STRUCTURE AND PHYSICAL CHARACTERISTICS OF OHMIC CONTACTS BASED ON Fe AND Ge FILMS

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In the the article the application of the method layered condensation followed by annealing from 300 to 900 K for formation of ohmic contacts based on the Fe and Ge films was proposed. The investigations of microstructure and phase composition of the contact systems Fe/Ge, which received symmetric linear current-voltage characteristics and the following operating parameters: resistance on the square area 0.3 Ω/m^2, thermal coefficient of resistance $6 \cdot 10^{-4}$ K^{-1} and symmetric linear current-voltage characteristics.

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INTRODUCTION

In using nonrectifying ohmic contacts, the quality of which depend heavily on the parameters and characteristics of microelectronic devices, their reliability and lifetime, there is electrical connection of the semiconductor with metal elements and conductors. As is known [1], contact metal/semiconductor (Me/Sem) can be either a rectifying (barrier) if potential barrier between the metal and semiconductor tunnel-opaque, or ohmic if the potential barrier is absent or is tunnel-transparent to electrons. Recently, has been considered a mechanism, when the presence of a potential barrier metal-semiconductor space charge layer shorted metal shunts, which are formed, for example, by deposition of metal atoms on dislocations and other defects in the semiconductor.

The main parameter ohmic contact, which consists of sequentially connected resistances: in the contact area of semiconductor and related to the passage of potential barrier electrons, is resistance to the square area. The authors [1] have shown, that the alloy ohmic contacts metal-semiconductor, when the heat annealing is dissolving semiconductor in the metal and recrystallization, may show the mechanism of current flow in the metal shunt, which represent a metal atoms, that are deposited on the line defects, for example, dislocation, and shunts the space charge layer. In this case, the edges of these lines is concentrated electric field and the current flowing by field emission. The presence of metal shunts in semiconductor devices observed in the study resistance epitaxial Ti/N films [2] and research mechanism of reverse current flow in diode structures in diode structures Ni/GaN [3]. The authors [4] the study by transmission electron microscopy of processes at interfaces ohmic contacts Ti/Al/Mo/Au to heterogenous structures Al/GaN, it was found, the amount of islands TiN – shunt diffusion channels was proportional of the concentrastion of dislocations.

The method of formation a contact based on Ge and Cu films in work [5] is as follows. On the surface of the plate n-GaAs (100) is formed by the mask. Then, by electron-beam evaporation is performed under vacuum layer deposition of Ge and Cu films of total thickness 0.2 mm and a film thickness of Ge, defining the weight content of Ge metallization equal to 40%. Thereafter, the plate is subjected to a first heat treatment of GaAs in a single vacuum cycle at T_1 = 100 °C for t = 60 min. The plate is removed from the vacuum chamber, and after removal of the mask is exposed to a second heat treatment at a temperature of T_2 = 400 °C for t = 30 min in vacuum. Implementation of the first annealing in a single vacuum cycle allows formation of a contact start conditions in which the surface of the deposited films is not more oxidized. The disadvantages of this method may include insufficiently low value of reduced contact resistance.

The surface morphology of the contacts and reflect the heterogeneity of physical and chemical processes that occur in the volume of contacts and the interface film/substrate. With increasing temperature in the contact system based on Au and Ge films on GaAs substrate at a temperature above 300 °C, the processes of formation of intermetallic compounds such as AuGa and AuGe, as described in detail in [6, 7]. Authors [8] showed that the nature of the processes of phase formation in contacts Au/Ge/Ni/GaAs during thermal cycling obtaining ohmic contacts determines their electrical parameters. After heating and holding at the maximum temperature and the physical and chemical processes proceed at the cooling.

In work [9] was investigated the ohmic properties of film systems Au/(Pd,Pt)/Zn/Pd/p-InP, focusing on the role of the Pd or Pt in Au-free metallization. Both the lowest contact resistivity of $7 \cdot 10^{-2}\, \Omega \cdot \mathrm{m}^{-2}$ and a flat diffusion front were obtained for a sample with a Au/Pt/Zn/Pd/p-InP contact material after annealing, indicating that the Pt layer was more effective than the Pd layer in preventing Zn external diffusion during the annealing process.

The purpose of this work was to research the microstructure, phase composition, thermoresistive properties and current-voltage characteristics of ohmic contacts based on films of Fe and Ge, the layer formed by condensation followed by annealing from 300 to 900 K.

