OHMIC CONTACTS TO N-TYPE
AND P-TYPE GALLIUM ANTIMONIDE WHISKERS

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Abstract. The ohmic contacts to the n-type conductivity gallium antimonide whiskers were created due to a current pulse shaper. It was established that I–V characteristics of GaSb whiskers at low temperatures are linear, regardless of the direction of current transmission. That allows using the investigated techniques to create electrical contacts and study their electrophysical characteristics. GaSb samples with a diameter of 12 μm and 20 μm were studied at temperatures 4.2 K and 77 K. A slide table with bath and microfurnace was made for welding ohmic contacts to GaSb whiskers. Gold microwire with a diameter of 30 μm was used as a contact material. The melting was carried out under the flux layer. It was revealed that the fusion is one of the most suitable methods for creating contacts to the whiskers grown by gas transport reactions.

Key words: n-type and p-type conductivity gallium antimonide whiskers; ohmic contacts; I–V characteristics.

1. Introduction

The task of creating a metal-semiconductor contact is of particular importance to the technology of manufacturing strain gages. Electrodes are areas of semiconductor whiskers, which have corresponding properties, such as magnitude and the type of conductivity, distribution of the dopping impurities, etc. Electrical contacts are needed to supply the required electrical potentials to the electrodes. Ideal contacts should be characterized by the following parameters: the value of the voltage on contacts must be minimal during current flowing through them; the contact must be linear, so the change in the magnitude and sign of the current through the contact should not caused a change in its resistance. The execution of these properties presupposes that contacts in semiconductor devices should be ohmic with the minimum possible values of transient resistance. In addition, the contact must be mechanically strong, reliable and stable over time. The contact resistance must also be independent of deformation.

As a rule, in practice, created contacts meet the above requirements only to a certain extent. It is only important that the deviation of their properties from the ideal does not significantly affect the operation of the devices. In low-power devices, the contacts can only be linear up to a certain current value.

However, there are a number of technological difficulties that encourage the search for new approaches to the creation of semiconductor structures [1, 2]. The authors of [3, 4] performed metallization on GaSb samples due to such structures as Pd/Ge/Pd/In/Pd/Pt/ Au. Materials characterization using cross-sectional transmission electron microscopy confirms that gallium indium antimonide alloy ($Ga_xIn_{1-x}Sb$) forms at the metal-semiconductor interface, and its formation is believed to be responsible for ohmic behavior. In [5, 6] we can observe recommendations for the use of other materials that can serve as contact materials for compounds A3B5, including GaSb. In study [7], the authors state that the reaction between Au or Au-based metallization and GaSb takes place even at temperatures as low as 180 °C. Ga and Sb appear at the surface of the contact at temperatures above 250 °C.

Often, in order for making the electrical contact with the electrode ohmic with a low transient resistance, the properties of the semiconductor layer adjacent to the metal need to be changed in some way. The desired contact properties are best achieved in two cases. The first one takes place when the layer of semiconductor adjacent to the metal contains an extremely large number of recombination centers. The second one occurs when such a layer has a high electrical conductivity of the same type as the electrical conductivity of the section of the semiconductor with which the contact is established [8–10]. To provide the desired properties to the contact region of the semiconductor, the same methods can be used as those for obtaining transitions: melt growth, fusion, diffusion and epitaxial growth. Sometimes structural imperfections are created in the contact layer by means of machining in order to increase the number of recombination centers.

In principle, to create a direct metal-semiconductor contact the following methods can be used:

– fusion – in this case, usually using a combine contact and providing certain properties to the contact area of the semiconductor;

– electrolytic or chemical deposition of metal from solution;

– spraying metal in vacuum;

– covering the surface of the semiconductor with varnish or glue, which is a suspension of metal particles in organic or organosilicon bases;

– electric welding;

– thermocompression welding;

– providing a simple mechanical contact under pressure (clamping contact).

In addition to the necessary electrical properties, contacts must withstand sharp changes in temperature and provide the ability to connect a terminal to a device. Since the power emitted by the device is mainly dissipated through the contacts, the thermal resistance of the contacts should be very insignificant. Although all of the listed methods are possible to use, in most cases, to create a metal-semiconductor contact the process of fusion is used due to its compliance with all the above requirements.

