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STUDIES OF OHMIC CONTACT AND SCHOTTKY BARRIERS ON Au-Ge/GaAs AND Au-Ti/GaAs

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Gallium Arsenide (GaAs) has increasingly become an important compound-semiconductor material suited for high speed digital circuits, microwaves and detectors for high energy physics. For the fabrication of ohmic contacts on GaAs (semi-insulating- SI) wafers with characteristics as: Cr doped, (100) oriented, and $\rho \sim 10^6$-10^7 Ωcm, has been used alloyed contact Au-Ge. The ohmic film was deposited in a high vacuum chamber (10^{-8} Torr), on a plasma etched surface of GaAs, followed by a rapid thermal annealing (RTA) at 450°C in low vacuum. For the fabrication of the rectifying contact- respectively the Schottky diode structure, we have used the same GaAs substrates. The wafers were degreased in a standard cleaning procedure, followed by a chemical etching. The Au-Ti contact has been deposited by thermal evaporation in vacuum (10^{-6} torr) followed by a RTA procedure at 300-320 °C. The carrier transport mechanisms through M/S interface are strongly influenced by the doping concentration in the semiconductor and temperature. There are presented the experimental I-V characteristics for selected samples in dark and illumination conditions. Schottky barriers height on Au-Ti/GaAs was 0.7325 V in accord with mean values on n and p type GaAs (0.5-0.8 V). The aim of this work is to fabricate a competitive X-ray detector.

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1. Introduction

The investigation of metal-semiconductor contacts is a very important task from both a practical and a theoretical point of view. Gallium arsenide semiconductor compound has intrinsec electrical properties superior to silicon including higher electron mobility, direct energy gap and lower power dissipation. These advantages of GaAs are atractive to develop high-speed, very large-scale integrated electronic devices, optoelectronic devices and discrete microwave devices. The poor properties of GaAs such as high defect density and poor mechanic properties are due to the fact that GaAs is composed of two elements and the control of the chemical stoichiometry of Ga and As is extremely difficult. The difficulty to control, also, the concentration of electrically active donors and acceptors is caused by the existence of two different vacancy sites of Ga and As sites.

The conventional ohmic contact formation involves deposition of a contact metal on GaAs and subsequent annealing at elevated temperatures (which enhances the chemical reaction between the metals and GaAs) to reduce the electrical voltage drop at the contact metal and GaAs interface [1]. The chemical reaction at interface involved the process parameters i.e metal selection, annealing temperature, time and atmosphere. These parameters are related to an ideal interfacial microstructure, which could not be determined on the basis of existing thermodynamic and diffusion data [2]. The deposition and annealing (DA) of ohmic contact preparation technique requires a relatively simple fabrication system and exhibits reproducibility once a fabrication process is established. In DA it technique exists a guideline of band diagrams to form low resistance ohmic contact, but there is no metallurgical guideline to fabricate interfacial microstructure with low energy barrier of the intermediate semiconductor layer (ISL) and/or high doping concentration ISL [1].

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Binary AuGe contacts were first used by Gunn in 1964 in his diode [3]. These contacts were attractive for microwave devices, which did not require very low contact resistance. For ohmic contacts the voltage drop across metal/semiconductor (M/S) interface is negligible to that compared voltage drop across the device. The nanometric ohmic film was formed under controlled conditions in a X-ray photoelectron spectroscopy (XPS) system that consists of a VGS ESCA MK II electron spectrometer combined with a custom ultra high vacuum UHV (10^{-9} Torr) sample preparation chamber. The Au-Ge film was deposited on a plasma etched surface of GaAs followed by a rapid thermal annealing procedure at 430-450 °C in low vacuum (1.5×10^{-1} atm.)

