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IMPULSE METHOD FOR TEMPERATURE MEASUREMENT OF SILICON DETECTORS

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A new impulse method of temperature measurement based on switching characteristic of the *P-N* junction is described. Temperature of silicon detector can be determined, due to the strong temperature dependence of minority carrier lifetime, from the charge registered during the switching-off process. The method has been tested in temperature range of 25 ÷ ÷ 60 °C. Advantages, drawbacks and precission of this method are discussed.

The investigation has been performed at the Laboratory of High Energies, JINR.

Импульсный метод измерения температуры кремниевых детекторов

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В работе описан метод измерения температуры, основанный на переходной характеристике *P-N*-перехода. Температурная зависимость времени жизни неосновных носителей позволяет использовать метод для определения температуры кремниевых детекторов. Представлены результаты измерений в диапазоне температур от +20 °C до +60 °C. Обсуждаются также преимущества метода и его точность.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

1. INTRODUCTION

Silicon detectors are widely used in nuclear physics for detection of ionizing particles. Their characteristics dramatically depend on temperature. For precise measurement either the temperature stabilization or continuous temperature measurement are required. For temperature measurement thermo-resistors or thermo-couples are commonly used. This solution requires a good thermal contact of the sensor and detector device, and implementation of the readout electronics. This presents an additional amount of material which can be critical in complicated multidetector tracking systems where the amount of material has to be minimized. In the ideal case the termo-sensor can be integrated directly on the detector. In this case the time response of sensor is very fast and it follows precisely thermal conditions of the detector wafer.

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Method described in this paper uses switching characteristics of *P-N* junction, which is an essential part of majority of silicon detectors.

2. TEMPERATURE DEPENDENCE OF MINORITY CARRIER LIFETIME

According to the the theory of generation-recombination processes [1] the minority carrier lifetime is determined by energy E_t of shallow localized states in the gap of the semiconductor (traps) with respect to the Fermi level (F_i) (see Fig.1). Position of the Fermi level depends on the temperature and thus also the population of traps is proportional to the temperature. To explain this behaviour let's consider *N*-type semiconductor, where holes are minority carriers. We assume that semiconductor is not degenerated in the whole range of measured temperatures. When the temperature is increased, F_i moves down, towards the valence band. This decreases population of electrons in the traps for the case $F_i < E_t$. Estimation has shown that for silicon in the temperature range of 100–400 K, when $F_i > E_t$, the minority carrier lifetime depends on the temperature.

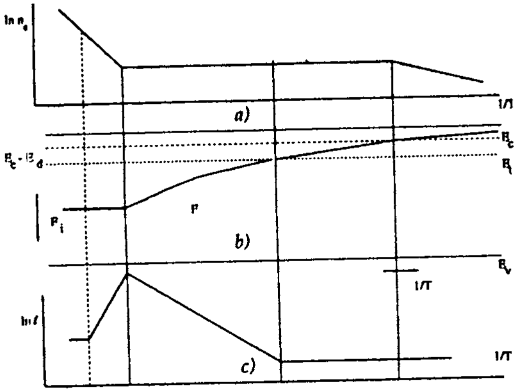

Fig. 1. Temperature dependences in *P-N* junction: a) the minority carrier concentration; b) the Fermi level; c) the minority carrier lifetime

3. TRANSITION PROCESS IN *P-N* JUNCTION

Let's assume *P-N* junction fabricated on *N*-type Silicon. Let the current is flowing for certain time in forward direction (see Fig.2a,b) [2].

In this phase the diffusion capacitance of the junction is charged by accumulated minority carriers. When the junction is polarized in reverse direction, the diffusion capacitance discharges within a certain time interval. Considering the switching characteristics on Fig.2c we observe that starting from switching time the reverse current steeply increases up to I_{rmx}. Then it remains constant for the storage time t_0 and then decreases during the recovery time t_i. The reverse current remains constant during discharging of the diffusion capacitance due to the constant gradient of minority carrier concentration on the *P-N* junction boundary. This happens only in the ideal case. In reality it is difficult to determine precisely the storage time, transition to the recovery region is for some detectors smooth. Also for some case the resulting current decreases all the time and the constant part is absent. Aplicability of methods used for temperature measurement of the storage time is therefore limited.