Other methods are also commonly used in combination with [11]. However, the method of creating contacts with electrochemical or chemical deposition is not always reliable. When contacts are made by this method, the surface is usually contaminated. A significant disadvantage of welding method is the low mechanical strength of the contact. The thermocompression method can be used to obtain semiconductor contacts directly with a conductive wire connecting it to the pre-sprayed surface on the semiconductor layer of metal. However, substantive disadvantage of such contacts, except for low mechanical strength, is a limited current value [12].

Some general recommendations for using a number of metals that can serve as contact materials for A3B5, including GaSb, are given in works [2, 5, 6, 7]. The creation of ohmic contacts Pd/In/Pd/Pt/Au to n-type conductivity GaSb was investigated in [3, 4]. A Pd/Ge/Pd/In/Pd metallization on GaSb was doped with Te up to concentration 5.6×10^{17} cm^{-3} at fusion temperature 350 °C applied for an hour. The specific contact resistivity as low as 1.4×10^{-6} Ohm´cm^2 and contact resistance of 0.068 Ohm´mm were exhibited. Pd/Ge/Pd metallization on GaSb:Te doped to 1.8×10^{18} cm^{-3} exhibited specific contact resistivities of 3.8×10^{-6} Ohm´cm^2 and contact resistances of 0.058 Ohm´mm at fusion temperature 350 °C applied for an hour. As the authors state, these results [3, 4] represent the lowest reported contact resistance for ohmic contacts to n-type GaSb. The ohmic contacts were created by the fusion of silver Ag+1 % Ga. The eutectic Ag-Cu and alloy Au+45 % Ag+1 % Ga were studied. The authors of [13] note that the fusion of Au+45 % Ag+1 % Ga in the atmosphere of purified hydrogen at a temperature of 530 °C in GaSb with both

hole and electronic conductivity which creates opportunities to get ohmic contacts. The authors also note that for GaSb crystals of both types of conductivity cracking was not detected after ten-fold cycling in the temperature range from –196 °C to +100°C due to the use of such alloys in the fusion area.

The interfacial reactions between GaSb and Au were investigated by Rutherford scattering, X-ray diffraction, and cross-sectional electron microscopy in [7]. The degree of decomposition of the GaSb substrate was evaluated first. The results of these metallurgical studies indicate that the reaction between metallization based on Au or Au and GaSb occurs even at temperatures up to 180 °C. However, Ga and Sb appear on the contact surface at temperatures above 250 °C. Therefore, the authors [7] note that Au metallization is not a good choice for ohmic contacts of GaSb-based devices at temperatures above 250 °C.

It is advisable to use tin as an electrode material, because it completely covers the cleaned surface of GaSb. In addition, tin does not corrode because it is soft. This provides a slightly strained contact. Tin also has a relatively low melting point of 232 °C, which allows obtaining contacts by both methods of melting and soldering. Contacts to p-type GaSb samples were created with the use of the undoped tin. Contacts to the n-type samples were made by using tin doped with tellurium. Doped tin was prepared by fusing 99at.%Sn and 1at.%Te in the evacuated quartz ampoule. Satisfactory results were achieved by fusing under a layer of flux, which served as rosin.

2. Experimental procedure

Omic contacts to the n-type GaSb whiskers were created by means of a current pulse shaper according to the schematic diagram shown in Fig. 1.
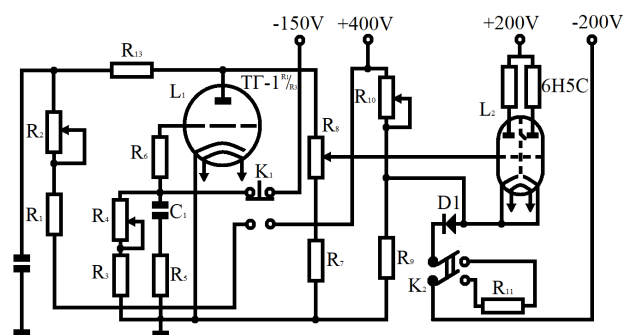

Fig. 1. Schematic diagram of the current pulse shaper.

