DETECTION PERFORMANCE STUDY OF SI-GaAs DETECTORS WITH NOVEL ELECTRODE METALLIZATION

F. Dubecký[1], B. Zaťko[1], E. Gombia[2], A. Šagátová[3], and V. Nečas[3]

[1]Institute of Electrical Engineering, SAS, Dúbravská cesta 9, 841 04 Bratislava, Slovakia,
[2]IMEM CNR, Parco Area delle Scienze 37/A, 43124 Parma, Italy, [3]FEEIT, Ilkovičova 3,
812 19 Bratislava, Slovakia

E-mail: elekfdub@savba.sk

Received10 May 2013; accepted 15 May 2013

1. Introduction

Semi-insulating (SI) GaAs has become one of the interesting candidates for the fabrication of radiation detectors [1] due to its good physical characteristics including attenuation factor, quality of the base material, well developed material technology and also high resistance to radiation damage. Applications of SI-GaAs in the field of detection in ultraviolet spectral region and THz devices have been also investigated [2, 3]. The crucial task regarding the SI-GaAs-based radiation detectors performance beside material [1] and topology mainly concerns the electrodes technology. The preferred structure includes a surface Ti/Pt/Au barrier metallization on one side of the SI-GaAs wafer coupled with a full area ohmic n^+ contact on the opposite side. An important improvement in the SI-GaAs radiation detector technology is related to the "non-alloyed" ohmic contact introduced by Alietti et al. [4]. A possible alternative to the ohmic contact technology is represented by formation of a metal-semiconductor (M-S) large area surface junction (back-to-back diodes configuration). It should be more convenient to use a metal with a low enough work function (w_f) in comparison with the semiconductor (SI-GaAs: w_f =~4.5 eV [5]). Supposing anti-blocking band bending, such a contact should block hole injection and behave as an ideal "non–injecting", quasi-ohmic contact. The application of a hole blocking metal contact to SI-GaAs radiation detector was proposed and investigated by our team [6]. The novel quasi-ohmic contact uses metals with low w_f such as e.g. In, Mg, or Gd. It has been shown that in a part of the forward bias range of SI-GaAs detectors the use of these contacts, especially Mg and Gd unexpectedly low currents in comparison with the „standard" AuGeNi eutectic alloy metallization. A possible physical explanation of the current transport through the low w_f metal contact on SI-GaAs was recently published [7].

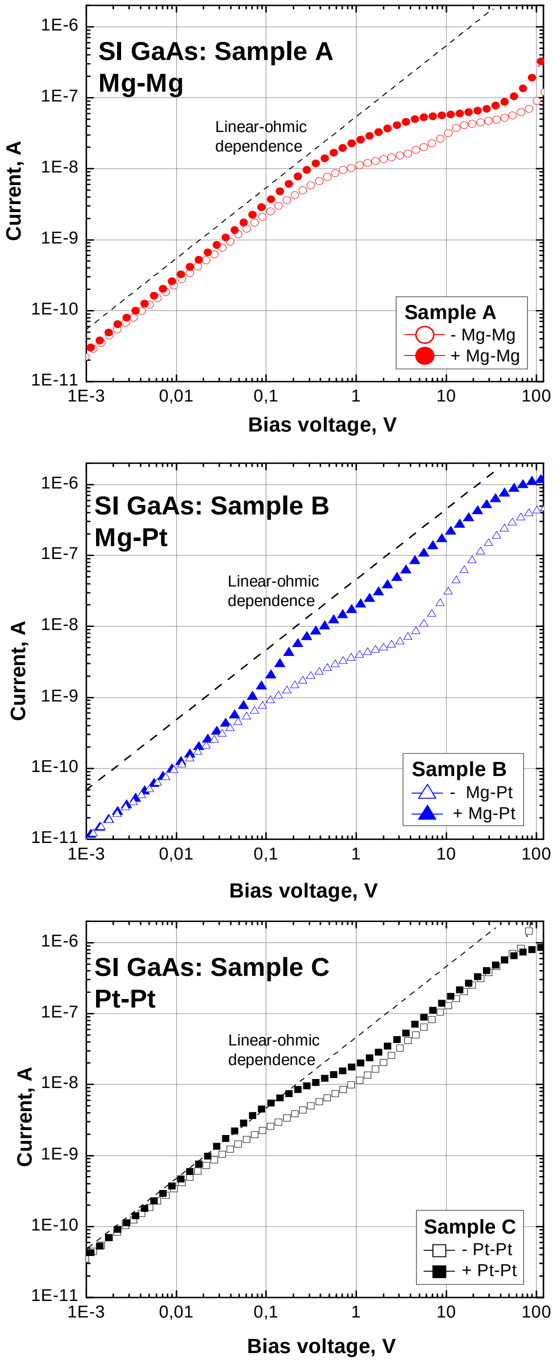
The present work reports on the detection performance of α-particles observed with the novel electrode using Mg as low w_f metal on SI-GaAs. Three types of structures with Pt and Mg full area contacts deposited on the same "detector-grade" bulk SI-GaAs are investigated and compared: (i) Mg-Mg, (ii) Mg-Pt, and (iii) Pt-Pt. The prepared structures are characterized by the current-voltage (*I-V*) and 5.5 MeV α-particles pulse height spectra measurements using ^{241}Am source. It is shown, that the various structures give rise to characteristic *I-V* dependences, detected spectra and charge collection efficiency (CCE) versus bias dependences. The irradiated low w_f contact (Mg-Mg structure) gives almost negligible CCE at zero bias voltage, while Pt contact detects α-particles about 10× more effectively. A tentative explanation of the observed effects is discussed and possible applications, based on the obtained results, are proposed.

