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CRN - ULP - PHASE

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Abstract

Strong gain variations have been observed for Micro Strips Gas Chambers (MSGC), especially under irradiation. These instabilities are due to the type of the substrate used for the realisation of these detectors. Previous studies have shown that a low resistivity, together with an electronic conductivity are a necessity for any useful subtrate.

Qualitative and quantitative analyses of different types of glass have been performed at the CRN-Strasbourg. From these analyses, one concludes that the best performance is obtained for glasses containing transition elements, yelding electronic conductivity, and that low atomic number alcali elements, that are mainly responsible for the ionic conductivity, should be avoided.

Using standard glasses, several improvements of the characteristics of substrates have been tested for more stable MSGC operation. Starting with a highly resistive glass ($\rho > 5.10^{15}$ Ω.cm) it has been possible to go down to a bulk resistivity of the order of 10^9 Ω.cm using iron doping, done by ionic implantation or thermal diffusion. Stability measurements under polarization and irradiation are presented.

1. INTRODUCTION.

Microstrips Gas Chambers (MSGC) are made from thin metallic strips - anodes and cathodes- deposited and engraved on a dielectric substrate using standard microelectronic techniques. A cathode drift plane, located a few millimeters above the substrate, defines the drift region for primary electrons. High voltage applied on the cathode strips sets up the electical field responsible for the electronic avalanche, leading to an observable signal on the anodes. Fig. 1. shows a typical transverse design for MSGC.

Recent developments on MSGC[1] show substantial improvements compared to classical drift chambers, especially with respect to spatial resolution and speed[2 - 6]:

- Position resolution for minimum ionizing particles of the order of 30 - 50 μm .
- Signal rise time < 50 nsec, allowing particle fluxes up to 10^6.mm^{-2}.sec^{-1}.
- Energy resolution of the order of 10-11% for 5.9 keV X-rays with a gain up to 10^4.

However, gain instabilities and variations have been observed. One can distinguish two types of behaviour:

- A fast variation of the gain immediately after voltage setting. This global effect can last several minutes before gain stabilization.
- A drop of gain under irradiation near the particles impact point. This effect may be irreversible.

These two effects are probably due to charge accumulation at the surface of the substrate, modifying locally the electric field. Under irradiation, some structural defects may appear in the bulk of the substrate. Possibly, these defects accumulate charges, leading to an additional modification of the field, inducing an additional loss of gain. This last modification may be permanent and lead to a significant change in the surface resistivity of the subtrate[4].

For semi-conductive glasses with electronic conductivity this loss of gain is less important or inexistent[7, 8]. These findings, which illustrate clearly the importance of substrate resistivity for a given irradiation rate, are reproduced by analityc approximations and numarical calculations based on the Rule of Charging Accumulation (RCA)[9].

A comparative study of glass composition and performances has been carried out at the PHASE-CRN group in order to define the optimal composition for a MSGC glass. It should then be possible to modify existing (standard) glass by means of ion implantation or diffusion in order to make these glasses compatible with MSGC operation. The main purpose is to prove the feasibility of future large MSGC detectors at LHC while minimizing the substrate cost. After modification of the glass, the stability of the obtained resistivity has been measured over long periods of time.

2. GLASS CHARACTERISATION.

Several types of glass have been analysed: Corning 7059, 7740 and D211, Schott D263 and the so-called "Moscow Glass" (Pestov Glass). The latter seems to be particularly promising because of its adequate resistivity (~10^8 Ω.cm) and stable operation of MSGC [8]. However, the reproducibility of its surface quality (needed for

good metal deposition and engraving) and its cost are still unsolved questions. All the other glasses mentionned may be good candidates for MSGC realisation from the point of view of surface quality, available thickness and cost, although the resistivity of these glasses is still far too high (up to 5.10^5 Ω.cm).

2.1 ANALYTICAL TECHNIQUES.

Techniques used at the CRN laboratory to determine the composition of glass samples are essentially based upon ionic beams and ion analysis:

- **SIMS** (Secondary Ion Mass Spectroscopy)
Secondary ions rejected from the substrate are identifed from their mass to charge ratio. All elements can be detected, including hydrogen and polyatomic molecules undetectables by other methods. This technique yields concentration profiles in a thin layer near the surface.

- **RBS** (Rutherford Back Scattering)
The energy of backscattered ions is measured at a fixed angle and gives information on the nature, concentration and distribution for the elements contained in the sample.