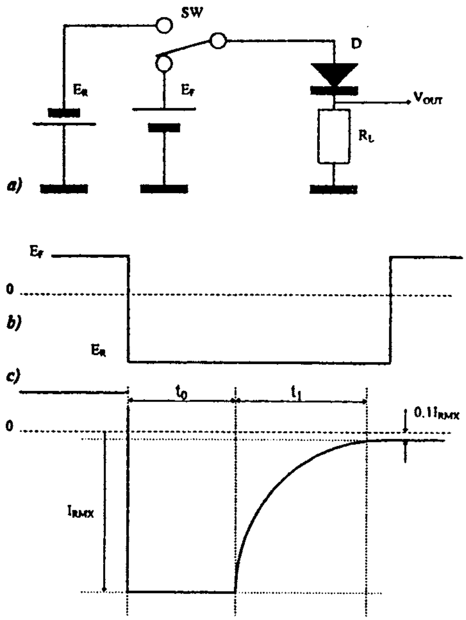

Fig. 2. a) Circuit for voltage switching; b) and c) voltage and current waveforms

If the load resistor is increased, I_{rmx} desreases, while the storage time increases. For the case of *P-N* junction with the long base, the storage time can be calculated from Eq.(1) [3]

$$erf\sqrt{t_0/\tau_p} = \frac{1}{1-B}, \tag{1}$$

where τ_p is the minority carrier lifetime, $B = \frac{I_{rmx}}{I_{fmx}}$, I_{fmx} is maximum of the forward current. During the recovery phase, the excessive charge is being removed dominantly by recombination. The recovery time for different values of the parameter B is given by Eq.(2).

$$\begin{aligned} &a) \quad B \leq 1 \quad \frac{t_1}{\tau_d} = \frac{\ln(10)}{\pi^2}, \\ &b) \quad B \geq 1 \quad \frac{t_1}{\tau_d} = \frac{1}{\pi^2}\left(\frac{1}{(1+0.1B)^2} - \frac{1}{(1+B)^2}\right), \end{aligned} \tag{2}$$

where $\tau_d = \tau_p \frac{L_d}{L_p}$, and L_d is thickness of diode base, L_p is a diffusion length. The recovery and storage lifetime and charge store diffusion capacitance depend on the minority carriers lifetime and this way also on temperature. Charge accumulated in diffusion capacitance is a good temperature probe because it can be integrated over the whole storage and recovery phase. As integral it is also less sensitive to the influence of the noise and to changes in position of the end of integration interval, where the current is low and contribution to the integral is small.

Due to differences in fabrication technology and in properties of the bulk material, it is necessary to calibrate each junction which has to be used as a temperture sensor. Also the radiation damage changes the concentration of traps, so that the calibration of the thermo-sensor changes with increasing fluence of particles through the detector. Level of the error due to this fact is currently studied and it will be reported in the next paper.

4. EXPERIMENTAL SET-UP

To test the metod the measuring circuit for switching of *P-N* junction shown in Fig.3 was used. Calibrated detector has been placed in the passive thermostat consisting of heating element and thermocouple. During the heat-up, the temperature has been measured by KEITHLEY 6517 electrometer connected to the thermo-couple. Heating element controlled by external voltage supply rised the temperature from 20 °C to 60 °C. Detector response to pulses from the pulse generator MS-9150 has been recorded by digital oscilloscope HP 54520 and the charge released from diffusion capacitance has been determined.

In our test, two dozimetric *P-I-N* type detectors have been investigated. First fabricated on 3.3 kΩ Si with area 0.1 cm^2, second on 1.4 kΩ Si with area 1 cm^2. For both detectors parameters of the input pulse were identical (+0.6 V; -1.8 V: R_{load} = 1 kΩ). Shape of output signals is shown on Fig.4a,b.

