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Determination of Si wafer resistivity distributions by C-V measurements

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A new method of resistivity distribution measurement of silicon wafers mercury probe was developed. It presents an extension of well known C-V measurement method. The capacitance of the locally created Hg-Si Shottky diode junction on the Si wafer was determined by charge injection into charge preamplifier through the tested diode. The known amount of charge was generated by scientific pulse generator. The capacitance and resistivity distributions of the epitaxial n-n$^+$ structure, the high resistivity Topsil float zone wafer and the epitaxial n-n$^+$ structure with resistivity locally modified by the Selective neutron Transmuttation Doping (SnTD) are presented. The new technological approach used for C-V measurement, together with determination of silicon wafer resistivity distribution are presented. The local modification of silicon resistivity by the SnTD is also determined.

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1. Introduction

The resistance uniformity of silicon wafers is essential for proper working of silicon detectors. It is especially important for Pulse Shape Discrimination Technique, where single detector signals are used for charge and mass identification. For these reasons we have elaborated a new method of evaluation of silicon wafer resistivity distribution using the C-V measurements. The method is based on charge injection from scientific pulse generator through tested, biased Hg-Si Shottky diode, into the charge preamplifier. The subsequently measured silicon resistivity distribution gives possibility for:

- Selection of silicon wafers parts with constant resistivity (useful for detector production).
- Correction of the silicon wafer resistivity distribution, using the SnTD [3].

In recent years several methods were developed for capacitance measurement: Bridge Method, Resonant method, I-V Method, RF I-V Method, Network analysis method, and Auto Balancing Bridge Method [1]. Thus, for testing of variable capacitance diodes (varcator diode) and investigation of the MOS structures the Auto Balancing Bridge Method and RF I-V Method with reverse bias was applied [1]. Recently, the silicon detector capacitance versus reverse bias potential was determined by using the Resonant Method [2].

2. The Method

The resistivity distribution of Si wafers is measured using C-V method for biased Shottky diodes formed by Mercury drop gravitationally pressed to the tested silicon surface [4, 5]. The Mercury probe is presented in Fig. 1. In order to allow measurements in all points of the wafer the probe was moved by the computer system. The electronic scheme for a capacitance measurement is shown in Fig. 2. A constant amount of charge was produced by very stable scientific pulse generator connected to the shielded chamber, using 50 Ω cable terminated by 51 Ω resistor. The 50 kHz pulses from the scientific generator had a following characteristics: negative polarity, amplitude 50 mV, rise time 50 ns and width 0.3 μs. The capacitance was evaluated by measuring of charge injected through the mercury probe working with reverse bias about -1.5 V into the charge preamplifier followed by the amplifier with time shaping τ=0.5 μs and bipolar output. The amplifier was connected trough 12 bits ADC with the acquisition system. At each point on the wafer, the pulses were collected by ADC during 0.25 s. The collected pulse spectrum contained about 10^4 events, corresponding to the number capacitance measurements performed by ADC. The most probable value calculated from the collected spectrum was assumed as an evaluated capacitance value. During one second about two points of the wafer were measured. For calibration procedure the Mercury Shottky diode was replaced by calibrating capacitors, connected in series with the calibrating resistance. The calibrating resistance describes of the series resistance of the back contact of the wafer. For a good back contact (very low resistance between evaporated Al and the silicon) the series resistance of the Shottky diode can be neglected and the calibrating resistance is assumed to zero. From capacitance distribution of silicon wafer the resistivity distribution, ρ [Ω·cm], can be calculated using formulae for depletion depth (2.1) and junction capacitance (2.2):

$$d[cm] = 5.3 \cdot 10^{-3} \sqrt{(}\rho(V_\circ + V)) \tag{2.1}$$

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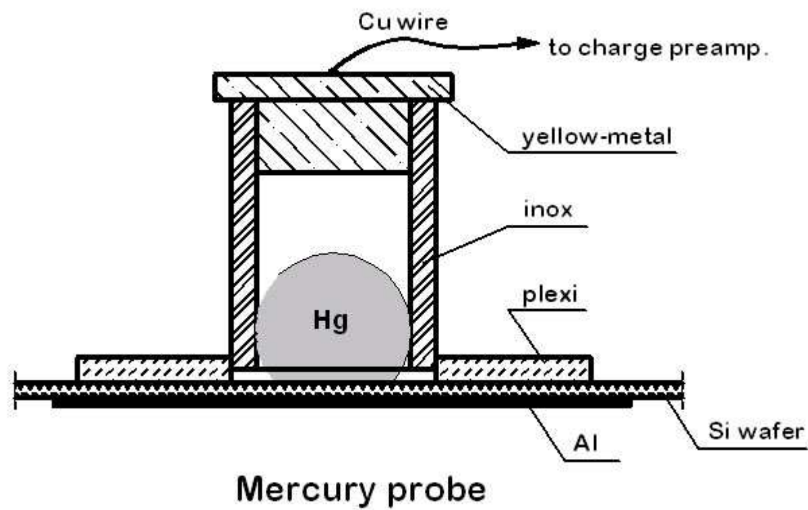