- **PIXE** (Particle Induced X-ray Emission)
Holes in internal electronic shells are induced by ionic bombardment. Electronic rearrangement leads to X-ray emission for elements in the sample. Identification and quantitative analysis of A>12 elements is possible.

- **NAA** (Neutron Activation Analysis).
The sample to be analysed is irradiated using by neutrons to create artificial radionuclides. Analysis of characteristic γ-ray emission leads to an unambiguous quantitative and qualitative identification of most elements in the glass sample.

2.2 COMPOSITION

Using these methods, most elements and their relative proportions were identified in various glasses[10]. As an example, table 1 presents NAA results for the mass fractions (%) of the most important elements:

- Moscow glass shows a low concentration of sodium (less than 1%), and large quantities of iron (more than 16%) and baryum (26%).
- Schott D263, Corning D211 and 7740 are similar. For these glasses, one notes a lerger component of sodium (up to 4% for D211) and potassium. On the other hand, complete absence of iron is the main features of these three glasses, which explain the high resistivity measured.

The presence or absence of certain elements can explain the observed behaviour of the glasses. The krypton-like structure of the sodium ions, together with their small radius, allows them to move easily in the glass matrix, making them responsible for the ionic conductivity [11]. In contrast, the mobility of iron ions is much smaller in the glass matrix. Trapped in the sructural defects of the glass, iron ions block the motion of smaller elements, allowing a better stability of the glass. In addtion, the multiple valence states of iron ions is at the origin of electronic conductivity[12] and the proportion of iron in the glass is the obvious determining factor for the resistivity of the glass. The presence of baryum is another interesting feature for MSGC operation: this ion has the advantage of reducing the glass polarisability[12].

These observations help to explain why a substrate like the Moscow glass is at present considered to be ideal for MSGCs. Considering the above mentioned problems of surface quality and cost, it is desireable to reproduce the main features of this type of glass, i.e. conductivity and resistivity, using another type of glass.

Corning 7059 presents a very low level of alcali elements and a high content of baryum, leading to an exclusive electronic conductivity. Using doping methods, it seems then possible to introduce iron (or other specific elements) into the glass matrix to lower its resistivity for MSGC operations.

3. GLASS MODIFICATIONS.

The original resistivity of Corning 7059 glass is larger than 5.10^{15} Ω.cm at standard room temperature. Techniques for iron doping in this glass are ion implantation or thermal diffusion. These two methods have been employed at the PHASE-CRN laboratory.

After glass modification, the surface resistance is measured by polarising the glass sample using two microelectrodes located 5mm apart on the surface. The polarising voltage is 200V. Measuring the current, one calculates the substrate resitivity ρ using the approximation $\rho = d.R$ where R is the surface resistance, and d the thickness of the modified upper layer of the substrate. This approximation is valid as long as d is small (less or of the order of 1μm).

3.1 ION IMPLANTATION.

For this precise and reproducible method an ion beam is used to introduce an element into the solid substrate in order to modify its chemical, optical, electronic or other properties. One advantage of this technique is an easy control of the implanted elements profile, which is function of the dose and energy of the implantation.

To avoid charge accumulation at the glass surface during the process, one has first to metallise the sample with a thin iron layer of 100 nm or less. Under bombardment with Fe^+ ions, the pulverisation rate is rather large, which can cause an alteration of the glass surface after the deposited metal layer has been removed. This can be the main cause of the observed surface degradation in the first implanted samples, leading to a loss of quality in the metallisation process before engraving the strips.

3.1.1 IMPLANTATION PROFILE.

Substrates are implanted at various ion doses at a constant beam energy of 150 keV. Figure 2 shows a typical iron concentration profile obtained with SIMS for an implanted dose of 1.10^7 ions/cm^2. One notices that the iron is concentrated in a thickness of the order of 100 nm. This thickness will vary for different implantation energies.

3.1.2 RESISTIVITY.

Figure 3 shows the resisivity obtained as a function of the implanted iron dose. Starting at a dose of 10^{17} ions.cm^{-2} it is possible to control the surface resistance to a value of the order of 10^9 Ω.

3.2 THERMAL DIFFUSION.

An alternative and less agressive method for iron doping is thermal diffusion. To process the 7059 sample, one has first to deposite an iron layer of 100 nm. The substrate is then baked for two hours at a controlled temperature. This temperature has to be limited to less than 700°C to avoid degradation of the glass surface. After diffusion, the remaining iron layer is removed.

