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ON THE STABILITY OF LARGE-AREA Al–p–Si JUNCTION

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О стабильности перехода Al–p–Si

Представлен дизайн p-кремниевого детектора излучений на основе 12-килоомного кремния и пассивации края перехода с применением эпоксидной смолы с отвердителями, как содержащими аминные группы, так и не содержащими их. Изготовлению детекторов большой площади предшествовало изготовление и изучение ряда тестовых детекторов малой площади. Изучалась стабильность данного Al–Si-перехода в течение долгого времени. Сделана реалистичная оценка времени жизни данного перехода.

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Tsyganov Yu. S. E13-2006-77

On the Stability of Large-Area Al–p–Si Junction

Design of silicon radiation detector made of 12 k$\Omega \cdot$ cm p-silicon with both amine- and amine-free hardeners epoxy resin junction edge passivation is presented. Before producing large-area detectors for measurements of efficiency of evaporation residues collection at the focal plane of the Dubna Gas-Filled Recoil Separator (DGFRS), a set of small-area test detectors was produced. Stability of the Al–(p)Si junction has been studied for a long time. Estimate of a realistic life time for the mentioned type of Al–Si rectifying junction is done.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 2006

INTRODUCTION

The Dubna Gas Filled Recoil Separator (DGFRS) is the most efficient facility in use in the field of synthesis of superheavy elements at the Flerov Laboratory of Nuclear Reactions (JINR) [1]. Their separation characteristics are based on the ion optical properties of the gas-filled magnetic dipole. For the synthesis and study of heavy nuclides, the complete fusion reactions of target nuclei with heavy bombarding projectiles are used. The resulting excited compound nuclei (CN) can deexcite by evaporation of a few neutrons, while retaining the total number of protons. Recoil separators are widely used to transport evaporation residues from the target to the detection system, simultaneously suppressing the background products of other reactions, the incident ion beam, and scattered target nuclei.

In this respect, it is very significant to measure the separator efficiency in different heavy-ion-induced nuclear reactions. The experimental collection efficiencies of the fusion-evaporation reaction products were measured [2] by comparing the number of EVRs, recoiling from the target and collected on the catcher with those collected on the detector array, using the reactions where appropriate long-lived radioactive product nuclei are produced. Namely, the detector described below, was employed in those measurements to measure long-lived activities from the catcher. In other cases, the experimental yield of nuclei collected on the focal-plane detector array was compared with the yield calculated from the known cross section of the reaction studied.

1. ON p-SILICON AS A RADIATION DETECTOR MATERIAL

It is well known that Au–Si(n) barrier is widely used as a working junction of silicon radiation detectors to measure energy and/or energy loss of highly ionizing particles in different research fields [3]. On the contrary, first attempts to use p-silicon with Al top electrode were not successful because of some instability of this metal-semiconductor junction.

It was taken about twenty days to destroy completely rectifying properties of junctions [4]. It was Kushniruk [5–6], who first recognized the role of intermediate dielectric amorphous Ge-layer between Al and p-silicon to avoid the mentioned drawback. The p–Si detectors have certain advantages as compared with n–Si ones – the more ruggerized surface* being one of them. Another one

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*Mechanically. And lower sensitivity to light than in the case of Au top electrode.

is relatively high radiation stability. From the viewpoint of the detector substrate material p-silicon can be more easily obtained in the form of high-purity and uniform material, whereas for n-silicon a neutron doping sometimes is required with the aim of producing of high-resistance material.

Another reasonable method to provide the surface stabilization is to passivate the metal electrode edge using epoxy resin in two steps consecutively with amine- and amine-free hardener agents. Of course, during this process of producing the junction, the etched silicon crystal wafer surface stays in contact with vapors of both agents for the certain time, usually for hours or more.

This technique is considered in the present paper. From the viewpoint of practical use, two large area p–Si (~ 12 k$\Omega \cdot$ cm) detectors were manufactured to measure the efficiency of heavy recoil transport at the Dubna Gas Filled Recoil Separator (DGFRS) focal in different heavy-ion-induced nuclear reactions. The active area of both detectors was about 11 cm^2.