EXPERIMENTAL TECHNIQUES

To obtain on double-layer film samples Fe/Ge/S (S – substrate) the vacuum chamber type VUP-5M was used. Layer to layer condensation and annealing of films carried thermoresistive method at the temperature of glass-ceramic substrate $T_s \cong 300$ K and annealing on the interval 300…900 K during three cycles of thermal stabilization «heating↔cooling».

Measurement of electrical resistance was carried out in automatic mode using the software and hardware complex (Fig. 1). Control the process of annealing out software style MDI interface, developed using the graphical programming LabVIEW was done. On the tab of the main application window are controls (see Fig. 1,b), that define the parameters of annealing, blocks read information, of work hardware and software elements and output information. Measurement of electrical resistance was carried out by four-circuit. On the program the buttons: «START» – the beginning of the program, «STOP» – end of exit from the program, «SAVE» – store data on annealing to the hard disk as a text table «AUTO» – enable or disable the automatic annealing, and switch «heating/cooling», which allows you to change the direction of the move process at any point in the program. To measure the resistance of each sample was designed separate measuring circuit based on constant high accuracy resistors. Output data elements include windows plotting (see Fig. 1,c) to visualize the temperature dependence of resistance $R_i(T)$ and temperature change with time T(t), and the data read off the table, the current temperature, rate of change, the current resistance patterns. Upgrade graphs and tables occurs after each new reading, current indicators are updated with the maximum possible frequency that depends on the hardware capabilities of the system.

Thermal coefficient of resistance (TCR) was calculated on the basis of the third annealing cycle by the ratio:

$$\beta = \frac{1}{R_0} \cdot \frac{\Delta R}{\Delta T},$$

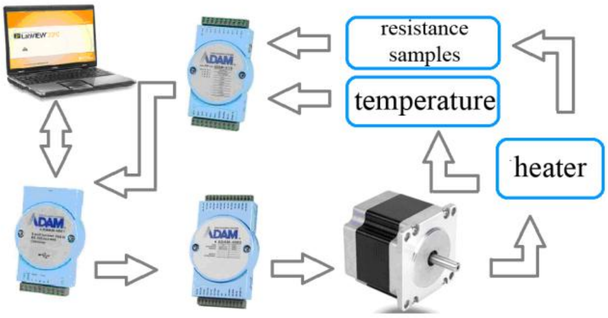
where R_0 – initial resistance of the sample; ΔT – temperature interval.

Crystal structure and phase composition of the films by electron microscopy and electron diffraction methods (microscope TEM-125K) was investigated. Structural and electrical schemes for current-voltage characteristics of the contact, diffraction pattern and temperature dependence of TCR for double-layer films Fe/Ge/S shown on the Fig. 2.

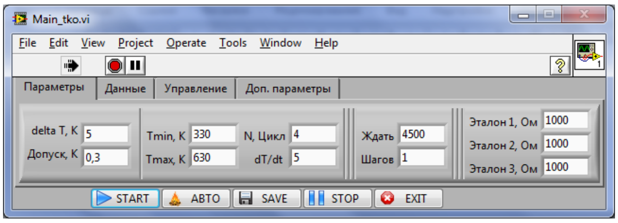
THE EXPERIMENTAL RESULTS

The study of the structure and phase composition of double-layer films based on Fe and Ge with a total concentration of atoms of individual components – 70 at.% (for example, Fe(30)/Ge(25)/S) indicates that the ohmic contact in the form of films in the annealed condition (see Fig. 2,c) have a crystalline structure (bcc-Fe + fcc-FeGe + traces GeO_2).

The main requirements for ohmic contacts these [1]: under forward bias they must ensure injection of majority carriers in the semiconductor; the reverse bias - hinder injection of minority carriers in semiconductor; have a minimum electrical resistance and linear current-voltage characteristic. These conditions are satisfied given the right pair of Me/Sem. For pair Me/n-Sem the electron work function of the metal (A_{Me}) less than the work function of electrons from the semiconductor (A_{Sem}). In a pair of the energy of electrons in metals are more, than the semiconductor, and in establishing thermodynamic equilibrium of the electrons from the metal flows into the semiconductor.