3.2.1 DIFFUSION PROFILE AND RESISTIVITY MEASUREMENTS.

A SIMS study of the resulting iron concentration shows a flat distribution at the limit of sensitivity. This indicates a probable quasi-uniform concentration of iron in the glass matrix over the whole thickness of the glass. This is confirmed by the resistivity measurements of the samples (Fig. 4). An appreciable decrease of resistivity can be observed on both sides of the glass (diffused surface and undiffused one). Considering the high diffusion coefficient for iron in silicon, one can suppose that a thermal diffusion of iron in glass leads to a ion concentration in the whole bulk of the sample, while the implantation is effective only in a thin (100-200 nm) layer.

Thermal diffusion allows a controlled decrease of resistivity. However, this method is less effective than ion implantation : the surface resistance has been lowered to a value of 10^{11} Ω only, at a diffusion temperature of 650°C. Using a less agressive temperature of 550°C, and by multiple diffusion, it has been possible to bring the resistivity to a much lower value, of the order of 10^{9} Ω.cm (see table 2.). Considering the resulting surface quality of the glass after diffusion, especially on the undiffused side, thermal diffusion can be considered as a good alternative to ion implantation that leads to comparable results at a lesser cost.

4. RESISTANCE STABILITY.

Doping glass with ions consists in forcing migration of elements in a stable glass matrix. It is possible for these elements to migrate further under external conditions like temperature and electrical field. These migrations can lead to important modifications of the resistivity with time as has been observed in glass doped with carbon, on which the resistivity has reached its initial value after a few days[13]. It is therefore a necessity to check the stability of the obtained resistivity over a long period.

4.1 STABILITY UNDER BIAS.

Surface resistances of the implanted and diffused glasses have been measured over a period of 10 days using the method described in sect. 3. Glass polarisation was kept at a constant value of 200V over the measurement period. We have used the samples indicated as A and B in figs 3 and 4. Figure 5 shows the results of these measurements for both glasses. Whichever the method of doping, the resistivity reaches a constant value. Sample A (implanted glass) is very stable with time: the surface resistance kept a constant value of 8.10^{12} Ω. For sample B (diffused glass) one notes a small rise of the surface resistivity for a period of 4-5 days, from $6.\ 10^{13}$ Ω to $3.\ 10^{14}$ Ω, followed by a plateau for the rest of the measurement period.

4.2 STABILITY UNDER BIAS AND IRRADIATION.

With a constant polarisation value of 200V, irradiation was performed using a ^{90}Sr source ($3.7\ 10^{8}$ Bq), corresponding to a daily dose of 5 krad. After an immediate

jump due to source exposure (excess of electrons), the measured current was remarkably stable over the 20 day period studied. One therefore concludes that there is good charge evacuation, hence good stability for the surface conductivity for both samples.

Surface resistance has been measured for both samples before and after irradiation. For the implanted glass, the resistance does not change its value of 10^{13} Ω. For the diffused glass, one notice a small increase of resistance, from R = 2.10^{14} Ω to R = 5.10^{14} Ω. This small variation is interpreted as an iron migration towards electrodes. The diffusion leading to a relatively small concentration of iron over the whole bulk of the glass, a small migration of ion can be more easily detected. However, after such a migration, a new state of equilibrium is reached, which is more stable.

5. SUMMARY AND CONCLUSIONS.

From previous studies, it is known that glass subtrates suitable for MSGC operation should be semi-conductive that is have a resistivity of the order of 10^9 Ω.cm, and present an electronic conductivity. These two characteristics are strongly dependent of the glass composition. From composition analysis, it has been shown that a very small content of light alcali elements together with a large concentation of transistion elements provide usefull subtrates.

Using doping methods, we have shown that it is possible to control the resistivity of the substrate to the proper value needed for MSGC. In the case of an implanted substrate, the obtained resistivity is stable under irradiation, although the risk of degradation of the surface quality can lead to difficulties in the metallisation of the strips. For diffused substrates some migration of iron semms to appear after thermal processing, leading to a small increase of resistivity before stabilisation.

MSGC detectors have been realised using modified and non modified glasses with the doping techniques described above. Gain studies and comparisons between both types confirm the stability of the detectors made with modified glasses[14].