2. FABRICATION OF THE Al–Si(p) HIGH VOLTAGE JUNCTION

Before producing two large area detectors, several detectors with smaller working area* (0.5-0.7 cm^2) were produced in order to test main working parameters and junction stability. Design of the detectors is shown in Fig. 1. As

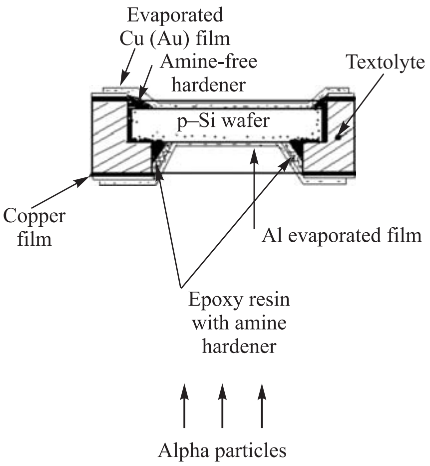

Fig. 1. Schematic view of Al–p–Si detector

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[*] Including one 0.7 cm^2 detector to measure energy of heavy ions from U400 cyclotron (operation cycle was about one year).

a housing of the detector a commercially available foil-clad textolite was used. After the mechanical treatment and before etching ($\sim$ 2.5 min) in HNO_3 + HF 3 : 1 mixture, p-silicon wafers (about 1.7 mm depth) were washed in the extra pure acetone, water solution (boiling, $\sim$20 min) of Trylon-B and de-ionized water flow ($\sim$7 k$\Omega \cdot$ cm), respectively, as well as the housings. After washing all housing was dried by the infrared lamp for about one hour at the temperature about 60 °C. Aluminum and Au (or Cu, back electrode) evaporation has been performed from two to three days after the silicon wafer was mounted in the housing by two epoxy resins, one with amine-free hardener agent and another with amine-containing one, and then it was placed in the desiccator. The day after the electrode evaporation of each detector was heated up to $\sim$ 50 °C for about fifteen minutes by infrared lamp. All the volt-ampere dependences shown below were measured several days after the final heating procedure. In Fig. 2 the voltampere dependences of the tested detectors are shown. One can easily see high break-down voltages for these detectors. After extensive testing of the detectors described above, two large-area detectors were produced in order to be used in the measurements of the GFRS efficiency for different heavy-ion-induced complete fusion nuclear reactions. After each set of measurements the active detector area was wiped by cotton which was wetted slightly with pure acetone. This precaution was done in order to eliminate the long term alpha-emitters accumulated on the active detector surface from the previous measurements. The initial resolution of the detectors was about 60 keV*. In Fig. 3 the dependence for one detector is shown whereas long-term change of the break-down voltage** is

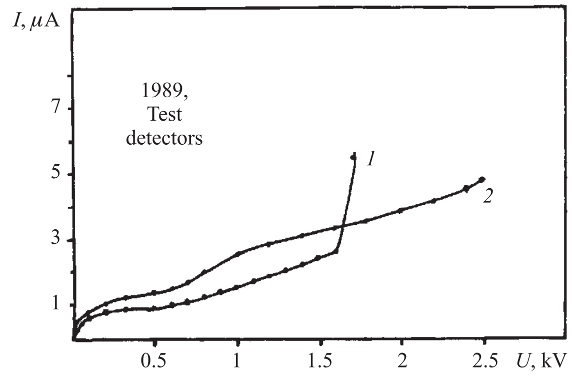

Fig. 2. The dependence of reverse current against bias for test detector with small (0.7 cm^2) working area

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*Bias was 75 V. Energy resolution was about 17–28 keV (FWHM) for small-area test detectors.

**Arbitrary choice of the author. $I > 5$ μA.

shown in Fig. 4. Note, that even in the case shown in Fig. 3, *c* junction should be considered as rectifying one. The last figure gives us a rough estimate of the life-time of the given structure.