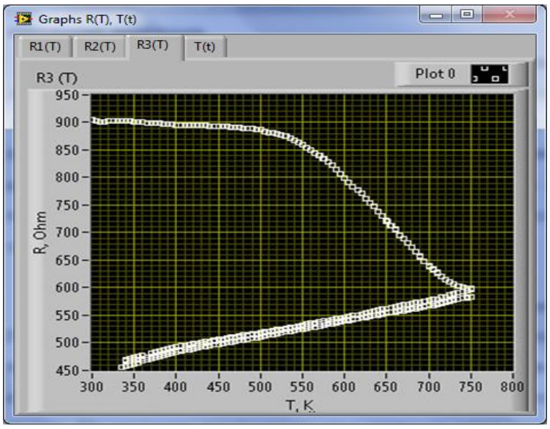


a



delta T, K 5
Допуск, K 0,3
Tmin, K 330
Tmax, K 630
N, Цикл 4
dT/dt 5
Ждать 4500
Шагов 1
Эталон 1, Ом 1000
Эталон 2, Ом 1000
Эталон 3, Ом 1000

b



c

Fig. 1. Block diagram of the automated system for determining the TCR of film materials (a), appearance of the main application window to automatically sample annealing (b) and program window for constructing of the temperature dependence (c)

Fermi level W_F the metal and semiconductor are aligned. Contact the electric field $E_к$ directed from metal to semiconductor, which results in bending of the energy levels of the minority carriers. If due to the choice of material value works out electrons from the metal and semiconductor differ insignificantly $A_{Me} \cong A_{Sem}$ ($A_{Fe} \cong$ 4.31 eV; $A_{Ge} \cong$ 4.40 eV), barrier height will be minimal.

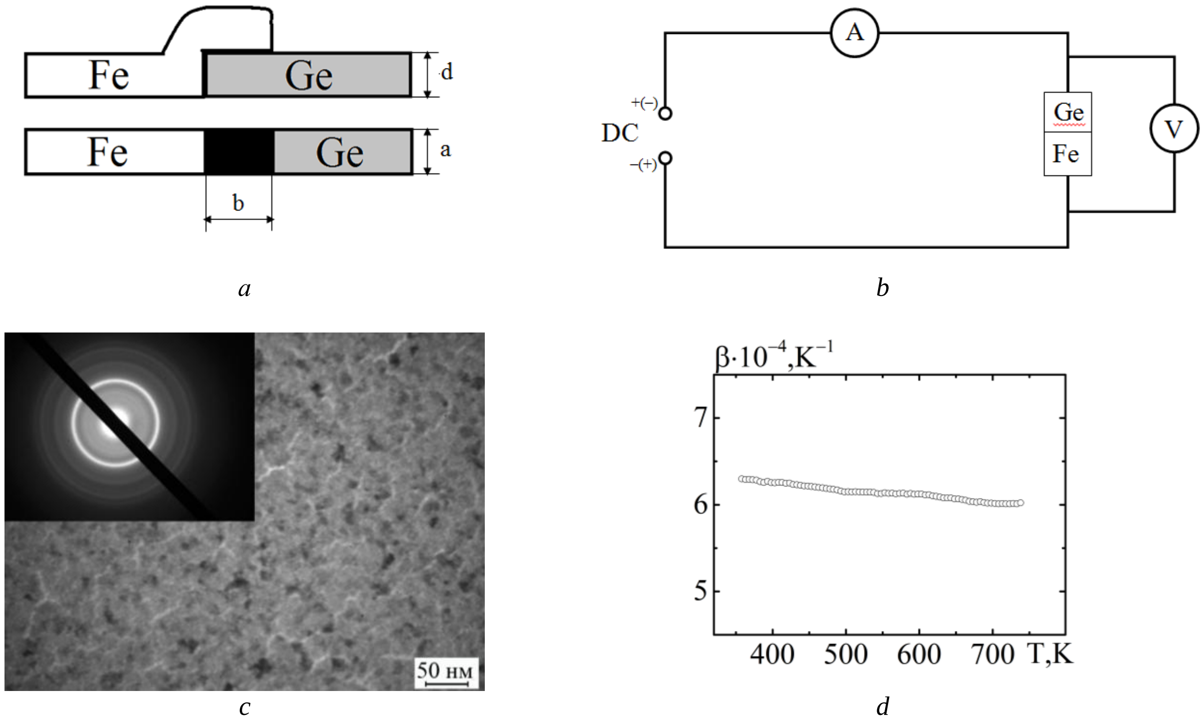


Fig. 2. Structural (a) and electrical (b) schemes for current-voltage characteristics, diffraction pattern (c) and temperature dependence of TCR (d) of double-layer films Fe/Ge/S

