TEMPERATURE DEPENDENCES OF CURRENT-VOLTAGE CHARACTERISTICS ON METAL/SEMI-INSULATING GaAs STRUCTURES

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1. Introduction

Bulk semi-insulating (SI) GaAs has been found as one of interesting semiconductor materials for the fabrication of radiation detectors applicable in X-ray digital imaging [1], especially in the medical field. Advantage of the bulk SI GaAs is in the possibility of fabrication of monolithic radiation detectors due to creation of the space charge region under the blocking contact, which represents the active part of a pixel detector. Crucial task relating to the radiation detector performance concerns about the electrode metallization [2], overall electrodes technology and topology (blocking Schottky or ohmic contacts) of the structure and finally a surface passivation. 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 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 [3]. It should be more convenient to use a metal with a low enough work function (WF) in comparison with the semiconductor (SI-GaAs WF is about 4.5 eV [4]). 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 [5]. The novel quasi-ohmic contact uses metals with low WF such as e. g. In, Mg, or Gd with work functions of 4.12, 3.68, and 3.10 eV, respectively. A possible physical explanation of the current transport through the low WF metal contact on SI-GaAs was recently published [6]. The present work is devoted to the technology and study of metal-SI GaAs diode systems with different contacts: Gd, Mg, Ni, and AuGeNi eutectic alloy. Charge carrier transport through the interface is characterized by the current-voltage (*I-V*) measurements in the temperature range 300 – 380 K. The temperature dependence of the conductance in the linear part of the *I-V* characteristics is determined and analysed.

2. Technology and experimental details

The structures were prepared from the bulk undoped SI GaAs 2" wafer grown by the vertical gradient freeze (VGF) method (producer CMK Ltd., Žarnovica, Slovakia) with (100) crystallographic orientation and dislocation density about 3000 cm^{-2}. The wafer was polished by the producer from both sides down to (250±10) μm. The resistivity and the Hall mobility measured by the van der Pauw method at 300 K in our laboratory give values of $1.8\times10^5\ \Omega\mathrm{m}$ and 0.70 m^2/Vs, respectively.

The wafer was segmented into four samples. The square Schottky electrodes of Ti/Pt/Au (10/40/70 nm) with four different sizes (0.75, 0.50, 0.30. 0.20 mm) was formed using photolithography lift-off masking, vacuum evaporating, and lift-off processing of one side (top) of each sample. Close before evaporation the surface oxides were removed by rinsing in $\mathrm{HCl:H_2O} = 1:1$ at RT during 30 sec. The quasi-ohmic (back) side of three samples was fully covered by double layer of In/Au, Mg/Au or Gd/Au (50/70 nm). Full area AuGeNi/Au (50/70 nm) eutectic alloy covered by Au was deposited on the back side of the fourth sample. Metal systems were evaporated in a dry high-vacuum system. *I-V* characteristics of the fabricated structures were measured in the temperature range 300 – 380 K with the step of 20 K in the dark and electrically shielded probe station using Keithley 6517A electrometer/high resistance meter controlled by personal computer. The reverse branches correspond to the negative bias polarity applied to the top Ti/Pt/Au electrode. The probe station was thermally adjustable with stability of temperature ±0.5 K. The temperature was measured by the thermocouple Cu-constantan.

3. Results and discussion

I–V characteristics of the fabricated M/SI GaAs structures measured in the temperature range 300 – 380 K in the dark are shown in Fig. 1. Some quantitative differences are clearly observable in the measured characteristics. The linear part of the characteristics in the voltage region under 0.1V is about 10 - 300 times lower than that correspond to the calculated ohmic