Energetic considerations indicate that the interfaces of transition metals (as Ti) on GaAs should be very reactive [4]. It is argued [4] that the formation of a stable interface compound should prevent interdiffusion and thus result in abrupt interfaces [4]. The XPS analysis performed on GaAs substrates as in literature [5] shows that the chemical etched GaAs is covered by a 10 Å thick surface layer of native oxide (a mixture of Ga_2O_3 and As_2O_3). Titanium is commonly used as a gate metal in the fabrication of GaAs field-effect transistors which means a technological importance of the interface Ti/oxidized GaAs. The Au-Ti film was deposited by thermal evaporation both in high vacuum conditions and low vacuum chamber, followed by a RTA procedure. The chemical reaction between Ti and the substrate is already apparent in the Ga 3d XPS spectrum [4] for coverage as low as 0.07 Å. The Ti is localized at the chemisorption site and the remainder of the surface is unperturbed [4]. At higher coverages is present a well defined Ga environment which suggests either small metallic Ga clusters or more likely a Ga-Ti alloy. Also, for Ti coverage over ~1 Å are present strong interactions Ti-As. Near the surface there exists a Ga and As disrupted layer in addition to Ti which lies on the top of GaAs [4]. Titanium can form intermetallic compounds with Ga and As.

2. Experimental procedure

The semiconductor samples used in this experiment were GaAs (100) oriented wafers uniformly doped with Cr with a resistivity $\rho \sim 10^6$-10^7 Ωcm (semi-insulating type). Also, for a comparison it has been used in the same contact deposition technology n-GaAs (111) samples. Prior to metal deposition, GaAs was degreased employing a standard cleaning process using trichloroethylene and acetone. The wafer of GaAs (100) was chemical etched in HCl (sol.6N) for 2 min, in a solution mixture H_2SO_4:H_2O_2:H_2O volume ratios: (3:1:1) for 2 min. and at last in HCl (sol. 6N) for 15 seconds.

The Schottky barrier interfaces Au-Ti were initially formed by vacuum deposition in low vacuum. The conditions were $p = 4\times10^{-5}$ Torr, evaporation from a boat made of wolfram, in the evaporation geometry R_{Au}=5 cm, R_{Ti}=5 cm. The initial thickness of Au-Ti film was: 200 nm(Au)-100 nm(Ti)). The metal contact Au-Ti was annealed for 1 min at T=360 °C, in low vacuum $p\sim1.5\times10^{-1}$ atm., conditions that defined a RTA procedure. Taking into account the results regarding the I-V characteristics it was imposed a Schottky barrier interface formed under controlled conditions in a X-ray photoelectron spectroscopy conditions (XPS) system which consists of a VGS ESCA MK II electron spectrometer combined with a UHV preparation chamber. The deposition implies plasma etching in argon ion beams accelerated at 6 KV for 10 min, intensity of beam current I = 170 μA, followed by a Ti deposition from a metal source in high vacuum conditions (10^{-7}-10^{-8} Torr). The Au film with 200 nm thickness was vacuum deposited, and the Au-Ti/GaAs (M/S) interface was formed by annealing in a RTA procedure.

Low resistance ohmic contact Au-Ge/GaAs (SI) was formed under controlled conditions in a XPS system from an eutectic alloy (Au-13 % wt Ge) band. After the deposition it follows a thermal treatment for 1 min at 430-450 °C in low vacuum (1.5×10^{-1} atm). For different samples (as Schottky diode no.2-DS2) it was performed a deposition through a tombac mask with preestablished contact areas. In no case were the substrates heated during metal-film deposition.

The electrical measurements (I-V characteristics) were performed on standard instrumentations in dark and illumination conditions (Hg lamp with power of 200 W and the emission maximum at λ = 313 nm).

3. Results and discussions

Fig. 1 presents I-V characteristics of Au-Ge ohmic contact on GaAs:Cr (100). The Au-Ge/GaAs (SI) was formed under controlled conditions in XPS system and then annealed in temperature range (430-450)°C. The linear fit of experimental data shows a resistance between contacts (including bulk resistance) of the order 10.8 MΩ with a standard deviation less than 5%. This characteristic indicates a good Au-Ge ohmic contact. As a general feature, the eutectic Au-Ge exhibits a thermal instability for electrical properties during subsequent annealing after contact formation [6], and a large spreading of the contact resistance on a given wafer. Different authors [6-12] observed a deep vertical diffusion depth to GaAs which limited the applicability of these contacts to advanced GaAs devices of small size. The surface morphology was slightly improved by decreasing annealing temperature to 360 °C in a RTA procedure. However, it is remarkable that Au-Ge contacts had a rough surface and, besides vertical diffusion, a lateral Au diffusion on GaAs surface was observed [12-14].