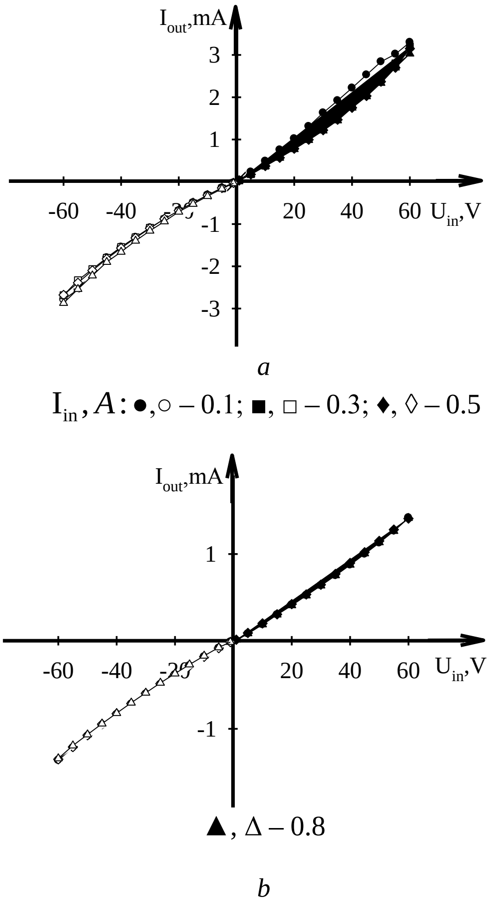


Fig. 3. The current-voltage characteristics for annealed to 900 K films Fe(30)/Ge(25)/S. The area of transition Me/Sem: S = a·(b+d): 10^{-5} (a) and $2.5 \cdot 10^{-6}$ m^2 (b)

On the Fig. 3 shows the experimental current-voltage characteristics for annealed to 900 K films Fe(30)/Ge(25)/S at the different area of transition Me/Sem.

In the case system Fe/Ge/S with atomic radius of the metal $r_{Fe} = 0.126$ nm and the lattice parameter of semiconductor $a_{Ge} = 0.566$ nm the resistance ohmic contact is calculated as follows:

$$R_c = \frac{(\rho + \beta T)W}{\pi r^2 p},$$

where $\rho \cong 10^{-7}$ Ω·m – resistivity of the metal; $\beta \cong 6 \cdot 10^{-4}$ K^{-1}; $W \cong 1$ nm – width of the space charge layer; $p \cong 2{,}1 \cdot 10^{10}$ m^{-2} [10] – dislocation density in the film Ge, which can be adsorbed atoms Fe.

For a system Fe/Ge/S value of contact resistance $R_c = 0.38$ Ω/m^2, which will not affect the contact values of parameters of electronic devices.

The films Fe/Ge/S in this case are relatively high resistivity ($\rho \cong (0.5…2.0) \cdot 10^{-6}$ Ω·m) and low TCR ($\beta \cong (5.8…6.2) \cdot 10^{-4}$ K^{-1}), that meets the requirements to the ohmic contacts.

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СТРУКТУРА И ФИЗИЧЕСКИЕ ХАРАКТЕРИСТИКИ ОМИЧЕСКИХ КОНТАКТОВ НА ОСНОВЕ ПЛЕНОК Fe И Ge

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Предложено применение метода послойной конденсации с последующим отжигом от 300 до 900 К для формирования омических контактов на основе пленок Fe и Ge. Проведены исследования микроструктуры и фазового состава контактных систем Fe/Ge, для которых получены симметричные линейные вольт-амперные характеристики и следующие рабочие параметры: сопротивление на квадрат площади 0,3 Ом/м^2 и термический коэффициент сопротивления $6 \cdot 10^{-4}$ К$^{-1}$.

СТРУКТУРА І ФІЗИЧНІ ХАРАКТЕРИСТИКИ ОМІЧНИХ КОНТАКТІВ НА ОСНОВІ ПЛІВОК Fe І Ge

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Запропоновано застосування методу пошарової конденсації з наступним відпалюванням від 300 до 900 К для формування омічних контактів на основі плівок Fe і Ge. Проведено дослідження мікроструктури і фазового складу контактних систем Fe/Ge, для яких отримано симетричні лінійні вольт-амперні характеристики та наступні робочі параметри: опір на квадрат площі 0,3 Ом/м^2 і термічний коефіцієнт опору $6 \cdot 10^{-4}$ К$^{-1}$.