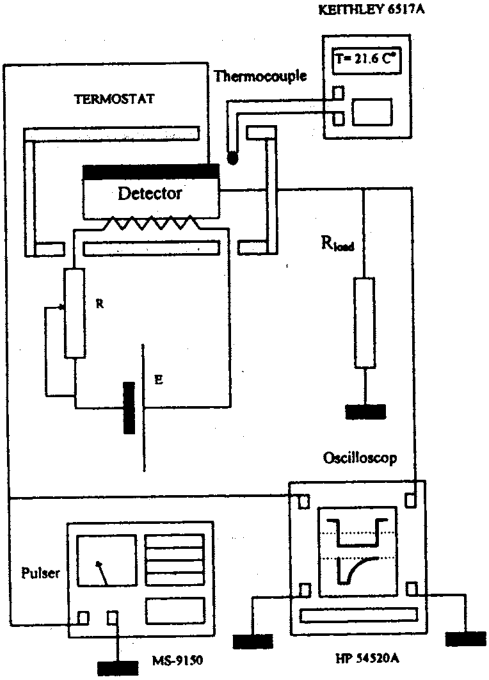

Fig. 3. Pulse temperature measurement set-up

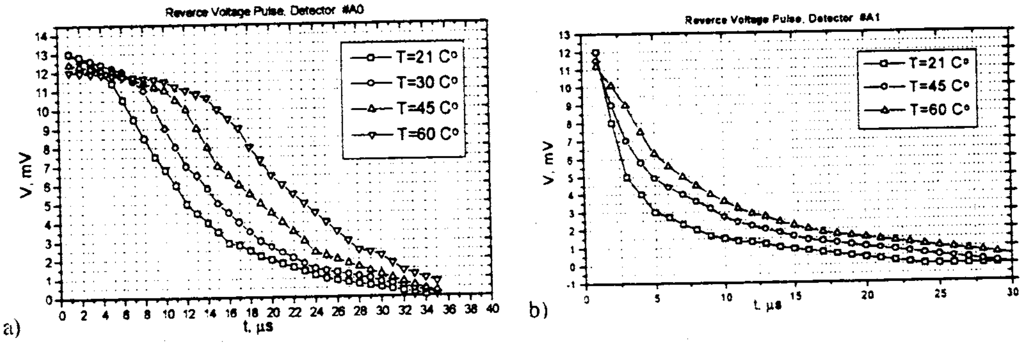

Fig. 4. Shape of output signal of 1 cm^2 detector(a) and 0.1 cm^2 detector (b)

5. RESULTS

Temperature dependence of the released charge for the small detector is plotted on the top of Fig.5. This dependence corresponds well to the simulation.

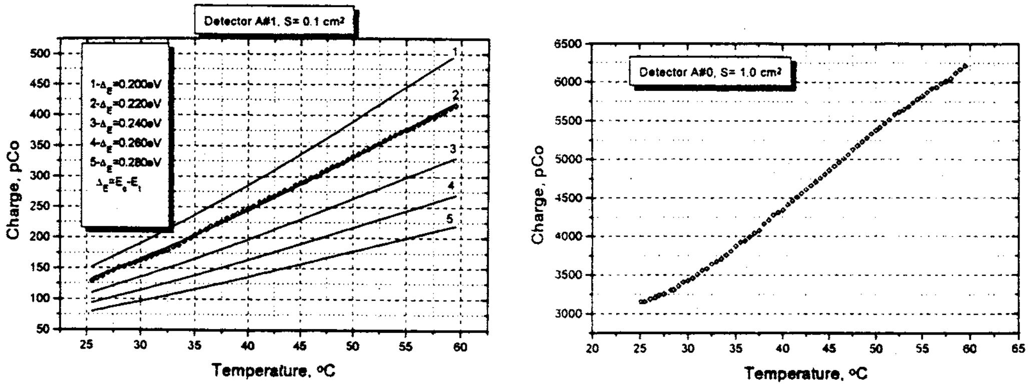

Fig. 5. Charge versus temperature for 1 cm^2 and 0.1 cm^2 detectors

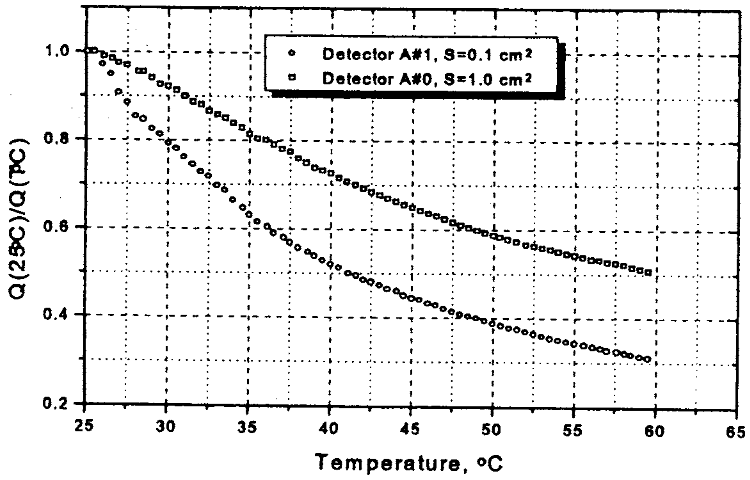

Fig. 6. Calibration curves indicate temperature dependence of normalized charge

Using the obtained dynamic calibration curve it is possible to determine temperature of the detector with precision better than 0.25 °C. For the test, the precision detector has been placed to the thermostatic chamber, where the callibration was performed again but in thermal equilibrium at each measured temperature. This way the more precise static calibration curve has been obtained (see Fig.6). For the large detector (down Fig .5) the released charge is larger, but at the lower edge of the investigated temperature interval we observed significant deviation from the expected shape of the calibration. We can conclude, that general sensitivity of the method is increasing while increasing resistivity of bulk material. Comparing the data with simulation it is even possible to estimate average energy of traps (see parameters on Fig 5).

6. CONCLUSIONS

We have investigated a new method of temperature measurement of silicon detectors based on integration of the charge released from the diffusion capacitance of the *P-N* junction during the closing of the junction. This method is more general compared to methods used as signal legth of storage and/or recovery time of the junction. It can be used even for *P-N* junction, where the storage phase is not well defined. Integral of the charge is less sensitive to the noise and to variation of the end of integration window. Time response of this method is very fast, thermo-sensor is integrated on the particle detector. With proper calibration, this method gives temperature of the detector with precission near to 0.1 °C. Changes in calibration due to the radiation damage will be further studied. In the next phase, we'll apply this method to temperature measurement of the Silicon Drift Detectors.

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