Figure 1: Mercury probe. The Hg drop having diameter 1.3 mm (with circular spot of about 1 mm) was gravitionally pressed to the n-type silicon wafer. To the back side of the wafer with the Al contact is evaporated.

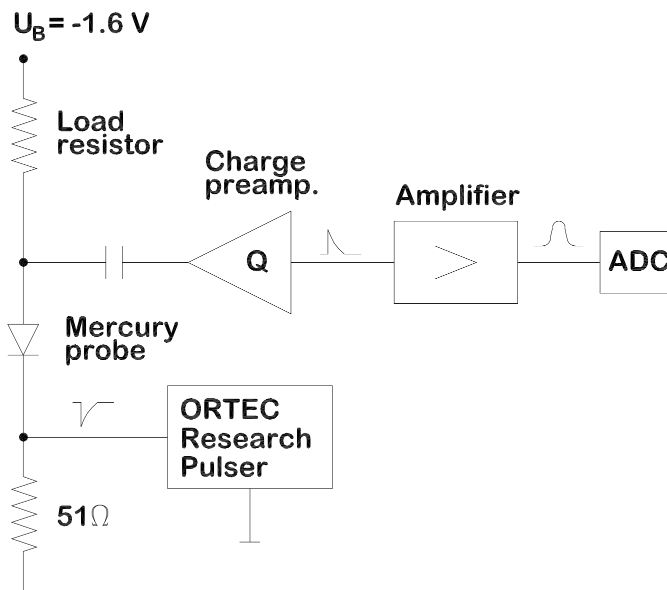

Figure 2: The capacitance of Mercury probe is determined by evaluation of charge injected into the charge preamplifier followed by the amplifier, ADC and aquisition system.

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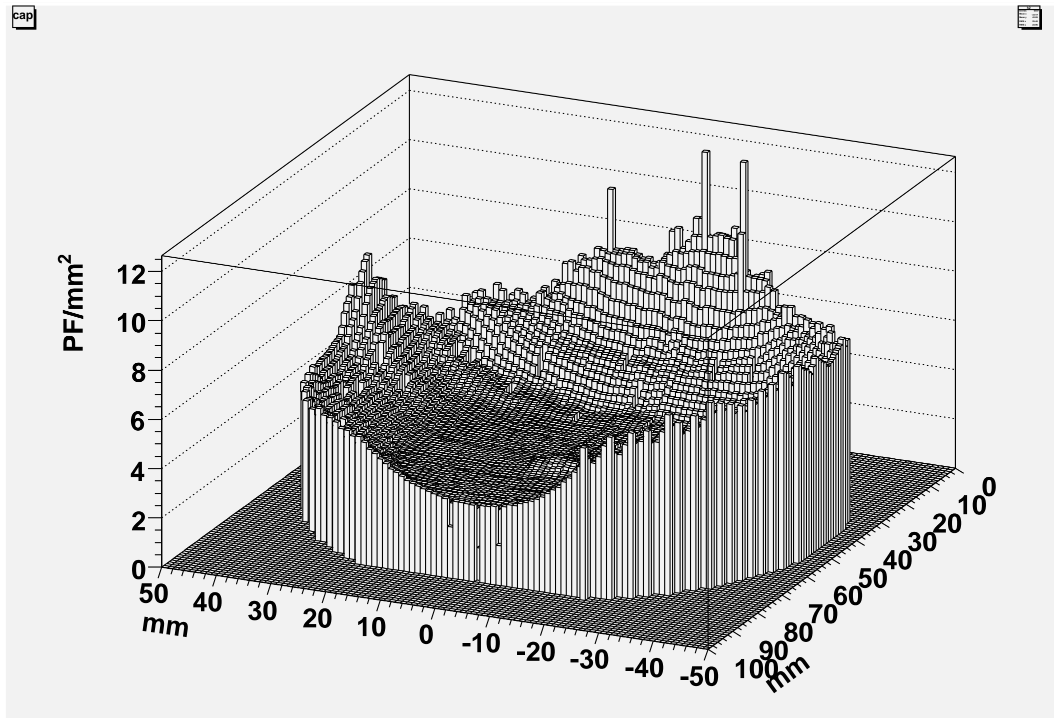