The operation principle of the current pulse shaper is as follows. The initial position of the switch P1 (K1) is in position 1. The capacitor C1 is charged to the voltage of the DC power supply (150 V). A large negative voltage is applied to the thyratron grid. The circuit of the

thyratron anode is disconnected from the DC voltage source (+400 V) and the voltage at the thyratron anode is zero. Thyratron is closed in the initial state. The positive voltage (170÷210 V) is applied to the cathodes of the output lamps, connected in parallel, from the voltage divider, which consists of R9, R10 and R11. The voltage on their grids is zero. The current through the sample marked on the diagram as RN (load resistance) is absent.

The capacitor C1 is disconnected from a source of 150 V and begins to discharge through the resistors R3, R4 and R1 when switching the switch P1 (K1) to position 2. The negative voltage on the grid of tiratron begins to decrease by law to change the voltage of the capacitor C1. The discharge rate of the capacitor C1 depends on the value of the resistances of the resistors that are included in the discharge circuit. Negative voltage drop rate can be controlled by changing the discharge resistance on the thyratron grid. The capacitor C2 starts charging. The voltage will increase at the anode of the thyratron as the capacitor C2 is charged. This voltage is supplied to the grid of output lamps from the voltage divider R7, R8. The output lamps open and a welding current will flow through them. At some ratio of the increasing voltage to the decreasing voltage on the anode that is determined by the parameters of the thyratron, it is ignited and shorted by the voltage divider R7, R8. The voltage on the thyratron grid decreases so much that the thyratron continues to burn. To return the circuit to its initial state, it is necessary to switch P1 (K1) to position 1. The amplitude of the welding current pulses can be set by changing the resistances of resistors R8, R11. However, it is more convenient to do this by changing the anode voltage of the output lamps. The pulse duration is mainly controlled by changing the resistance of the discharge section of the capacitor C1 (using potentiometer R4).

A slide table was made for welding ohmic contacts to GaSb whiskers. The bath with microfurnace was fixed on the table. The scheme is presented in Fig. 2. The welded microwire 7 with a diameter of 30 μm is fixed in a clamp connected with the micrometer screws 10. Micrometric screws allow us to move the clamp with the microwire 7 smoothly in three directions. That provides the supply of the tip of the wire 8 to a given point on the surface of the monocrystals 6. The proposed method is a kind of the fusion that is carried out under flux being one of the most suitable techniques for creating contacts to the whiskers grown by the method of gas transport reactions. A gold microwire with a diameter of 30 μm was used as the contact material.

It is known that strong local overheating of the semiconductor material causes the formation of impurity defects in the place of overheating. These defects have acceptor properties reducing the quality of the ohmic contact. To prevent this phenomenon, the crystal is preheated to a temperature of 300 °C in such a way that a small current pulse passed through the sample is sufficient to obtain an eutectic Au-GaSb. A micro-furnace 4 built into the ceramic bath 1 was used for this purpose. The furnace is filled with a mixture of silicate glue and talc 3. After drying this paste, the small bath with an equal bottom is formed. To prevent some roughnesses, the ceramized plate 5 can be glued to the bottom of the bath with the same putty. A gallium antimonide whisker 6 is placed on this plate and pressed with a platinum clamp 8, as shown in Fig. 2. Bronze foil 9 served as an elastic element of the clip 11. Then rosin 12 is poured into the bath. Rosin is melted by heating the crystal to a temperature of 300 °C.
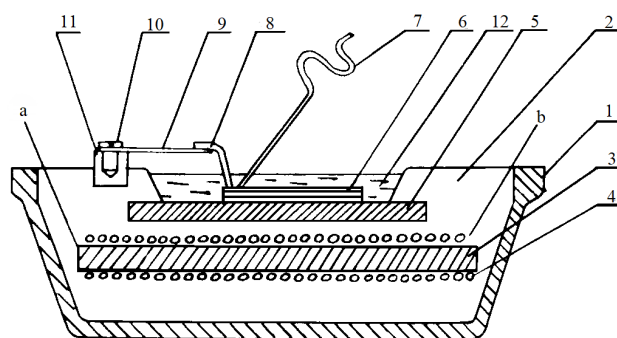

Fig. 2. Scheme of welding contacts to GaSb whiskers: bath (1), solution (2), mixture (3) micro-furnace (4), ceramized plate (5), monocrystals (6), microwire (7), platinum clamp (8), bronze foil (9), micrometer screws (10), clip (11), rosin (12).