Further development of doping method will consist in thin layer deposition at the surface of any glass substrate. Such a layer will be made of Silicate Gel, for which the composition can include various metallic elements (Fe, Ni, Co, Cr, V, etc.) to obtain the needed surface resistance.

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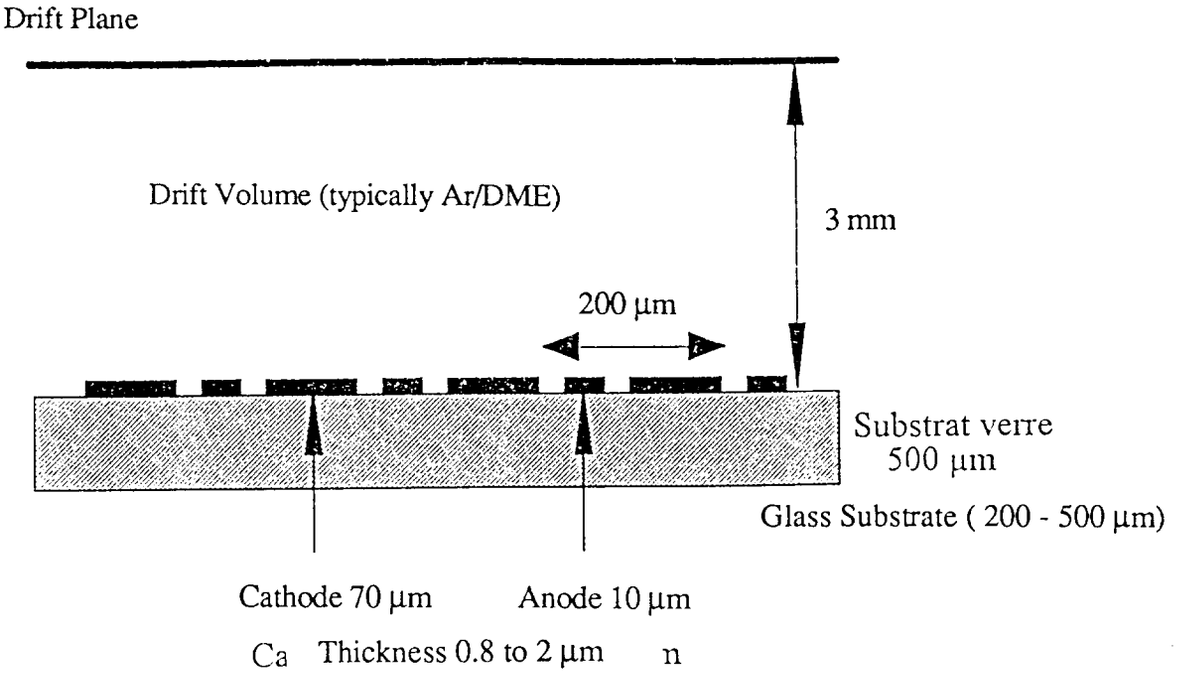

Fig. 1. Transversal design of a typical MSGC.

ELEMENT	MOSCOW 10^9 Ω.cm	D263 $>10^{15}$ Ω.cm	D211 $>10^{15}$ Ω.cm	7059 $>10^{15}$ Ω.cm	7740 $>10^{15}$ Ω.cm
Na	0.125±0.009	3.7±0.2	4.1±0.2	0.046±0.004	1.63±0.09
Al		2.11±0.06	0.41±0.02	4.0±0.1	0.33±0.01
K		3.2±0.3	3.2±0.3	0.06±0.03	0.25±0.06
Ti		1.9±0.2	1.57±0.07		
Fe	16.3±0.5				
V	2.51±0.08				
Zn		4.2±0.1	4.9±0.2		
Sr	4.5±0.2			2.1±0.03	
Sb		0.098±0.005	0.26±0.01	0.08±0.004	
Ba	26±1			19.9±0.6	0.015±0.003

Table 1.

Glass composition (mass fraction in percent)
Results obtained by Neutron Activation Analysis

Note: Fractions of Si and O are not presented in this table.