Fig. 2 presents the I-V characteristics of the structure Au-Ti/ GaAs (111)- Schottky diode no.0-DS0 on the front side of the wafer and Au-Ge/GaAs on the back side. Au-Ge is a ohmic contact and Au-Ti/ GaAs structure has a reduced breakdown voltage, and the characteristics is typical for a Zenner diode.

Fig. 3 presents the I-V characteristics for a Au-Ti Schottky diode on GaAs: Cr (100)-Schottky diode no 1-DS1- with small reverse current and breakdown voltage of approximately 50 V. As can be observed from Fig. 4 the Schottky diode DS1 is an active structure in electromagnetic field as it has been tested under UV illumination.

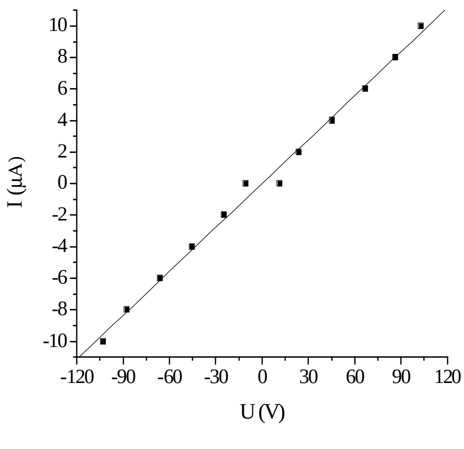

Fig. 1. I-V characteristic for AuGe ohmic contact.

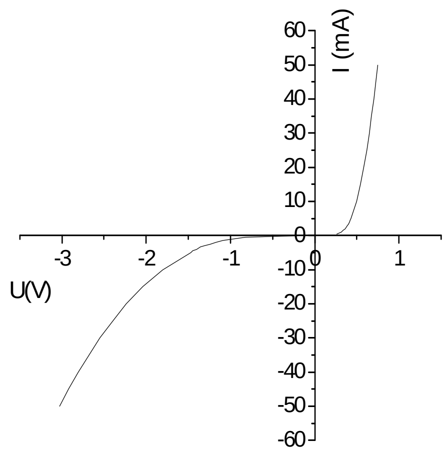

Fig. 2. I-V characteristic for AuTi/ /GaAs(SI) (111)-DS0.

The breakdown voltage is approximately U_B= -100V with a relatively low reverse current. This characteristic recommended the proposed structure of Au-Ti/GaAs(SI)(LEC) as a possible candidate for a nuclear solid-state detector [15].

These data were analyzed in the framework of the thermo-ionic diffusion model to give the Schottky barrier height Φ_B (in V) for DS1

$$j=j_{ST}(\exp^{qV/kT}-1) \tag{1}$$

where : j_{ST}-saturation current density

$j_{ST}=A^*T^2(\Phi_B/kT)$ where A^* is Richardson constant and Φ_B is barrier voltage.

For GaAs (100) in intense electric field of a constant A^*=144 $Acm^{-2}K^{-2}$ [3]-the resulting barrier height after annealing is Φ_B=0.7325 V in agreement with the mean Schottky barrier height of 0.5-0.8 V for p and n-type GaAs [1].

Fig. 5 and Fig. 6 are characteristic for I-V measurements on GaAs (SI) with high Schottky surface contacts (~ 24 mm^2) and low surface Schottky contacts (~3 mm^2). The characteristics were tested in dark in UV radiation conditions and as a general remark the structure Au-Ti/GaAs/Au-Ge is sensitive to electromagnetic field, a necessary step to a X-ray detector.

For the as prepared sample of Au/Ti/GaAs the Rutherford backscattering (RBS) spectrum [16] presents a defined interface responsible for a weak signal from Au. The titanium signal interfered with GaAs as a result of a weak diffusion process.