Figure 3: Capacitance [C] distribution. $< C >$ = 2.8 pF/mm^2, FWHM = 3.4 pF/mm^2. High resistivity, 4 inches, epitaxial n-n$^+$ structure of 118 μm thickness - produced in the Institute of Electronic Materials Technology, Warsaw, Poland.

$$C = 1.17/d\ [pF/cm^2] \tag{2.2}$$

where V$_\circ$ and V are the Hg-Si barrier potential and the applied bias potential, respectively.

3. Capacitance and resistivity distributions for the epitaxial n-n$^+$ structure and the n-type Topsil wafer

The capacitance distribution of high resistivity epitaxial n-n$^+$ structure is presented in Fig. 3. Maximal capacitances are localized at the edges of the wafer. Using formulae (2.1) and (2.2), the resistivity distribution of the wafer can be calculated - see Fig. 4. Due to the enhanced epitaxial edge doping, the resistivity at the wafer edge is considerably reduced. For the Topsil wafer only the resistivity distribution is presented - see Fig, 5. Resistivity distribution of the wafer is uniform, except of the wafer edges where it is mostly increased.

4. Capacitance distribution of the n-n$^+$ structure with resistivity distribution modified by the SnTD process

The SnTD [3] is a process in which the silicon wafer resistivity is locally modificated by the phosphour donors, produced by the neutron transsmutation doping, using the thermal neutron induced capture reaction:

^{30}Si(n,γ)^{31}Si$\rightarrow^{31}$P+β^-

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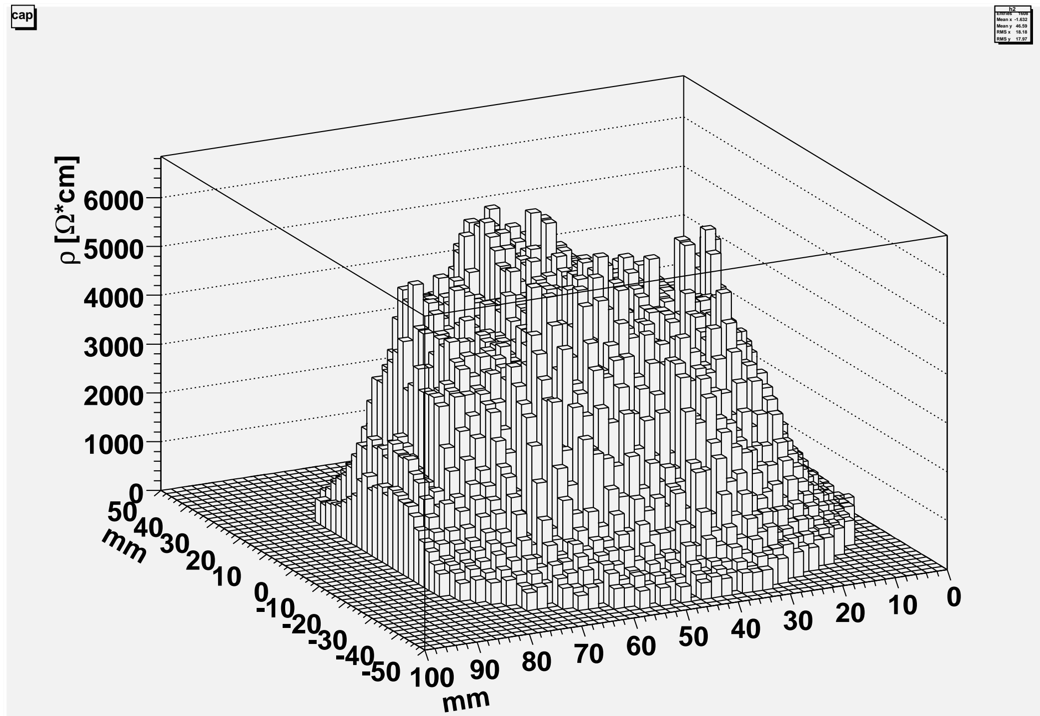

Figure 4: Resistivity [ρ] distribution (2 mm steps). $<\rho>$ = 3.9 kΩ·cm, FWHM = 5.5 kΩ·cm.

