrier concentration  $N(x,t)$ :

$$\frac{\varepsilon_r'(x,t)}{\varepsilon_r} = 1 + kN(x,t) \quad (6)$$

via the constant  $k$ , the third parameter of the present approach, related to  $K$  ( $K = k(\pi r_c^2)$ ). For  $x > l$ , outside the ion range, the carrier concentration  $N(x,t)$  is null and consequently  $\varepsilon_r'(x,t)/\varepsilon_r = 1$ .

### 3.2. Results and discussion

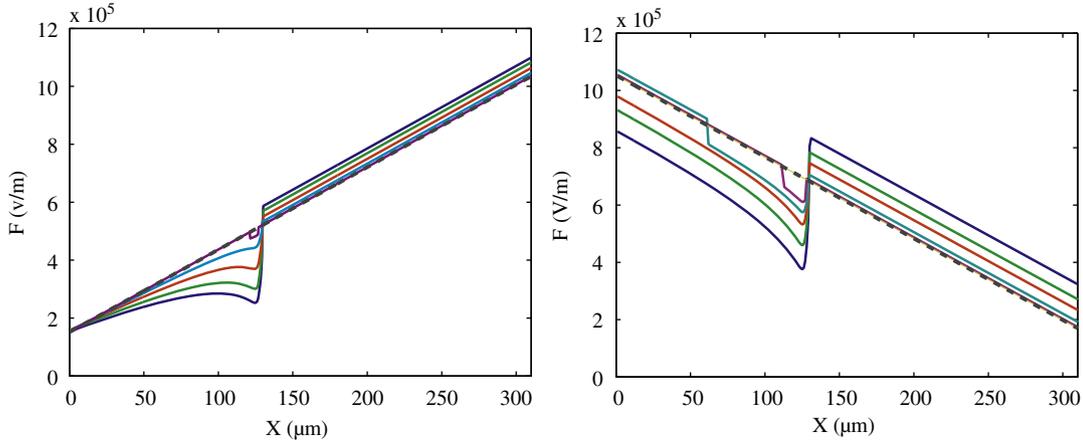
From the free charge conservation condition, implying:  $N_D x_n = N_A x_p$  and because in our detector  $N_A \gg N_D$ , one get  $x_p \ll x_n$  and  $x_n \approx d = x_n + x_p$ . Thus, for a rear side entrance along the field direction, the electric field strength inside and outside the ion range may be written as

$$F_{in}(x,t) = \frac{\varepsilon}{\varepsilon'(x,t)} \left[ \frac{2V_d}{d^2} x + \frac{V - V_d \left( 1 + \frac{2\varepsilon}{d^2} \int_0^l \frac{xdx}{\varepsilon'(x,t)} - \frac{l^2}{d^2} \right)}{d \left( 1 + \frac{\varepsilon}{d} \int_0^l \frac{dx}{\varepsilon'(x,t)} - \frac{l}{d} \right)} \right], \quad 0 < x \leq l$$

$$F_{out}(x,t) = \frac{2V_d}{d^2} x + \frac{V - V_d \left( 1 + \frac{2\varepsilon}{d^2} \int_0^l \frac{xdx}{\varepsilon'(x,t)} - \frac{l^2}{d^2} \right)}{d \left( 1 + \frac{\varepsilon}{d} \int_0^l \frac{dx}{\varepsilon'(x,t)} - \frac{l}{d} \right)}, \quad l < x \leq d. \quad (7)$$

As compared to the undisturbed field  $F(x)$  case, the quantities  $V_d$  and  $d$  appearing in both the upper  $F_{in}(x,t)$  and the lower  $F_{out}(x,t)$  expressions of Eq. (7) are multiplied by round brackets taking sub-unitary values. They are thus influenced by the ratio  $\varepsilon/\varepsilon'(x,t) = \varepsilon_r/\varepsilon_r'(x,t) < 1$ , embedded under the integral signs along the  $x$  coordinate (from 0 to  $l$ ), and for  $F_{in}(x,t)$  as a multiplicative factor too. Therefore, the both expressions depend on the three parameters of our formalism: the parameter  $k$  from the permittivity described by Eq. (6) but also the parameters  $\lambda$  and  $N_{th}$  from the dissociation described by Eq. (1).