2. Experiment

The M-S-M structures were prepared from a bulk undoped SI-GaAs 3” wafer grown by vertical gradient freeze with (100) crystallographic orientation and dislocation density of about 3000 cm^{-2} polished from both sides down to (180±10) μm. Resistivity and Hall mobility measured by the van der Pauw method at 295 K, give values of 1×10^{8} Ωcm and 5950 cm^{2}/Vs, respectively. The measured values fulfil the key requirements for a “detector-grade” bulk SI-GaAs [1]. The wafer was segmented into fragments used for the fabrication of three sets of different samples. The sample labelled as **A** has Mg/Au contacts on both sides, the sample **B** has Mg/Au-Pt/Au contacts, and the sample **C** has Pt/Au contacts on both sides. Just before metals evaporation the surface oxides were removed in a solution of $HCl:H_2O = 1:1$ at room temperature (RT, 300 K) for 30 sec. The low w_f Mg ($w_f = 3.68$ eV) and high w_f Pt ($w_f = 5.65$ eV) metal contacts with topside/backside thickness of 10/40 nm covered in situ by 5/60 nm Au, were evaporated in a dry high-vacuum system using electron gun. After the evaporation, samples with dimensions of about 3×3 mm^{2} were cleaved from the wafer fragment and contacted by silver paste onto sample holder. The *I-V* characteristics of the prepared structures were measured using a Keithley 237 source controlled by personal computer. Pulse height spectra of 5.5 MeV α-particles generated by ^{241}Am radioisotope were detected using laboratory spectrometric chain consisting of a preamplifier based on CREMAT CR 101D, ORTEC 572 linear amplifier (shaping time of 1 μs), analog-to-digital converter ORTEC 800 and a multichannel analyzer M2D. The detector was ac-coupled to the preamplifier input during the measurement. The distance between the detector and source was about 1 mm. Vacuum system was not used and the energy loss of α-particles in air is estimated not to exceed 70 keV. Measurements were performed at RT in the dark using an electrically shielded probe station. The „reverse“ branch corresponds to the negative bias polarity applied to the top, irradiated electrode.

3. Measurement

The *I–V* characteristics of the fabricated structures measured at RT in the dark are shown in Fig. 1. The dashed straight lines correspond to the calculated linear-ohmic dependence (LOD) controlled by the bulk material resistivity and the structure geometry giving a resistance of $R_{\mathrm{LOD}} = 2\times10^{7}$ Ω. The initial linear part of the measured *I-V* characteristics of samples **A, B** and **C** give resistances $R_{\mathrm{Mg\text{-}Mg}} = 4.6\times10^{7}$ Ω, $R_{\mathrm{Mg\text{-}Pt}} = 1\times10^{8}$ Ω and $R_{\mathrm{Pt\text{-}Pt}} = 2.5\times10^{7}$ Ω higher than those of R_{LOD}. The value of $R_{\mathrm{Pt\text{-}Pt}}$ of sample **C** with Pt-Pt contacts is close to the value of R_{LOD}. These resistances correspond to higher apparent SI-GaAs resistivity, as predicted by Manifacier and Ardebili from numerical modeling [8] for a p^{+}-SI GaAs-n^{+} structure based on deep trap-dominated overcompensated n-type SI-GaAs and experimentally observed in ref. [7]. The initial linear part in the reverse branch is followed by soft sublinear, “saturation” region, observed in a bias voltage region of about 0.1 V-5 V (**A**, **B**) and 0.05 V–0.5 V for the sample **C**. This region is followed by a superlinear part over about 50 V with onset to breakdown in the case of sample **A**. The sublinear part of sample **B** is followed by a superlinear injection region ($i \sim V^{2}$) in a bias range of 5 V–30 V followed by a second saturation at voltages over about 50 V. In sample **C** the first saturation is followed by a linear part and a second saturation similarly to sample **B**. The bias voltage >50 V represents the obvious operation region of a radiation detector, which is characterized by a dominant transport mechanisms controlled by the saturation drift velocity at high electric field [9]. The reverse breakdown voltage of samples **B** and **C** exceeds 100 V. As for the forward branch, the initial linear part is followed by slight superlinear injection over a voltage ~0.03 V. The following parts of the forward characteristics over about 1 V correspond to those of reverse direction, but shifted to higher currents.