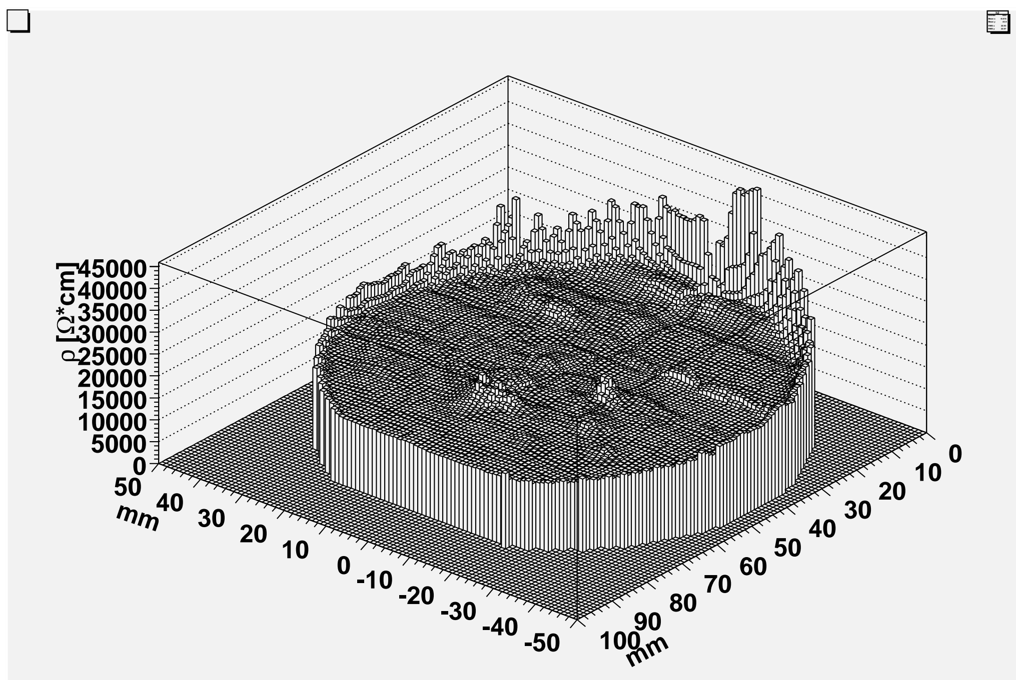

Figure 5: Resistivity [ρ] distribution.Topsil wafer of 4 inches diameter and resistivity ρ = 14 - 27 kΩ·cm. Series resistance of the back contact is about 130 kΩ. $<\rho>$ = 16 kΩ·cm, FWHM = 6.3 kΩ·cm.

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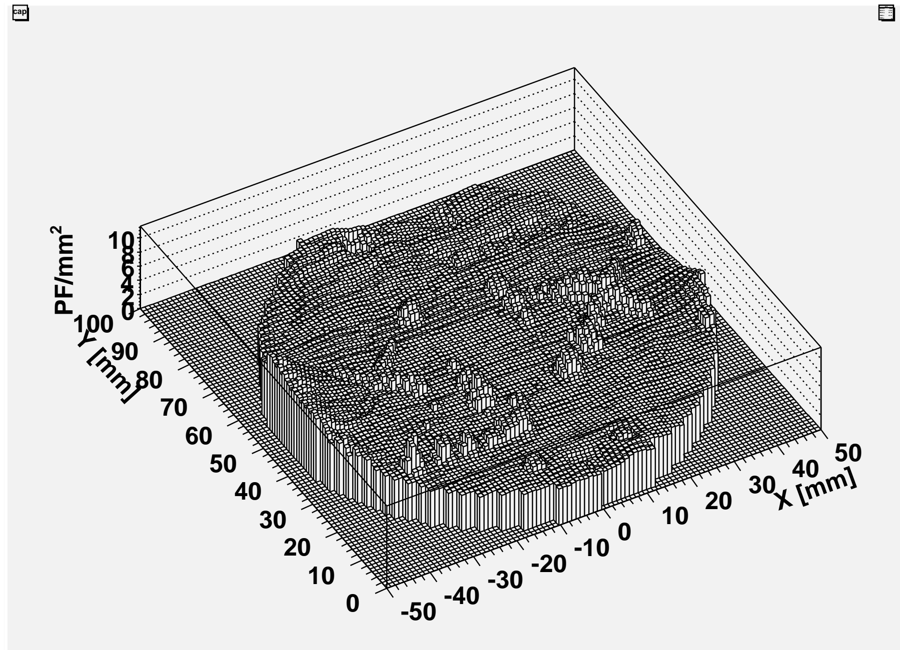