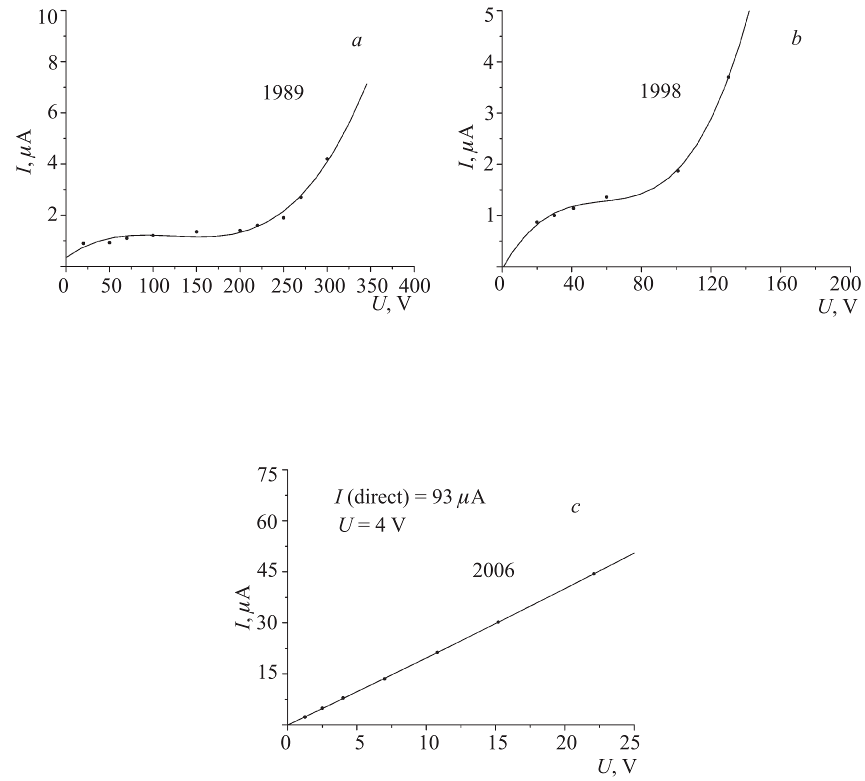

Fig. 3. The dependences of reverse current against bias for detector with large (11 cm^2) working area measured in the years 1989 (*a*), 1998 (*b*) and 2006 (*c*), respectively

As concerning the reasonable scenarios of mechanisms leading to the discussed above behavior, one should mention the following:

- Influence of amine- and amine-free hardener agent vapor on the formation of the n–p junction and smoothing the edge effect is quite probable.
- Partial or complete elimination of mechanical stresses arising in the vicinity of the junction active area edge by slight small heating of the detector. Of course, the author does not exclude any probable reasons in formation of long-term instability, and diffusion of Al atoms into working silicon depletion region is one of them.

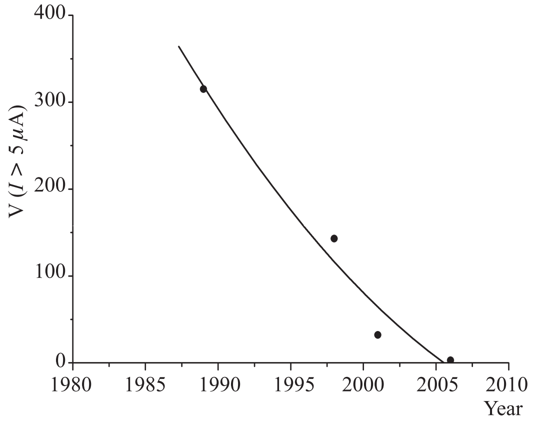

Fig. 4. The dependence of breakdown voltage on time

Besides these two points, one should mention, that using high resistance p-silicon is, probably, preferable from the viewpoint of stability, than low resistance ($\leqslant 10^3$ k$\,\Omega\cdot$cm) one. This statement does not concern high purity p–Si with resistance about 100 k$\,\Omega\cdot$cm.

CONCLUSIONS

Method to provide stabilization of Al–p–Si junction has been suggested. The behavior of the produced detector shows, that life time of such rectifier structures can be estimated from four to nine years[*]. Note, that fabricated junction allows one to some extent to provide some limited scope of the mechanical operations, like surface cleaning by acetone wetted cotton for a few times. Short ($\sim$ 15 min) heating of the junction area by infrared lamp prolongates its normal operation life time. Reasonable scenario of partial smoothing of long-term instability has been proposed. On the other hand, in order to distinguish different probable factors additional research with around 10^1 k$\,\Omega\cdot$cm p-silicon material is required.

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[*] In the spectroscopy mode. Resolution (FWHM) was not worth than 110 keV (45 keV for small area).

APPENDIX A

SMALL CORRECTION[*] OF DIRECT $E_{\mathrm{meas}} = f(E_{\mathrm{in}})$ DEPENDENCE FOR LOW ENERGY EVR'S

Let us consider full pulse height defect value (PHD) in the form

$$\Delta = \Delta_n + \Delta_r + \Delta_w.$$

Here, indexes n, r and w are correspond losses due to nuclear stopping, recombination and passing through dead entrance window [7].

So, if one use calibration equation for heavy recoil in the form of functional dependence of measured energy value against incoming one, one should take into account some small deviations, due to difference in Z and A, with respect to the average parameters are used for calibration. Therefore, in the vicinity of some «average» parameters it can be written as

$$d(\Delta) = d(\Delta_n) + d(\Delta_r) + d(\Delta_w),$$

and after some simplifications and neglecting of the last term

$$d(\Delta) = \frac{\partial \Delta_n}{\partial Z}\Delta Z + \frac{\partial \Delta_n}{\partial A}\Delta A + (E_{\mathrm{in}} - \langle \Delta_n \rangle)\frac{\partial \lambda}{\partial R}\Delta R.$$

Here λ is the value of relative recombination loss, and R — heavy recoil range in silicon (units of microns, usually). The value of difference of generating electron-hole pairs after nuclear scattering process for the recombination term is neglected too. An electron-hole pairs generation density is considered as uniform (linear density $n_L = (E_{\mathrm{in}} - \langle \Delta_n \rangle)/R$), like it is accepted in the Seibt track erosion model.

