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LIST OF ACRONYMS AND ABBREVIATIONS

HPGe	High Purity Germanium Detector
SIMS	Secondary Ion Mass Spectrometry

Executive Summary

Technological improvements on the production of coaxial detectors, with newly passivation technologies, are on-going together with developments on test cryostats and encapsulation techniques to protect the passivated surfaces. A new hydride treatment has been found very promising.

Developments on semi-planar detector with point contacts is ongoing at GSI at the level of prototype. Results promising but read-out test are still to be performed to optimally evaluate the efficiency of the prototype.

Introduction

The PSeGe JRA within ENSAR2 contributes to the R&D of detector technology for position-sensitive HPGe detector arrays. Key areas are detector production technology, the basic characteristics of the novel detectors, electronic instrumentation and software developments. In particular the tasks aim to the following goals.

Task 1: to investigate new technologies on passivation and segmentation,

Task 2: to perform R&D on novel Ge-detector geometries for ultimate position resolution and efficiency,

Task 3:to perform R&D on segmented p-type coaxial detectors.

Task 4: networking efforts on Demonstration of imaging applications and associated detector technologies. Several European institutions contribute with their specific expertise through workshops and personnel training visits.

The present Advancement Report will inform about the work performed in the first 30 months of the ENSAR2 PSeGe JRA on the Tasks 1 and 3.

Section 1 Advancement Report on the Investigation of new technologies on passivation and segmentation

During the first 30 months of the ENSAR2 grant the INFN group has worked on the technologies used for the production of standard coaxial HPGe detectors by developing the necessary techniques for the full shaping of this detector geometry. A young technologist has been enrolled for working on this activity at the INFN LNL laboratories. A new drilling machine has been developed, constructed and is ready for that purpose.

In relation with the passivation treatments we have worked on the surface preparation by comparing the machine and manual lapping procedures for the external crystal surfaces as well as the determination of the etching times for minimizing the number of surface dislocations.

A new hydride treatment has been found that minimizes, in relation with other treatments, the charges trapping processes near the surface and maximizes the active volume of the detector.

We have also studied the passivation of the germanium surface between two adjacent segments in segmented detectors. For this study we developed and tested a procedure for the deposition of an Au metal coating, which can be used to precisely delimit the different segments. The metal coating is resistant to the very aggressive etchings, which are used in the manufacturing of HPGe detectors. Figure 1a shows a small prototype of HPGe detector with two segments, one for the central contact (circular contact) and the other for the guard ring (external contact). The two segments are electrically insulated and can be biased independently.

The first tests of Boron implantation in planar detectors to produce new contact technologies were performed successfully. Figure 1b shows the expected ^{11}B concentration profile measured by means of SIMS (secondary ion mass spectrometry) at DFA, confirming the surface confinement of the p+ dopant.

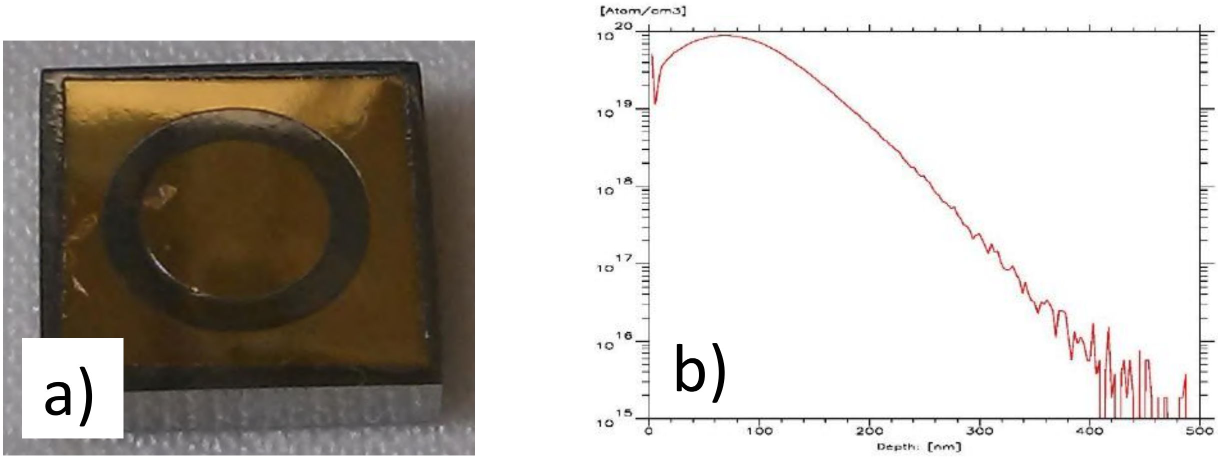

Figure 1 a) Prototype of HPGe detector with two electrically separated segments. b) Concentration profile of the ion-implanted ^{11}B dopant measured by SIMS technique.