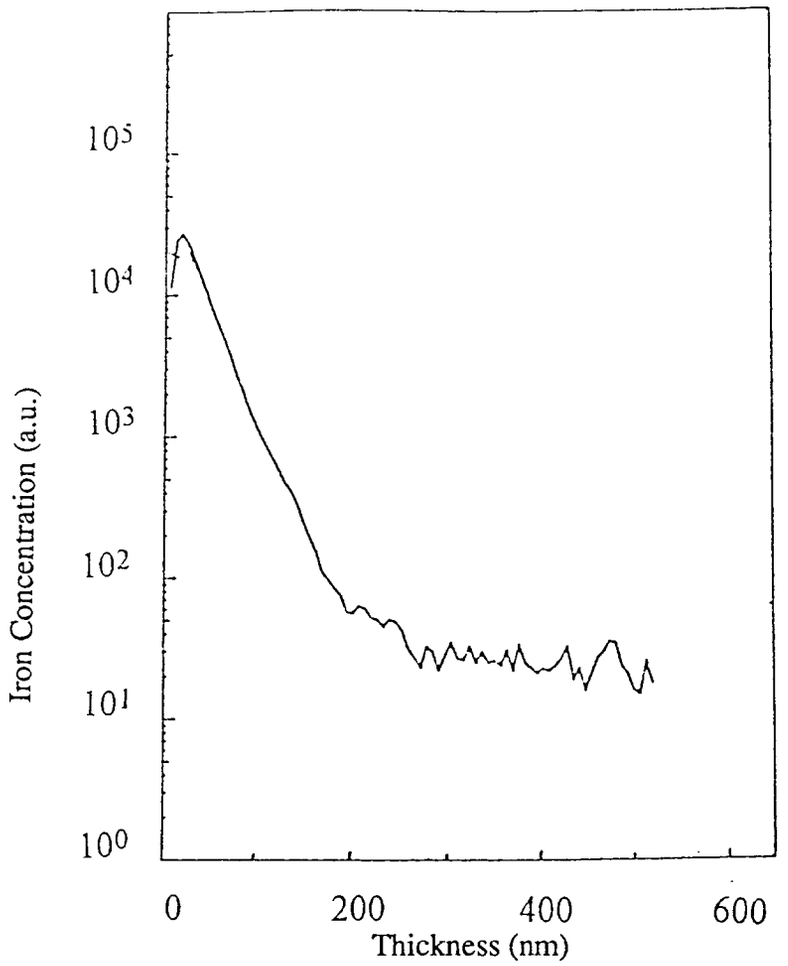

Fig. 2. Concentration profile of Fe content after ionic implantation (SIMS measurement)
Glass: Corning 7059 -
Implantation energy: 150 keV
Implanted dose: 1. 10^{17} ions/cm^2

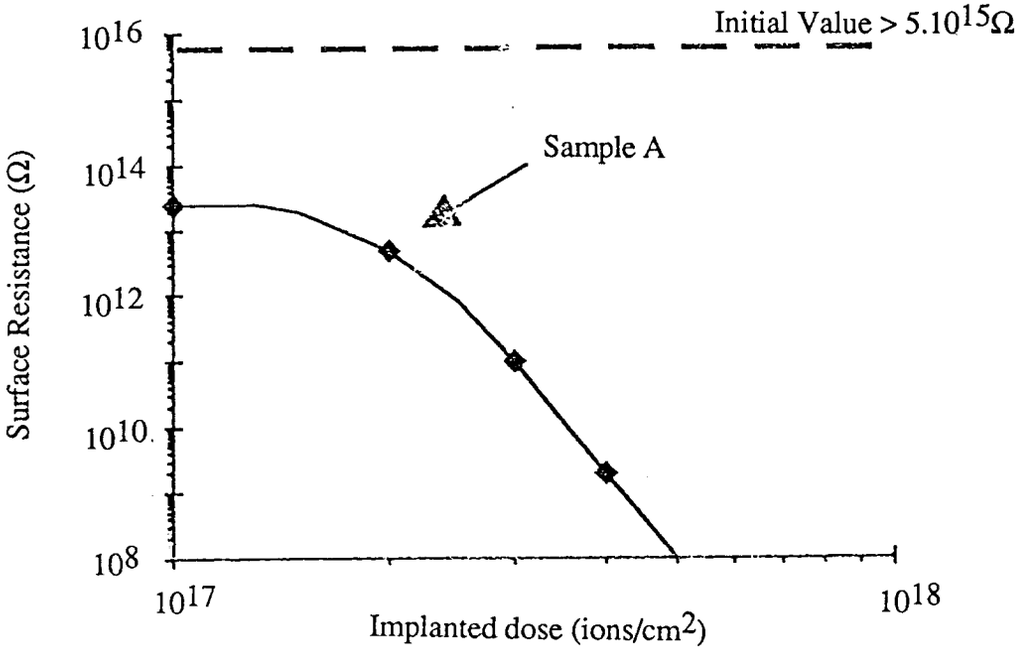

Fig. 3. Surface resistance as function of the implanted dose
Glass: Corning 7059
Implantation energy: 150 keV.