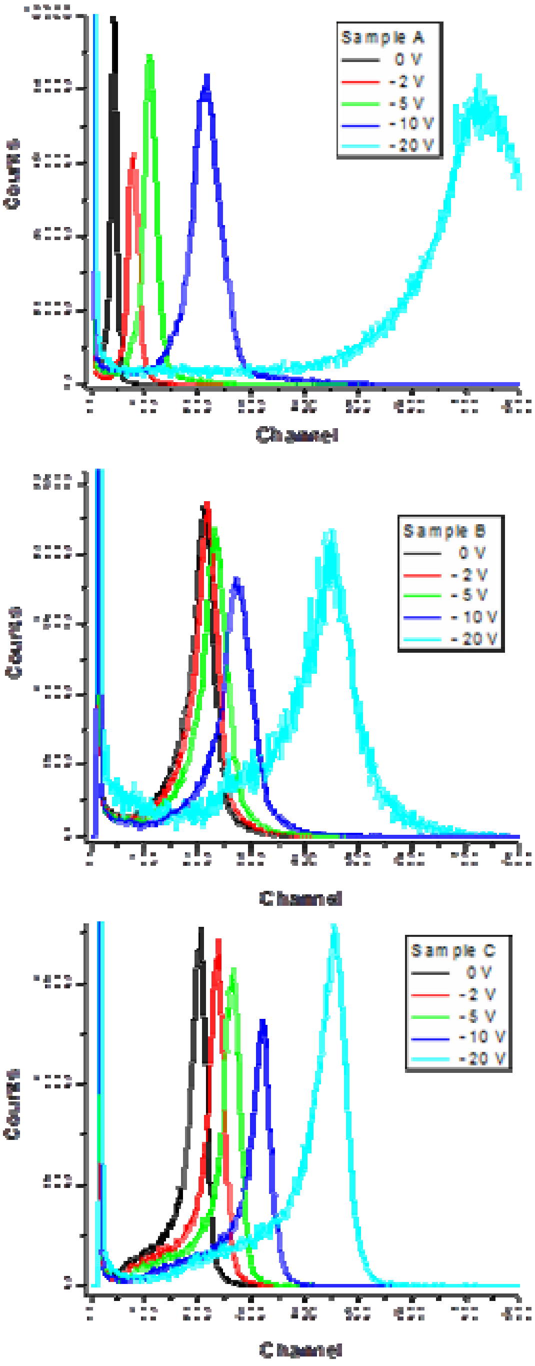


Fig. 1: *I-V characteristics of the fabricated M/SI-GaAs/M structures at RT plotted in log-log scales: Mg-Mg (A), Mg-Pt (B), and Pt-Pt (C).*

Fig. 2: ^{241}*Am pulse-height spectra measured at different low voltages at RT by the fabricated M/SI-GaAs/M structures (front irradiation).*

The measured spectra of 5.5 MeV α-particles at different reverse bias voltages are depicted in Fig. 2. The maximum applicable voltage is quite different for each sample. Sample **B**, with Pt-Mg nonsymmetric contacts was able to operate at the highest bias voltage of -270 V and detected photopeak has the estimated CCE higher than 95 %. Lower maximum operational bias voltages of -90 V and -150 V are typical of the samples **A** and **C** with the symmetrical Mg-Mg and Pt-Pt contacts, respectively. The dependence of the relative CCE vs. reverse bias voltage for irradiation from both sides illustrated in Fig. 3, shows that at zero bias voltage the samples **B** and **C** have a higher signal of 8-10 times with respect to the sample **A**. The observed results indicate that the symmetrical arrangement of Mg contacts on