The tip of the contact microwire 7 is moved to the end of the crystal in an area close to the platinum clamp 8. The circuit of the current pulse is closed according to the scheme: shaper – gold microwire – small section of the whisker – platinum clamp – shaper.

As noted, the current pulse passes through this small section of the whisker. As a result, the main part of the whisker is not overheated that could influence its electrophysical properties. It should be pointed out that this part of the whisker is the base of the element sensitive to comprehensive compression. Current welding modes are selected by testing. These welding modes depend mainly on the thickness of the investigated whisker. The operation is repeated after welding one of the electrodes.

3. Experimental results and discussion

To conduct experiments for determining the electrophysical parameters, it is first necessary to make sure that the contacts are ohmic. The I–V characteristics of the contacts were measured. At least three contacts (two contacts on the edges of whisker and the investigated one – in the middle of it) were created to study the I–V characteristics of the contact. The results of the studied I–V characteristics are shown in Fig. 3.
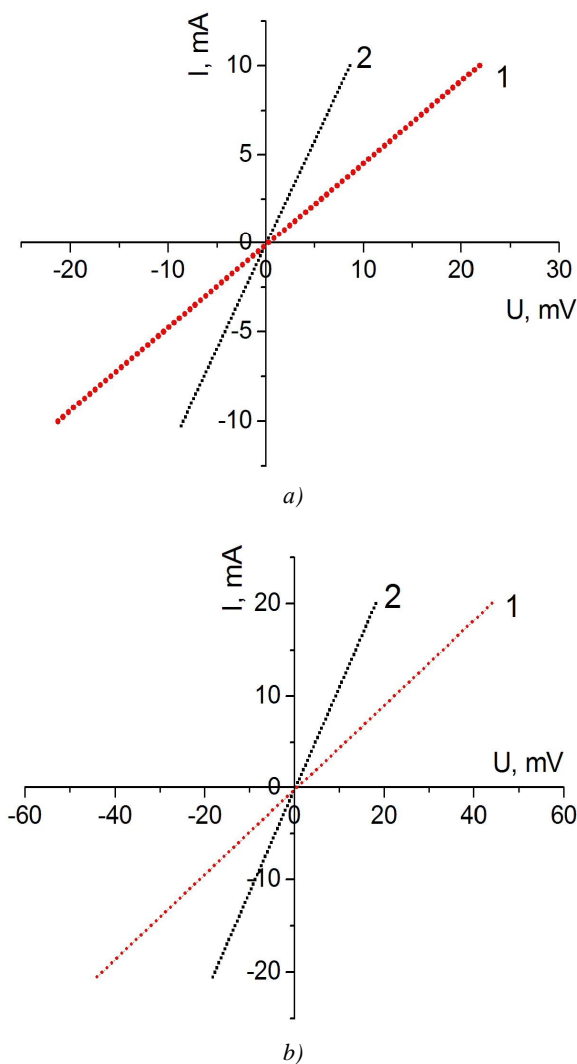
a)

b)

Fig. 3. I–V characteristics of GaSb whiskers
with a diameter of 12 μm (a) and 20 μm (b)
at temperatures 4.2 K (1) and 77 K (2).

mechanical strength of their contacts was measured using a special installation. A force was applied at an angle of 45° to normal in the plane of welding. A rupture of the gold microwire was revealed in all cases. Consequently, the strength of contacts exceeds the strength of the microwire. The proposed method allows creating ohmic contacts to GaSb whiskers grown by the method of gas transport reactions [14, 15]. The minimum sizes of the studied whiskers were determined due to their microwire thickness. In our case, the minimum whisker thickness was 20 μm. There are no restrictions on welding ohmic contacts to thick monocrystals.

a)