As it was remarked [4] at the GaAs (SI) surface existed a thin layer of oxide (10 Å composed of As_2O_3 and Ga_2O_3). From XPS measurements [17] the as prepared sample interface is Ti/oxidized GaAs, a interface where the titanium signal arise in a 66% concentration from TiO_2. The Ti deposit is fairly uniformly spread and it interacts strongly with the substrate. At the surface the reaction products with Ga and As are located at Ti/GaAs interface or they are well dispersed in GaAs [5]. Finally, in the annealing process Ti reacts with As to form TiAs compound.

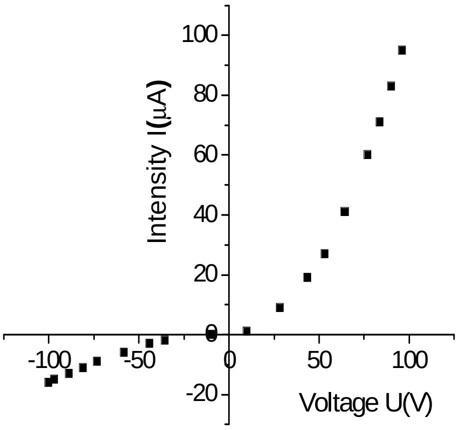

Fig. 3I-V. characteristics AuTi/ /GaAs:Cr (100) (DS1).

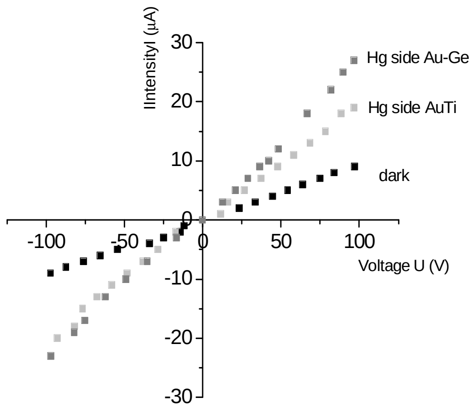

Fig. 4I-V. characteristic AuTi//GaAs(SI) in dark and under illumination (DS1).

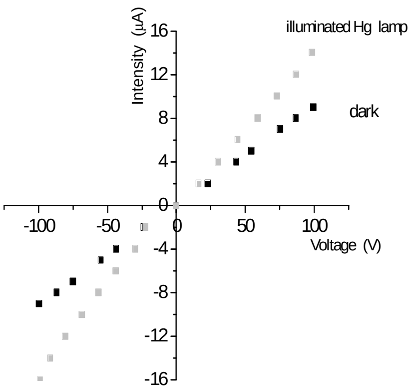

Fig. 5I-V. characteristics for contact area 24 mm^2 in dark and under illumination.

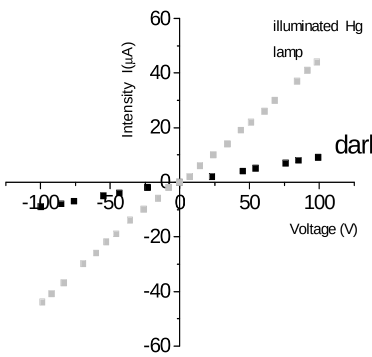

Fig. 6I-V. characteristics for contact area 3 mm^2 in dark and under illumination.

4. Conclusions

The ohmic contact AuGe/GaAs has been developed on a trial–and-error basis. The metallic film was deposited in high vacuum chamber (10^{-8} Torr) on a plasma etched surface of GaAs followed by a RTA procedure in low vacuum in the temperature range 430-450 °C.

The rectifying contact Au-Ti/GaAs(SI) was deposited by thermal evaporation both in high vacuum chamber (10^{-8} Torr) and in relatively low vacuum conditions (4×10^{-5} Torr), followed by a RTA procedure in low vacuum (10^{-1} atm) in the temperature range (300-320)°C. Titanium lies on the top of GaAs and the chemical interaction between Ti and substrate suggests that Ti forms intermetallic compounds with Ga and As.

From the thermo-ionic diffusion model the Schottky barrier heights for GaAs: Cr (100) in intense electric field and after annealing are Φ_B~0.733 V, a result in agreement with the Schottky barrier characteristic on GaAs.

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