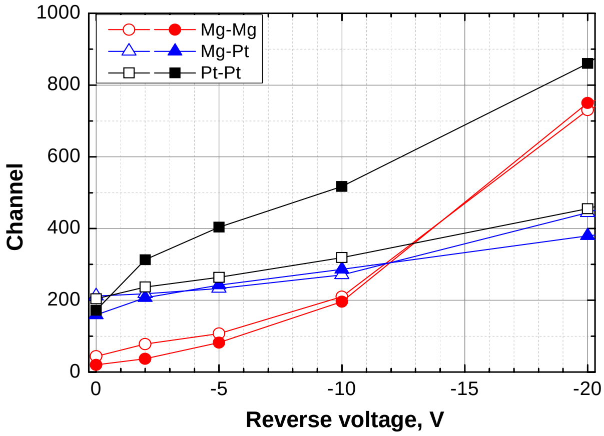


Fig. 3: *Plot of the relative CCE vs. reverse bias voltage for three fabricated M/SI-GaAs/M structures. Front- and rear-side irradiation: empty and full symbols, respectively.*

both sides of SI-GaAs base (sample **A**) led to the formation of an interface region with a negligible space charge at zero voltage. Low detection ability could be attributed to the electric field close to zero, created only by the incident α-particles. However, under the reverse bias the CCE of the structure **A** increases more rapidly, so, that already at -20 V exceeds the CCE of **B** (both contacts irradiated) and **C** (rear Pt contact irradiated). On the contrary, structures **B** and **C** with the irradiated Pt or even Mg (**B**) contacts give about 10× higher signal at zero bias, indicating the presence of an internal electric field at the irradiated contact interface due to the space charge region.

4. Discussion

The observed anomalous *I-V* characteristics appear to be in contradiction with the standard expectations. The sample **C,** with Pt-Pt contacts, gives the highest current for both, low as well as high bias voltages. It is an anomalous result because in the Schottky barrier controlled by the high w_f, Pt, the saturation current should be lower with respect to those of sample **A** and **B** due to its limitation by the thermionic emission. As for the high operation bias at about 100 V, the lowest current is observed for sample **A,** just with the symmetrical Mg, low w_f contacts. For now it is not clear what is the physical mechanisms playing the key role here. A possible explanation of the anomalous current transport in the case of low work function metal contact could be related to the formation of a strong electron accumulation at the M-S interface due to the creation of a quasi-degenerate region at the interface [6]. In such circumstance the commonly observed pinning of the Fermi level at the M-S interface should be substantially reduced, or the bend-bending leading to the formation of a degenerate region is induced by a dipole between contact and GaAs. An electrostatic screening of the electron injection could be the dominant mechanism which seems to control the limitation of the current. Another interesting aspect that is worth mentioning is that none of the two structures **A** and **C** with symmetrical contacts configuration gives symmetrical *I-V* characteristics. A possible explanation is related to the influence of the deposited contact on free carrier concentration in SI-GaAs bulk as was proposed in [6] or to the different thickness of deposited metal layers. Hence, the second contact seems to be deposited to a SI-GaAs base with different - higher apparent resistivity, i.e. barrier characteristics. The observed very low CCE of 5.5 MeV α-particles support the hypothesis of the formation of a quasi-degenerate electron-rich region induced by Mg, the low w_f metal contact. A new light into the understanding of the underlying physics could bring just performed XPS analysis of the deposited contact layers. In any case, the new observations open novel application choices of SI-GaAs as radiation detectors and also in photonic applications due to the suppression of the low bias leakage current by metal contact with low work function, particularly Mg.

5. Conclusions

A study of a novel contact using low work function metallization (Mg), in SI-GaAs is presented An anomalous decrease of the reverse current has been observed with such contact in comparison with the high work function, Pt Schottky barrier. Possible explanation relates to a strong electron accumulation at the M-S interface due to the creation of a quasi-degenerate region at the Mg/SI-GaAs interface. In order to better understand the above effects more detailed theoretical and experimental investigations will be carried out. The observed effects can be utilized mainly in improvement of radiation detectors and in novel photonic devices.

Acknowledgement

This work was partially supported by the Slovak Grant Agency for Science through grants Nos. 2/0167/13, 2/062/13, 2/0175/13, and by the Slovak Research and Development Agency under contract No. APVV-0321-11. The work was also supported by the EURATOM/CU Slovak Association and through the CNR-SAS collaboration agreement.

References:

[1] F. Dubecký, et al., Nucl. Instr. Meth. Phys. Res. **A 576** (2007) 27.
[2] M. Caria, , et al., Appl. Phys. Lett. **81** (2002) 1506.
[3] Y. Shi, et al., Appl. Phys. Lett. **89** (2006) 081129.
[4] M. Alietti, et al., Nucl. Instr. Meth. Phys. Res. **A 362** (1995) 344.
[5] J. Massies, et al., J. Vac. Sci. and Technol. **16** 1244 (1979).
[6] F. Dubecký, et al., Nucl. Instr. Meth. Phys. Res. **A 607** (2009) 132.
[7] F. Dubecký, et al., Solid-State Electronics **82** (2013) 72.
[8] J. C. Manifacier and R. Ardebili, J. Appl. Phys. **77** (1995) 3174.
[9] J. J. Mareš, et al., J. Appl. Phys. **82** (1997) 3358.