The first test of Boron contact segmentation has been performed. Preliminary results show that more efforts are needed especially in improving the contacts. The tested technologies could reduce the final costs of these detectors and improve their robustness for commercial applications. All this work has been done in a strong collaboration with Task 3.

Cryostat development is ongoing for new detector prototypes in a collaboration between IKP-Cologne and INFN.

Within Task 4 activities, IPHC personnel has been trained on chemical treatment of Ge crystal surface in order to prepare the test of the passivations in the scanning table of Strasbourg.

Additionally IKP-Cologne is developing a new encapsulation technology for the present and future segmentation technologies. This new encapsulation technology was developed for highly segmented hexagonally shaped HPGe detectors. The development was pursued at Nuclear Physics Institute, University of Cologne together with the industrial partner Canberra, France – Mirion. The main advantage of the new technology to close hermetically the capsule is a non-destructive solution, which allows reusing the detector capsule after opening the detector container and modifications or repair of the delicate HPGe crystal. This is in strong contrast to previous solutions like electron beam welding which did not allow to recycle the aluminum container more than one or two times. In autumn 2016, first detectors with the new encapsulation technology were delivered to IKP Cologne and were subject of extensive test measurements especially on the mechanical performance, impact of the microphonic effect, cross talk contributions and energy resolution of the new detectors. Selected results on energy resolution and cross talk contributions of these detectors are shown in Fig. 2.

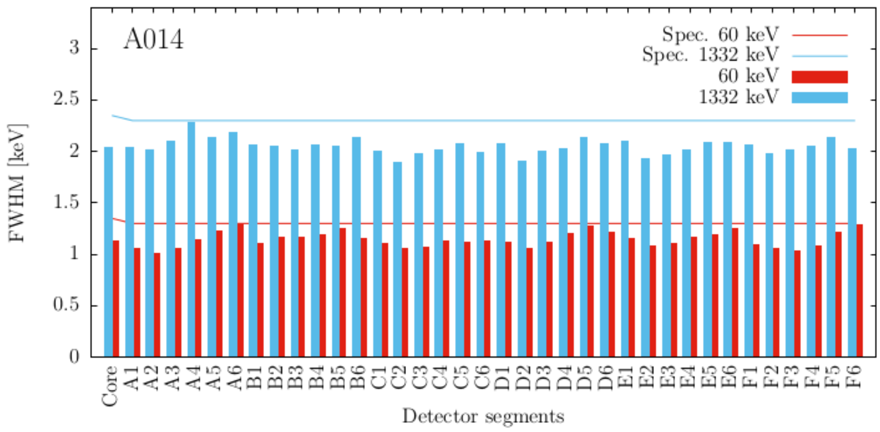

Figure 2: Energy resolution values for an encapsulated HPGe detector. Values are given for the central core contact and 36 segment signals for low energies of 60 keV and high energies of 1.3 MeV. The specifications are indicated.

SECTION 2 ADVANCEMENT REPORT ON THE R&D ON NOVEL GE-DETECTOR GEOMETRIES FOR ULTIMATE POSITION RESOLUTION AND EFFICIENCY

The activity within the ENSAR2 PSeGe JRA of the GSI collaborators during the last 30 months, has focused on the development of semi-planar detector with point contacts as a segmentation tool. This includes a detailed study by numerical simulations the electric field and the charge transport inside the detection crystal and a search for the optimal geometry. The main idea is to make several point read-outs on a planar crystal which are sensitive to certain area. The distribution and number of these points can be estimated by performing simulations taking the electric field and charge transportation into account. In this framework, a semi-planar HPGe detector with a single point contact read-out is being studied in order to characterize the behavior of such a novel contact technology replacing the segmentation of the crystal. A non-segmented p-type HPGe crystal with a dimension of *33.2x33.2x15.5* mm^3 and Carrier concentration of $3.3x10^9$ $atom/cm^3$ was used for the test purposes. The crystal which has an amorphous Ge (aGe) blocking contact with an efficient use of Ge material (see Fig. 3) has a sensitive surface to low-energy radiation on contrary to the Li-diffused contact technology commonly used.