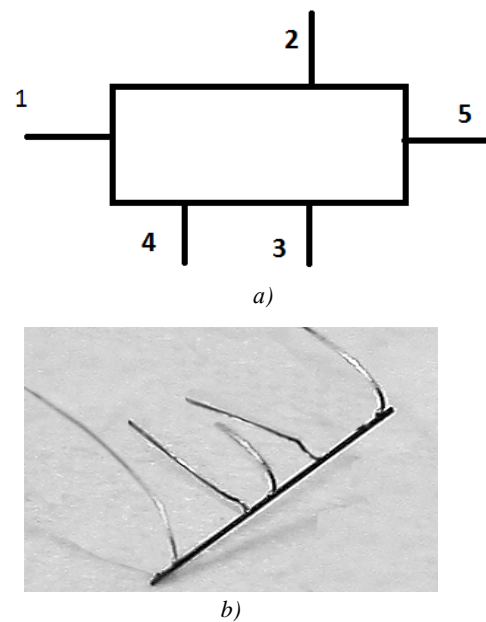*b)*

Fig. 4. Schematic arrangement of contacts
on the sample for Hall measurements (a);
photo of a GaSb whisker with contacts (b)

As it can be seen from Fig. 3, obtained I–V characteristics at low temperatures are linear, regardless of the direction of current transmission that allows using this method to create electrical contacts and study the electrophysical characteristics of GaSb whiskers. The samples of GaSb with diferent resistances with diameters 12 μm $R_{4.2K}$ = 2.32 Ohm, R_{77K} = 0.87 Ohm; and 20 μm $R_{4.2K}$ = 2.31 Ohm, R_{77K} = 0.92 Ohm were studied.

The Hall potential difference and electrical conductivity of the samples were measured to determine the physical properties of the charge carriers that allowed to estimate their concentration and mobility m_H. In addition to the Hall EMF, other galvanic and thermomagnetic effects can contribute to the total voltage during measurements. Therefore, it is necessary to use a five-contact circuit, shown in Fig. 4. The contacts to GaSb whiskers created in this way meet all the requirements for ohmic contacts. To study the mechanical properties of the whiskers, the

4. Conclusions

The use of rosin as a flux is caused by the following conditions. Preheating the crystal to the melting point of rosin reduces the amplitude of the welding pulse and, consequently, the concentration of defects associated with the peculiarities of the contact creating method. Defects in the welding place have an acceptor nature. The p–n junction in the welding place is obtained due to welding of ohmic contacts to n-type conductivity whiskers. Therefore, it is necessary to take measures to reduce the concentration of welding defects. Rosin isolates the crystal from the atmosphere and prevents the adsorption of oxygen during welding. Welding under rosin improves the mechanical properties of the contacts.

Contact resistance was determined being 0.5 Ohm due to studies of samples with resistance 0.8–1 kOhm. Improving the quality of contacts can be achieved by

making the alloy of 50 %Au + 50 %Ag + 1 %Te for the microwire material, or due to doping the gold microwires by their immersing in tin with the addition of 1 % tellurium.

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ОМІЧНІ КОНТАКТИ ДО НИТКОПОДІБНИХ КРИСТАЛІВ АНТИМОНІДУ ГАЛІЮ N-ТИПУ ТА P-ТИПУ ПРОВІДНОСТІ

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За допомогою формувача струмових імпульсів створено омічні контакти до ниткоподібних кристалів антимоніду галію *n*-типу провідності. Їх ВАХ за низьких температур є лінійними незалежно від напряму пропускання струму, що дає змогу використовувати описаний метод для створення електричних контактів і дослідження електрофізичних характеристик ниткоподібних кристалів GaSb. Дослідження проведено для зразків діаметром 12 мкм та 20 мкм за температур 4,2 К та 77 К. Для приварювання омічних контактів до кристалів GaSb виготовлено предметний столик, на якому закріплено ванночку з мікропіччю. Як контактний матеріал використано золотий мікродріт діаметром 30 мкм, а вплавлення здійснено під шаром флюсу. Цей спосіб є різновидом вплавлення і одним із найпридатніших методів для створення контактів до ниткоподібних кристалів, вирощених методом газотранспортних реакцій.

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