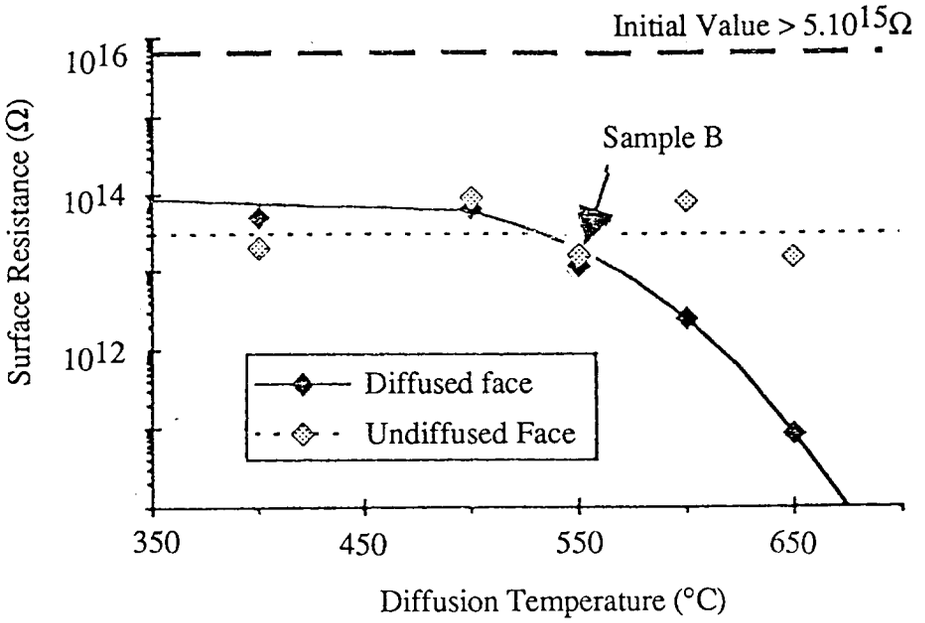

Fig. 4. Surface resistance as function of the diffusion temperature
Glass: Corning 7059
Diffusion time: 2h.

	DIFFUSION 1	DIFFUSION 2	DIFFUSION 3
R (Ω)	4.10^{14}	3.10^{13}	4.10^{9}

Table 2.

Resulting surface resistance after multiple thermal diffusions.
Diffusions for 2 hours at 550°C under N_2 atmosphere.
Each diffusion consists of: - Metallization (1000 Å)
- Baking at 550°C (2 hours)
- Cleaning (removing of the remaining Fe layer)

