DISTRIBUTION OF ELECTRIC FIELD AND CHARGE COLLECTION IN SILICON STRIP DETECTORS.

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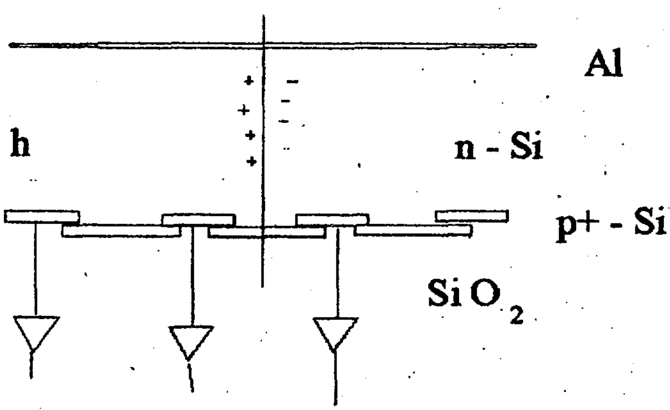
Abstract. The distribution of electric field in silicon strip detectors is analyzed in the case of full depletion as well as for partial depletion. Influence of inhomogeneous electric fields on the charge collection and performances of silicon strip detectors is discussed.

INTRODUCTION.

In the last decade several types of semiconductor position sensitive detectors were developed [1,2]. Among them the silicon strip detectors (SSD) are the most widely used especially in high energy physics experiments [3,4]. The SSD can also be used for precision coordinate determination of short range particles [5]. The characteristics of SSD crucially depends on diffusion, drift, trapping, recombination of electrons and holes in detectors, because this processes determined the collection of charges and therefore the response of detector, their spatial and energy resolution. The processes of the charge collection can be divided in some stage : i) thermalization of electrons and holes in the ionization track with characteristic time of the order of 10^{-12} s. ii) diffusion and drift in the plasma column of track with times $< 10^{-9}$ s. iii) diffusion and drift in external electric field E(x,y). In the present paper we will consider the last stage. In the majority of papers the main attention was paid to diffusion processes. The consideration of the carrier drift requires the knowledge of the electric field distribution. Usually only longitudinal component of E(x,y) is taken into account [6]. In this paper we have solved two-dimensional problem and calculated both longitudinal and transverse component of the electric field. The case of full depletion as well as partial depletion have been considered.

MODEL AND BASIC EQUATIONS.

The principle of operation of SSD is based on collection at the strips of electrons and holes generated by high energy particles. SSD schematically is shown in fig.1.



h - the detector thickness,
l - the interstrip distance,
L- the pitch

Fig.1.The schematic view of the silicon strip detector.

Analysis of collected charges $Q_i(t)$ on i^{th}-strips allows to determine the coordinate and energy of particles (for detail see [6]). The values of charges collected on neighbouring strips strongly depend on the electrical field distribution.
To calculate $\vec{E}(x,y) = -\vec{\nabla}U(x,y)$ we must solve the Poisson equation with appropriate boundary conditions :

$$\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)U(x,y)=-\frac{4\pi\rho(x,y)}{\varepsilon} \quad (1)$$

$$U(x,y)=U(x+L,y) \quad (2)$$

$$\begin{cases} U(x,h)=0 \\ U(x,y)\big|_{y=0}=-U_0, x\in[-L/2,-l/2]\cup[l/2,L/2] \\ \partial_y U(x,y)\big|_{y=0}, x\in(-l/2,l/2) \end{cases} \quad (3^{a,b,c})$$

where U(x,y) - is the electrostatic potential, $\rho(x,y)$ - is the charge density, ε - is the dielectric constant.
The region [-l/2;l/2] represents the interface $Si\text{-}SiO_2$. As well khown the thin layer of high electron concentration arises near this interface and compensates the positive charge of surface electron states and the oxide layer[7].

It is convenient to introduce dimensionless values :

$\xi=x/(L/2)$, $\eta=y/h$, $\xi_1=l/L$, $p=h/(L/2)$, $\varphi(\xi,\eta)=U(x,y)/U_o$.
Here we consider the case of fully depleted SSD, which is often used in practice especially for the coordinate determination of minimum ionizing particles (m.i.p.). We assume that $\rho(x,y) = N_d$ = const in the whole bulk of detectors.The full depletion voltage V_{dep} can be obtained from relation

$$V_{dep}=(2\pi e N_d h^2)/\varepsilon$$

Eq.1 in the dimentionless form are

$$\left(\frac{\partial^2}{\partial \xi^2}+\frac{1}{p^2}\frac{\partial^2}{\partial \eta^2}\right)\varphi(\xi,\eta)=-\frac{2}{p^2} \quad (4)$$

The solution of the equation (4) which satisfy boundary conditions can be written in the form

$$\varphi(\xi,\eta)=-(1-\eta)^2+\sum_{n=1}^{\infty}C_n*\frac{sh(\pi np(1-\eta))}{sh(\pi np)}*\cos(\pi n\xi) \quad (5)$$

where coefficients C_n are determined from the boundary conditions at the axis y=0. Satisfying the boundary condition in the fixed points we obtain the system of linear equations for calculation uknown coefficients C_n.

$$\begin{cases} \sum_{n=1}^{N} C_n*\cos(\pi n\xi_m)=0; & \xi_m\in[-1,-\xi_1]\cup[\xi_1,1] \\ \sum_{n=1}^{N} C_n*\pi np*cth(\pi np)*\cos(\pi n\xi_m)=-2; & \xi_m\in(-\xi_1,\xi_1) \end{cases} \quad (6)$$