Figure 6: Capacitance distribution of an epitaxial n-n^{+} structure with thickness about 100 μm and resistivity 5000 Ω·cm, after irradiation by thermal neutron flux through the Cd mask of thickness 1 mm with empty holes and two empty crosses. The neutron fluence of about $6{\cdot}10^{16}$ n/cm^{2} was used. The visible "hill structures" correspond to the empty holes and crosses of the Cd mask.

The tested SnTD process was performed by covering four inch high resistivity n-n^{+} structure by 1 mm thick Cd mask with empty holes and two empty crosses. Then mask with n-n^{+} structure was inserted into the thermal neutron flux of about $1.7{\cdot}10^{12}$n/cm^{2}s, using virtual vertical neutron beam channel of reactor Maria at Świerk in Poland [6]. After irradiation by thermal neutrons, the regions of silicon not covered by Cd mask the silicon have reduced their resistivity. Consequently the measured capacitance increased, what is well illustrated in Fig. 6.

5. Discussion and conclusion

The capacitance of the Hg-Si Shottky junction is not stable - see Fig. 7. In all 8 tested points of the wafer the capacitance dropped about (10-30)% during 140 minutes of measurements. It was probably due to the modification of the silicon by the electric field of the bias potential. To avoid this process we have measured capacitance just after changing of measurement point, with short time of measurement about 0.25 s.

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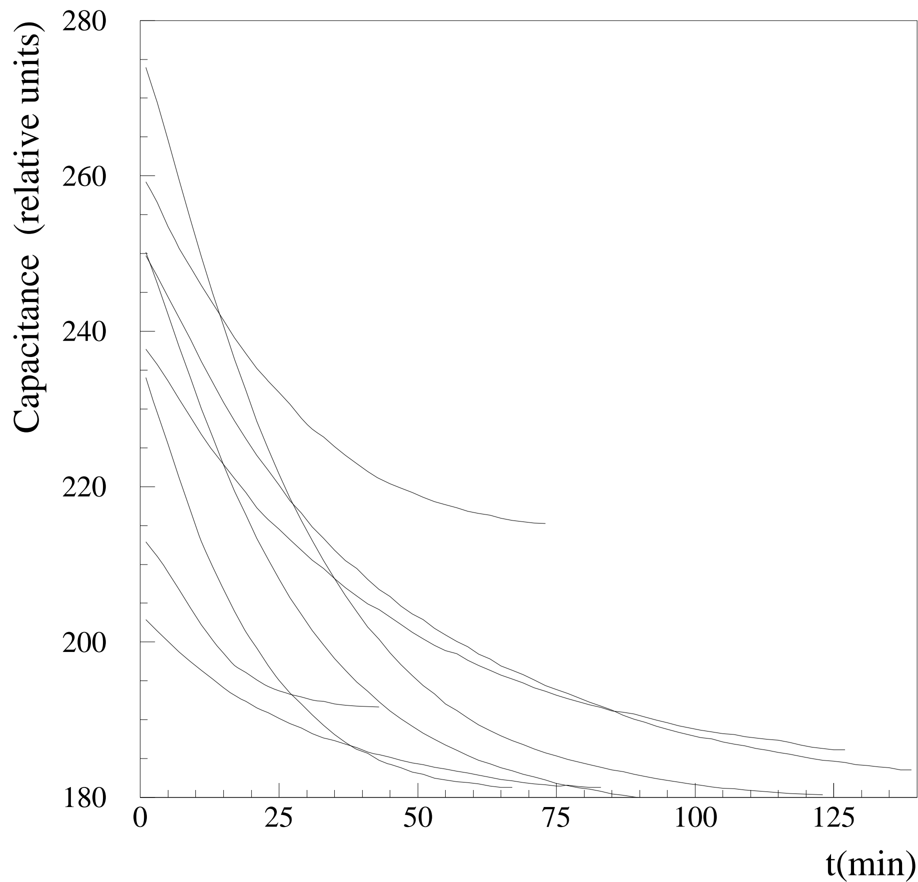

Figure 7: Dependence of Shottky diode capacitance versus time at eight selected points of the wafer.

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