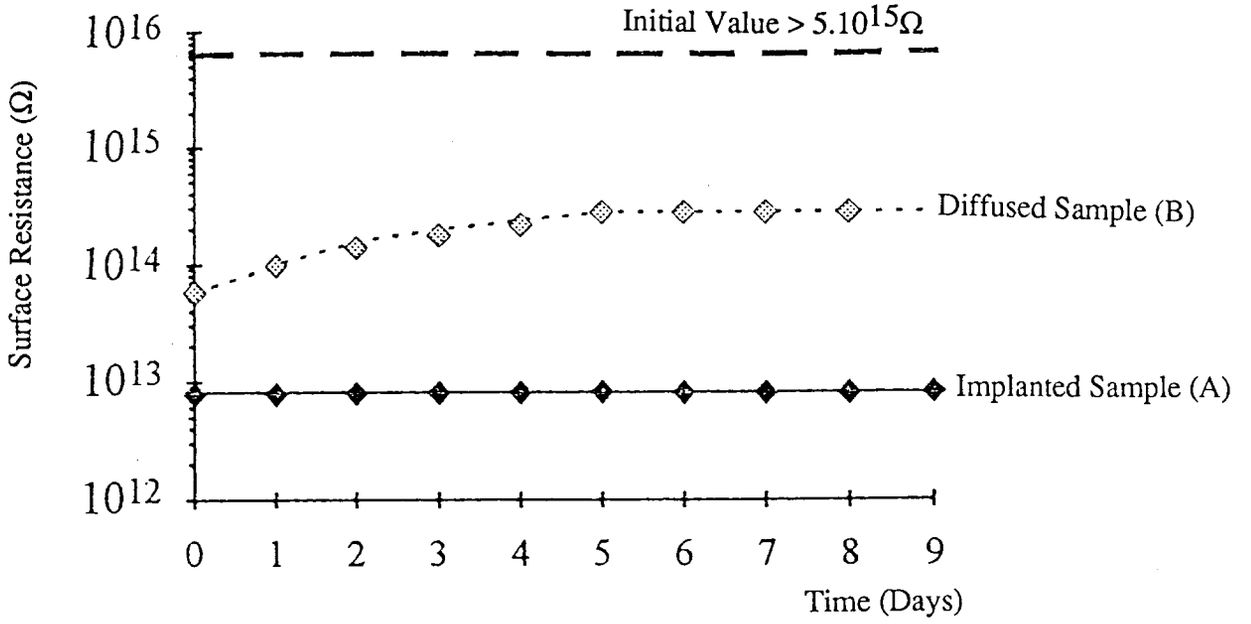

Fig. 5. Stability of the surface resistance as function of time
A: Corning 7059 implanted at 2. 10^{17} ions/cm^2 - 150 keV.
B: Corning 7059 diffused at 550°C - 2h.
Constant polarisation voltage: 200V.

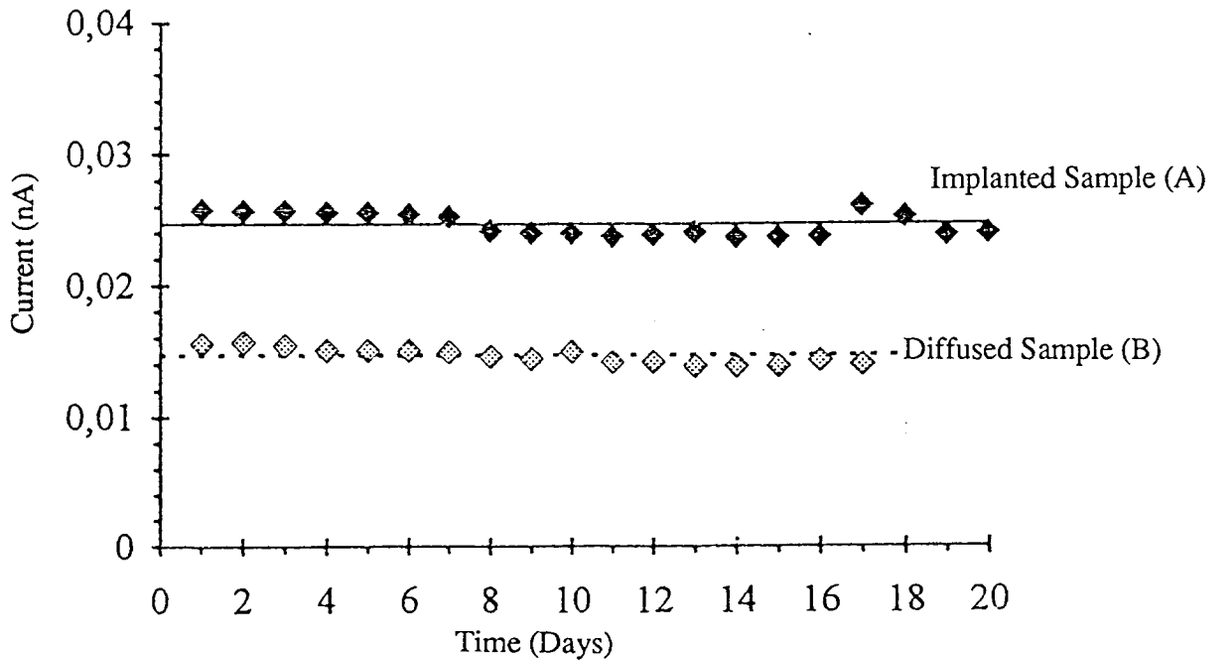

Fig. 6. Stability of measured surface current under irradiation as function of time
A: Corning 7059 implanted at 2. 10^{17} ions/cm^2 - 150 keV.
B: Corning 7059 diffused at 550°C - 2h.
Constant polarisation voltage: 200V.
Irradiation source: ^{90}Sr - 3.7 10^8 Bq