The corresponding field behaviour for 80 MeV  $^{12}\text{C}$  ions impinging on the rear side of the detector is plotted in Fig. 2 (left) as a function of the coordinate  $x$ , to be compared to the straight dashed line corresponding to the undisturbed electric field. The lowest distorted field curve corresponds to the initial e-h pairs linear density  $N_0(x)$ , established by means of stopping power calculation [10]. The discontinuity appears at  $x = l$ . The modified field is lower than the undisturbed one inside the ion range but higher outside it. The other curves represent the



**Fig. 2.** The distorted electric field strength inside the silicon detector, at different moments, due to the ionized column induced by 80 MeV  $^{12}\text{C}$  ions penetrating on the rear side (left, with  $x = 0$  at the rear side contact) and the front side (right, with  $x = 0$  at the front side contact) of the detector. The straight dashed line gives in each case the undisturbed electric field.

distorted field at different later moments namely at every 5 ns, during the restoration of the electric field. The parameter  $k$  used in the calculation was adjusted to reproduce the experimental signal for the rear side incidence, as we shall discuss later. For the front side incidence and  $x$  considered from this side, one get the field values  $F_{in}(x, t)$  and  $F_{out}(x, t)$  by multiplying by  $-1$  the expressions in the right side of Eq. (7) and by changing  $-V$  in  $+V$ ; this procedure relates also the undisturbed electric field expressions. The results, obtained by means of the same value of  $k$  as before, are presented in Fig. 2 (right). The lowest curve represents the distorted electric field at  $t = 0$ , while the others at every 2.5 ns later. In both cases and at every moment, the integral along the detector thickness  $d$  is the same and equals to  $V$ . The influence of the bulk dielectric polarization on the distorted electric field depends on the initial external electric field, but not in a linear way. By studying at  $x = 0$  and  $t = 0$  the ratio of the distorted field  $F_{in}(x = 0, t = 0)$  to the undisturbed one  $F(x = 0)$ , we could learn that, from a mathematical point of view, the multiplicative factor  $\varepsilon/\varepsilon'(x, t) < 1$  (inducing the decrease of the final quantity), and the second term in the square brackets (increasing the final quantity) have a quite compensatory effect on the resulting value of the mentioned ratio when the HI impinges on the rear side of the detector. Conversely, for the front side incidence, both factors are reducing the value of the expression  $F_{in}(x = 0, t = 0)/F(x = 0)$ . Actually, one may see in Fig. 2 that the electric field diminishes of a few percents at  $x = 0$  and  $t = 0$  in the left panel, but of a few tens of percents in the right panel. Note that the extraction of carriers takes a longer time in the Bragg's peak domain, of higher density. Consequently, the electric field keeps temporarily lower values than the undisturbed one in this limited zone and exceeds the straight line elsewhere. The extracted carriers are then driven by this modified field inducing a signal amplified by the preamplifier current facility.

One may observe that the field behaviour is completely different from that found in the calculation of Ref. [22] which seems to have imposed a null electric field at the edges of the detector.

The three coefficients of the model:  $\lambda$ ,  $N_{th}$  and  $k$  in Table 2 were firstly determined as fit parameters by a  $\chi^2$  minimizing procedure for the rear side current signal, which offers a longer duration. The agreement of the simulated and experimental curves is quite satisfactory as shown in Fig. 3 (left). For the front side incidence, Fig. 3 (right), the value of the permittivity coefficient was held fixed:  $k = 3.64 \times 10^{-6} \mu\text{m}$ . Both  $\lambda$  and  $N_{th}$  take higher values and this makes sense: as the incident particle is slowing down and

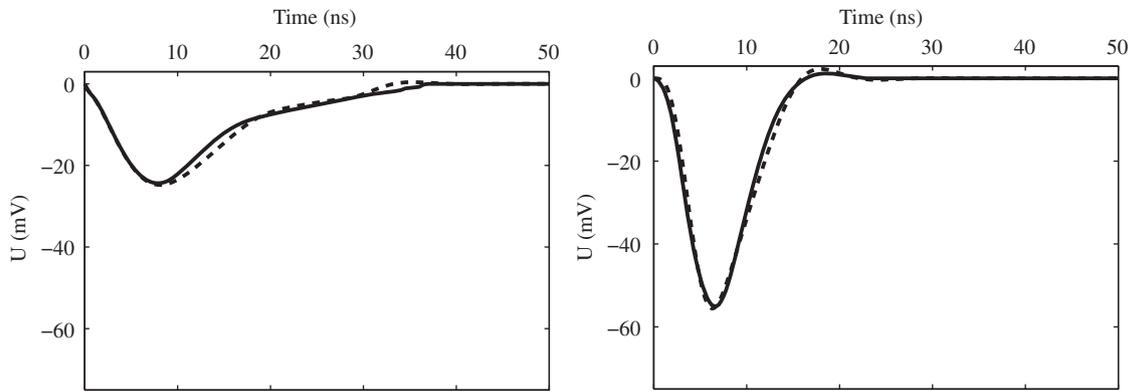
**Table 2**

Values of the fit parameters for 80 MeV  $^{12}\text{C}$  (see text for explanations).