And, of course, if one will use the equation from [7] for recombination term, it is necessary to take into account a factor of about ~ 0.5 (e. g., [8]), which reduces plasma time due to a strongly spherical geometry, except for a cylindrical one, as it was considered by Seibt et al. in their model of space charge limited currents of charged particle track erosion and was reported in [9]. That is

$$\lambda = K_{\mathrm{geom}} \frac{sT_P}{R},$$

where $K_{\mathrm{geom}} \sim 0.5$.

In the case of PIPS detectors, an effective velocity of surface recombination should be taken from about several hundreds to one thousand cm/s as it was

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[*] It concerns all types of detectors not only that ones reported in the present paper.

reported in [10, 11]. The value of the nuclear stopping component should be taken as reported by Wilkins et al. [12]. Additionally, it can be stated, that an effective value* of surface recombination velocity is slightly smaller for p-silicon, than for n-type one [13].

As an example, in Fig. 5 the calculations for EVR's of ^{288}114 are shown by lower line, whereas the next two lines are corresponded to ^{210}Po and ^{217}Th nuclei.

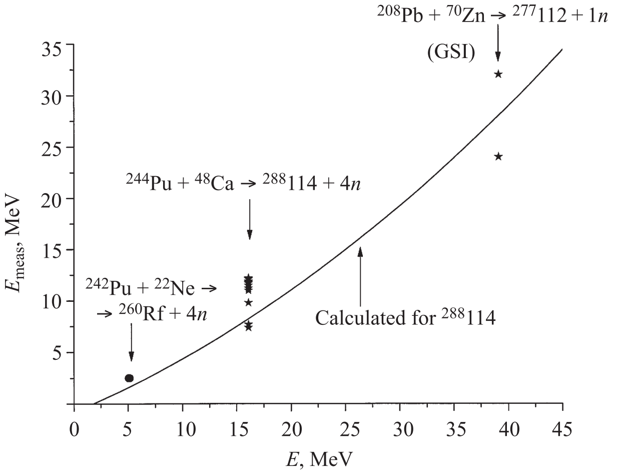

Fig. 5. Calculations of the measured energies against incoming ones performed for recoils of ^{288}114. Experimental values are also shown

APPENDIX B

SMALL EMPIRICAL CORRECTION TO THE CALCULATED VALUE OF MEASURED ENERGY EVR'S SPECTRA WIDTH

In [14], the method to calculate both mean value and energy width of the EVR's measured with silicon radiation detector energy spectra is proposed. Note, that there was no difference in the position of the detected events. The reported code provided calculations for all area of the DGFRS focal plane detector without statistical weight of each position sensitive strip. Therefore, the calculated width of the recoil energy spectra is slightly broader than that with fixed horizontal position (point, strip, group of strips, etc.). But having considering the data

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*In the case of calculations of both plasma time and λ for p-type silicon detector.

reported in [15], for EVR measured energy against strip number dependence, it will be possible to provide the mentioned correction.

REFERENCES

1. *Subotic K. et al.* // Nucl. Instr. Meth. Phys. Res. A. 2002. V. 481. P. 71–80.

2. *Lazarev Yu. A. et al.* FLNR Sci. Report. E7-93-57. Dubna: JINR, 1993. P. 203–205.

3. *Dirnley G., Nortrop B.* Semiconductor counters for nuclear radiation. M.: Mir, 1966. P. 9–359.

4. *Kushniruk V. F., Nikitina R. A., Kharitonov Yu. P.* // FTP. 1973. V. 7. P. 1396.

5. *Kushniruk V. F., Nikitina R. A.* JINR Communication 13-4612. Dubna, 1969.

6. *Kushmiruk V. F.* JINR Communication P13-8919. Dubna, 1975.

7. *Kushniruk V. F.* JINR Communication P13-11933. Dubna, 1973.

8. *Tsyganov Yu. S.* JINR Communication P7-91-565. Dubna, 1991.

9. *Seibt W., Tove P. A.* // Nucl. Instr. Meth. 1967. V. 51. P. 261.

10. *Tsyganov Yu. S.* JINR Communication P13-96-430. Dubna, 1996.

11. *Tsyganov Yu. S.* // Appl. Radiat. Isot. 1997. V. 48, No. 9. P. 1211.

12. *Wilkins B. D. et al.* // Nucl. Instr. Meth. 1971. V. 92. P. 381.

13. *Kushniruk V. F., Tsyganov Yu. S., Kharitonov Yu. P.* FLNR Sci. Report. E7-91-75. Dubna: JINR, 1991. P. 195–196.

14. *Tsyganov Yu. S.* // Nucl. Instr. Meth. Phys. Res. A. 1996. V. 378. P. 356.

15. *Tsyganov Yu. S.* JINR Communication E13-2006-19. Dubna, 2006.

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