RESULTS AND DISCUSSION

Truncating the system(6) at different n, we obtain an approximate solution of the problem and can investigate the convergence of the solution. A computer code has been developed which allows to calculate the potential and the electric field distribution for

different values of the detector parameters. Here we present as illustration the result of numerical calculation for the case $\xi_1 = 0.5$ and $p = 3.0$.
Fig.2 presents the potential and the distribution of the x- component $E_\xi(\xi)$ for different values of η

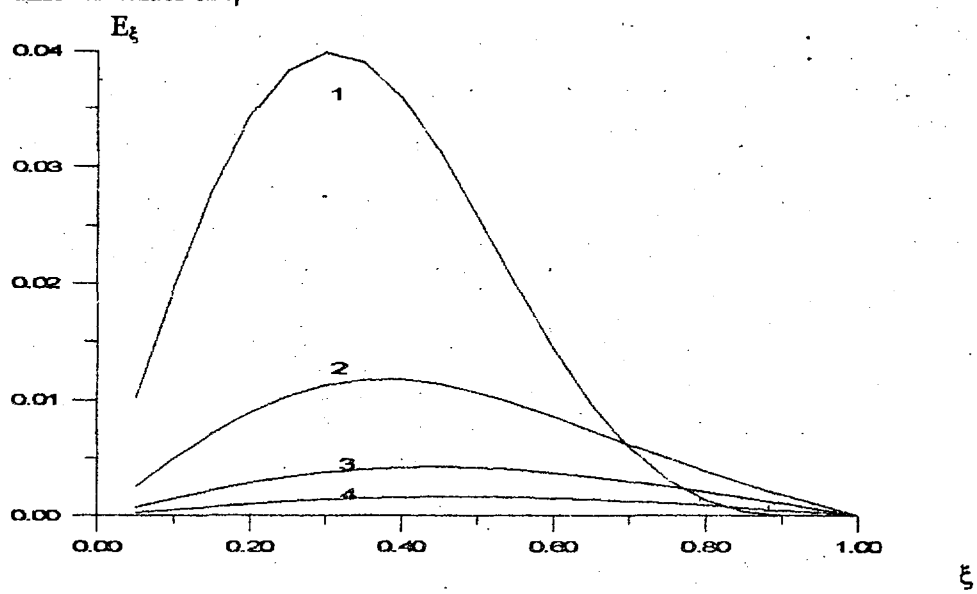


Fig.2. Dependences of the electric field component $E_\xi(\xi,\eta)$ for diferent values of η.
1. η=0.2; 2. η=0.3; 3. η=0.4; 2. η=0.5;

The case of partial depletion is more complicated. We must solve the problem with variable boundary and the form of this boundary must be found self-consistently. The equation for the boundary one can choose in the form

$$\eta = \eta_d(\xi) = \eta_0 + \sum_{n=1}^{\infty} F_n * Cos(\pi n \xi)$$

and boundary conditions has to be modified.
As previously we can obtain the systems of linear equations for determination of unknown coefficients F_n, C_n.
Influence of the electric field on the charge collection depends on detector characteristics (geometry i.e. parameters l/h, L/h, l/L, the detector material, applied voltage) and on type of incident particles and their energy. Using calculated E(x,y), one can estimate the role of $E_x(x,y)$ in the detector response. In the case of m.i.p. and L/h << 1 (usualy used geometry) and full depletion the main contribution to the charge collection gives the diffusion spreading and the drift in the field $E_y(x,y)$. More complicated situation is in the case of short range particles and large interstrip distances. The acount of component of $E_x(x,y)$ is essential because of the track length is compared to l. In this case the track is located in the region of inhomogenious E(x,y). This condition was realized in experiments [6]. For a typical detector with dimension L = 100 μ, l = 50 μ, h = 300 μ and the resistivity n-Si ρ = 1 kOhm cm we have U_{depl} = 285 V. The electric field E_x can be of order of 300 V/cm. Relatively large magtitude of E_x is observed in the interstrip region at distances y < l. Hence, the field E_x can essentially affect on the collection of charges generated by short range charged particles.

As the limit case we have a situation when all genereted carriers are collected practically at one strip ("either-or response" in 2-D analysis for the cordinate determination [6]). The role of the inhomogeniety of $E_x(x,y)$ in the time mesuarements (or pulse-shape) for coordinate determination was pointed out for short-range particles [6]. The calculation of the electric field distribution and their dependence on geometry and applied voltage are nessesary for optimization of the detector design or the operation mode.

In the drift approximation when $t_{drift} << t_{diff}$, $eEl >> \kappa T$ (for $l = 50\ \mu$, $E > 5$ V/cm) a simple estimation of the collection time is possible

$$t = \int_{(l)} \frac{dx}{\mu * E_x(x,y)}$$

, were μ- is the carrier mobility, integration is carried out over the electric field strength line. Assuming $E = \alpha x$ for $-l<x<l$ one can obtain the time interval betwen correleted pulses at neighbouring strips :

$$\Delta t = t_i - t_{i+1} = \frac{1}{\mu\alpha} \ln \frac{C - xo}{C + xo}$$

where C (Q_{th}) is a function of the registration threshold Q_{th} (see [6]), xo is the incident particle coordinate.

CONCLUSION.

The expression for distributions of the electric field in SSD are obtained. A computer code has been developed for calculation of the potential and the electric field . Calculations and comparison with experemental data indicate on essential role of the drift in inhomogenious electric field on the charge collection at the strips of detectors.

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