Side	$\lambda$ (ns $^{-1}$ )	$N_{th}$ (pairs/ $\mu\text{m}$ )	$k$ ( $\mu\text{m}$ )
Rear	0.131	$3.2 \times 10$	$3.64 \times 10^{-6}$
Front	0.210	$1.0 \times 10^2$	$3.64 \times 10^{-6a}$

<sup>a</sup> Fixed.

stops in a higher electric field, the extraction and the drift of the carriers proceed more rapidly. Actually, the whole signal is two time shorter, while the amplitude is roughly two times higher because the collected charge (the integral of the current signal) is the same; the front side orientation is indicated for timing experiments, while the rear side is more appropriate for Z and A identifications of incident ions. In the “conductor” image, the plasma polarization requires a first displacement of the generated charge carriers to the ends of the ionization track. As the inside electric field is thought to be completely suppressed, the outside field has then to erode the plasma before the extraction of the carriers and all these sequences are difficult to be mathematically described. In the present alternative image, implying a sudden bulk dielectric polarization, a feed-back is realized via the relative permittivity between the variation in time of the internal electric field strength and that of the carrier concentration, initially driven by the impinging HI energy loss. The simplicity of the associated formalism and the relative success of the arising fitting procedure in describing the shape of the signal may constitute a posteriori arguments in favour of this scenario too. Eq. (6) shows the influence of the dielectric polarization on the permittivity and consequently on the electric field distortion at every moment. By means of the values of  $\langle N_0 \rangle$  from Table 1, one may estimate at  $t = 0$  an average increase of 62% for the relative permittivity in case of carbon but only about 2% for protons (mainly localized in a thin zone corresponding to the Bragg's peak). This fact explains why the basic description of the signal shape is successful in this LCP case. The value of  $N_{th}$  (orders of magnitude lower than the initial one) is not essential for the quality of the simulation; consistent with zero, it was introduced just to end in a finite time the simulated signal tail of no significant low values implied by the exponential solution of Eq. (1). Conversely, the value of the transition probability  $\lambda$  is crucial for the simulation and its dependence on the electric field strength may constitute at a first sight a drawback in a tentative of ion Z and A assignment via the



**Fig. 3.** Mean experimental current signals induced by 80 MeV  $^{12}\text{C}$  ions impinging on the rear side (left) and on the front side (right) of a silicon detector—full line; the simulation using a distorted electric field—dashed line.

PSD technique, but this dependence goes in the right sense. Further investigations will be pursued in this direction, in connection with the carrier concentration induced by different HI impinging on the rear side of silicon detectors and their identification too [23].

#### 4. Conclusions and prospects

In conclusion, we have considered the polarization, in the electric field existing in a reverse biased silicon junction, of the e–h pairs induced by an ionizing particle in a cylinder along its path, parallel to the field. The concentration of the carriers was connected to the local stopping power inside the particle range. The carrier extraction was supposed to take place with a constant rate along the whole particle range. The rear and front side entrances put in evidence a dependence of this parameter on the initial electric field strength. We gave an exact solution to the Maxwell's equation for the electric field in this inhomogeneous medium. In this time dependent infinitesimal treatment, we established the expressions of the modified electric field strength, inside and outside the ion range. This distorted field drives the carriers towards the electrodes affecting the shape of the pulse induced by 80 MeV  $^{12}\text{C}$  ions. The simulated pulse depends on three fit parameters. The comparison with the experimental signal has shown an important improvement of the simulation result compared to the prompt collection of the carriers in the undisturbed, linear electric field strength case. Further efforts towards a complete description by means of hopefully constant coefficients will be done.

Many materials, having polar constituents and subject to an electric field, undergo a change of physical properties, e.g. small variations of the refraction index. The typical example is the birefringence: Kerr's effect in liquids, Pockels' effect in crystals. Under the combined influence of the electric field and the ionizing particle, the semiconductor, an ordinary dielectric medium in the field theory, becomes for a few tens of nanoseconds a highly polarized one. It will be thus able to discriminate among various HI and even different isotopes of the same element, at present a hot open problem in nuclear physics detection in compact

geometries. Related to this topic, this “giant” dielectric polarization raises exciting questions and is promising for new implementations. Extended to transparent media for example, the dielectric polarization via ionization due to energetic charged particles or laser pulses implying a strong increase of the dielectric permittivity and therefore of the refraction index for extremely short periods of time, get generality and supplementary potential applications.

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