The assembly of the crystal was done at GSI by installing it into POPTOP capsule illustrated in Fig. 4. The charge signal was extracted from the p+ electrode. The detector was operated at 100V and 1.2 pA leakage current was observed. Sudden increase of the leakage current when increasing the bias voltage caused the saturation of the preamplifier which is related to the type of coupling used for the signal read-out. The detector was tested using ^{57}Co and ^{60}Co sources in order to cover the low and high energy region. For each source different shaping time constants were tested. Experimental data were fitted using an exponentially modified Gaussian function and the results for two different shaping time constants are given in Fig. 5 for ^{57}Co and for ^{60}Co sources. The energy resolution values obtained for the defined cases are listed in Table 1. Using the ^{57}Co source, 2.1 keV and 2.3 keV energy resolution values at 122 keV line were obtained for 3 µs and 6 µs shaping time constants, respectively. While with the ^{60}Co source, 4.5 keV and 4.3 keV energy resolution values were obtained for the 1332 keV transition for 3 µs and 6 µs shaping time constants, respectively.

Figure 3: Quasi-planar prototype p-type HPGe detector with dimensions of 33.2x33.2x15.5 mm^3 used in order to determine the energy resolution of such a system with a single point contact read out. The depletion voltage was calculated as 450V.

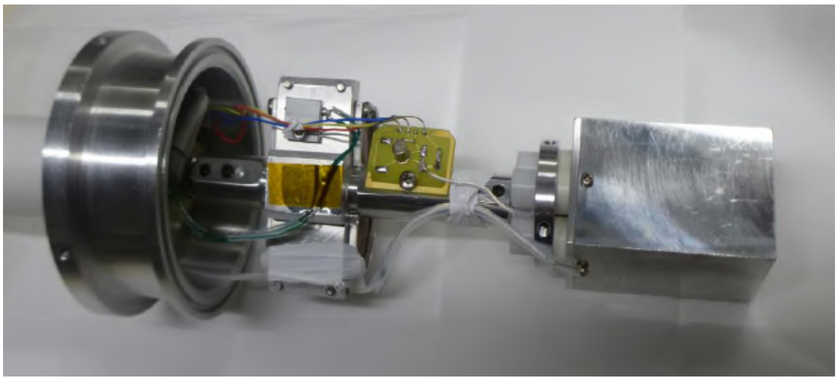

Figure 4: Semi-planar crystal placed in a POPTOP type capsule. The assembly and front-end electronics is shown.

The experimentally observed results were compared to the literature data obtained from the SEMIKON company where the crystal was bought. The verification tests were performed by using ^{241}Am, ^{137}Co sources and a pulser signal by SEMIKON. Additionally, the operation voltage was studied and defined as -480 V. Operating the detector at -480 V, an energy resolution of 2.59 keV was achieved at 59.6 keV using a ^{241}Am source and 2.55 keV with a pulser. The detector current at this operational voltage was 3 nA. The reason is assumed to be the different couplings that are used in two different systems. SEMIKON used AC coupling for the preamplifier, resulting in insensitivity of the gain potential from the detector current and higher operation voltage causing a larger depletion region, than used in the GSI measurement. The electronic drawings of these two different AC and DC couplings are shown in Fig. 6 below.