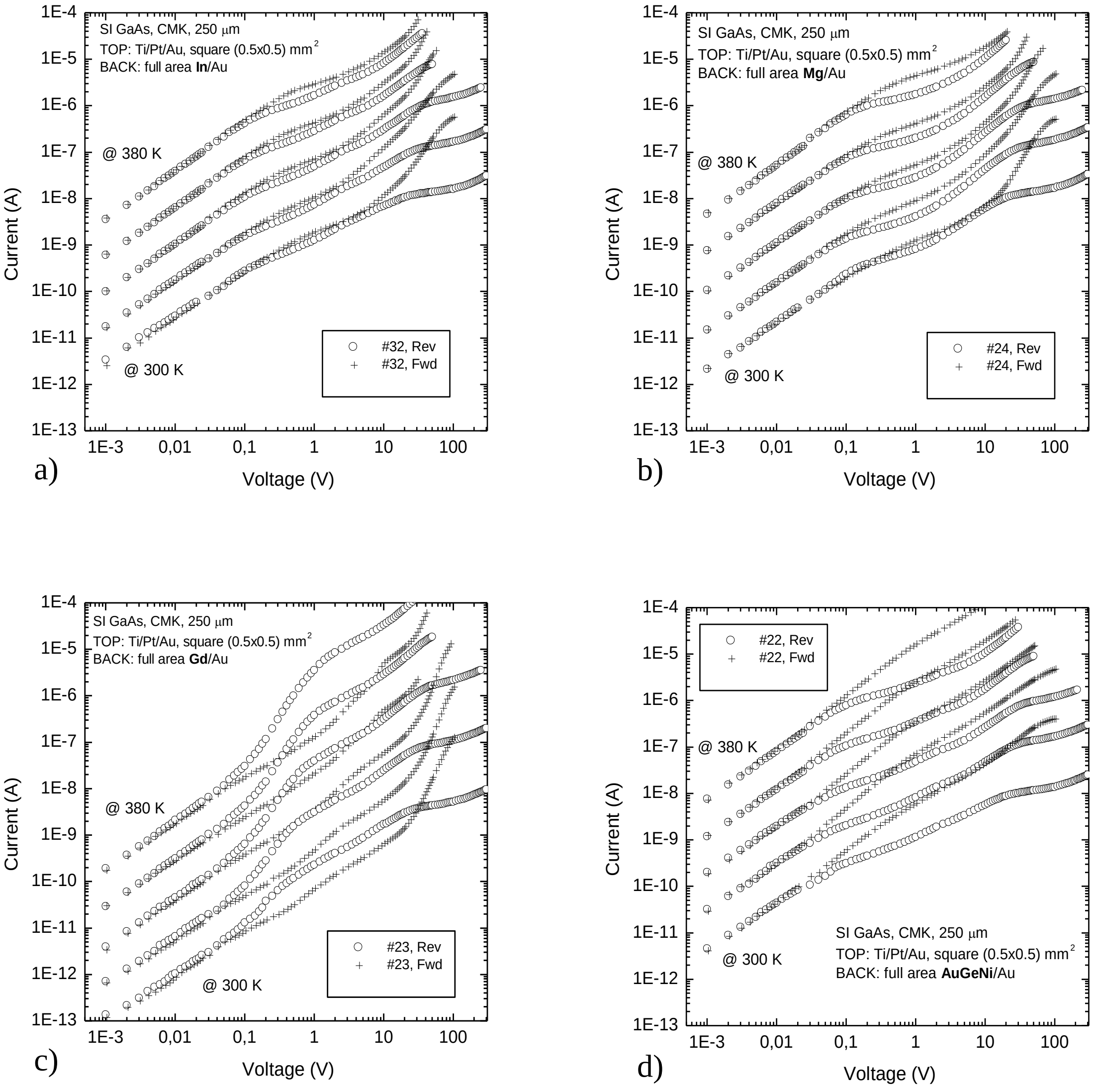

Fig. 1: Reverse and forward I–V characteristics of M/SI GaAs structures in log-log scale:topside Ti/Pt/Au small anode and full area backside cathode (a) In/Au,(b) Mg/Au, (c) Gd/Au, (d) AuGeNi/Au measured in the temperature range 300-380 K .

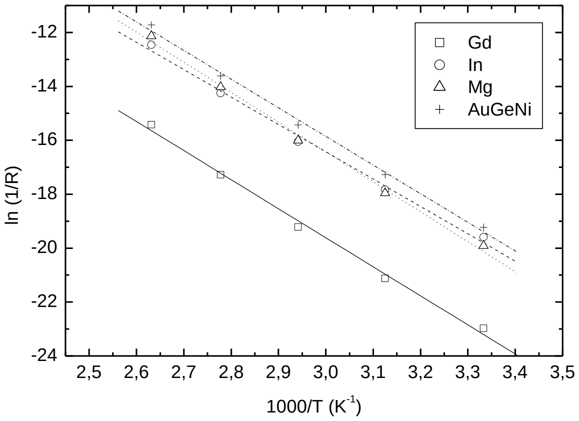

Fig. 2: Arrhenius plot for the samples with different backside metallization.

current for all contacts. The deviation is larger for the contacts made with the new metals, the largest is for the Gd contact. The ohmic bulk transport gives an apparent resistance value 2.6x10^7 Ω at 300 K. In the calculation was taken into account also the spreading field increasing apparent top contact area to 1 mm^2. First sublinear part of reverse characteristics between 0.1÷10 V corresponds to the saturation current of the thermionic field emission for samples with In, Mg, and AuGeNi contacts. Only the structure with Gd metallization exhibits a superlinear injection region. The second sublinear part at voltages over 10 V, which presents the obvious operation bias region of a radiation detector, corresponds to the transport controlled by the high electric field [7] for all metallizations. The value of saturation reverse current lays in a range of 9÷15 nA at a bias of 200 V. Following the initial linear part of the forward characteristics there is a superlinear injection region reaching the linear-ohmic current limit in the case of AuGeNi contact. The structures with In, Mg, and Gd contacts exhibit slightly sublinear dependences between 0.1÷10 V and over 20 V strong increase of the current. Arrhenius plot for the structures with different backside contacts is shown in Fig. 2. The straight lines are the linear fit of experimental points. The resistance R was determined from linear part of reverse *I-V* characteristics. The slope of dependences is between -10.15 and -11.09 for In and Mg contact, respectively.

4. Conclusion

Four SI–GaAs surface barrier diodes with different contact metallizations were prepared and characterized by the *I–V* measurements in the temperature range 300 – 380 K. The metals In, Gd, and Mg with low work function were used to form the new contacts. It has been observed, for Gd metalization, an anomalous decrease by about 1.5 order of magnitude of the current at a reverse voltage bias < 0.1 V in comparison with standard Ti/Pt/Au Schottky contact. Possible explanation is to formation of electron-reach region close at the metal/SI GaAs interface [8]. In order to better understand the above effect more detailed theoretical and experimental investigations will be carried out. The observed anomalous lowering of the reverse current can be utilized mainly for performance improvement of photodetectors requiring low dark current at low operating voltage.

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