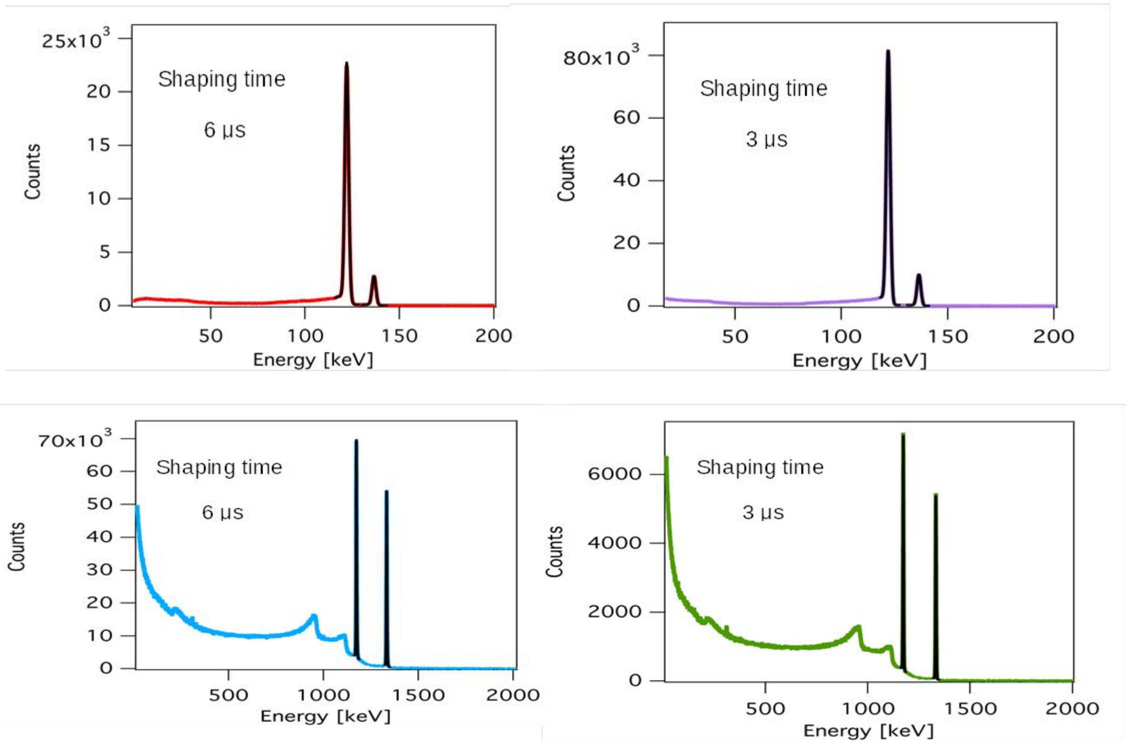

Figure 5: The observed energy spectrum with ^{57}Co source. The spectrum on the left side was recorded using a 6 µs shaping time constant while the one on the right side was obtained with a 3 µs shaping time constant.

Table 1: Energy resolution values obtained with a semi-planar point-contact detector listed for ^{57}Co and ^{60}Co transitions, using different shaping time constants.

Shaping time (µs)	3	6
Energy (keV)	122	122
FWHM (keV)	2.13(1)	2.35(1)
Energy (keV)	1332	1332
FWHM (keV)	4.53(1)	4.32(1)

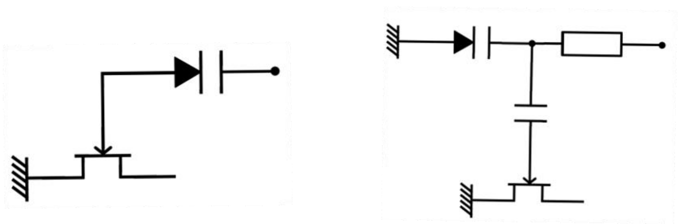

Figure 6: Different kind of couplings were used in order to read the signal at GSI and SEMIKON. Left drawing illustrates the DC coupling used at GSI and the left drawing shows the AC coupling used by SEMIKON.

Further tests are currently being performed with different kind of read-out schemes in order to compare the performance in an efficient way. Moreover, the detector will be tested at the GSI 3D scanner table in order to determine the pulse shapes recorded from interactions occurring at different positions along the crystal.

Then, these pulse shapes will be compared with the simulated results and the effect of the field distribution on the pulse shapes as well the field defect sizes are to be studied.

CONCLUSION

In this document we report on the advancement of Tasks 1 and 2 of the work package 10, the PSeGE JRA, within ENSAR2.

Regarding task 1, a strong collaboration, with INFN and the Padova University, IKP Cologne and IPHC Strasbourg as main actors, is working on segmentation and passivation techniques, test setup and protection of the pasivated surfaces with encapsulation techniques and on characterization of prototypes. The preliminary results with hydride passivation and segmentation of the Boron contact are very promising. The new encapsulation technique has been commissioned.

Regarding task 3, a detector prototype with the most promising geometry, the quasi-planar, that is expected to maximize both the position resolution and the detector active volume, has been produced and is partially tested The results, regarding resolution seems to be positive and the next step will be the characterization of the prototype, in order to determine the position resolution performance.