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Ohmic contacts to Hall sensors based on *n*-InSb–GaAs(*i*) heterostructures

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Abstract. We consider ohmic contacts to the *n*-InSb epitaxial layers grown on a semi-insulating GaAs substrate. The ohmic contacts are formed through titanium metallization with subsequent gilding. Using the structural (AFM and XRD) and analytical (AES) techniques, we showed that thermal annealings at $T = 300$ °C (for 60 s) and 360 °C (for 30 s) do not change the phase composition of the metallization. This ensures thermal stability of the contacts and Hall sensors made on the basis of Au–Ti–*n*-InSb–GaAs(*i*) structures.

Keywords: *n*-InSb–GaAs(*i*) heterostructure, Au–Ti metallization, Hall sensors.

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1. Introduction

When developing and producing various semiconductor sensors, severe requirements are imposed not only on the quality of starting semiconductor material, but on the structure and electrophysical properties of ohmic contacts as well [1, 2]. This is particularly true when a narrow-gap semiconductor is used, either alone or as a component of heterostructure, for production of Hall-effect magnetic field sensors. Here we shall consider formation of ohmic contacts to the *n*-InSb–GaAs(*i*) heterostructure.

2. Samples and experimental procedures

The Hall sensors were made on the basis of *n*-InSb–GaAs(*i*) heterostructure. The concentration of noncompensated donors in InSb was $(3\ldots6)\times10^{17}$ cm^{-3}; the thicknesses of the *n*-InSb layer and semi-insulating GaAs substrate were ~2 and ~350 μm, respectively; resistivity of semi-insulating GaAs was ~10^7 Ohm·cm. Ohmic contacts to *n*-InSb were formed using two-layer titanium and gold metallization (both thicknesses of 50 nm) performed at temperatures of 300 °C (for 60 s) and 360 °C (for 30 s).

Auger electron spectroscopy (AES) was used to study the concentration depth profiles of contact components before and after rapid thermal annealing (RTA). Morphology of the metal–InSb interface was investigated using atomic force microscopy (AFM), while the phase composition of metallization was studied using X-ray diffraction (XRD).

The sensitive elements of Hall sensors were prepared using the following microelectronic procedures: (i) preparation of metal films for electrical contacts by magnetron sputtering and electrochemical deposition; (ii) photolithography to form the topology of the sensitive elements and metal contacts; (iii) micromachining to produce the sensing element; typically 1.0 mm^2 square and 0.35 mm thick (see Fig. 1). We measured temperature dependences of both sensor input and output resistances and Hall voltage U_H using chips and contact resistivity of test structures.

3. Experimental results and discussion

Surface morphology features of the starting InSb films and Au–Ti layers sputtered onto them and treated thermally as well as roughness height distribution over the sample surface have shown that surfaces of both the starting and metallized epitaxial films are essentially non-uniform. This is due to the nature of structure defects produced in the InSb layers during their epitaxial growth that are related, first of all, to misfit of InSb and GaAs crystal lattices (see Fig. 2). Our AFM studies of the gold film surface made before and after annealing of the contacts showed that the long-term thermal annealing at lower temperatures (see Fig. 3a, b and Table) leads to bigger changes of surface relief than the short-term one at a higher temperature (Fig. 3c).

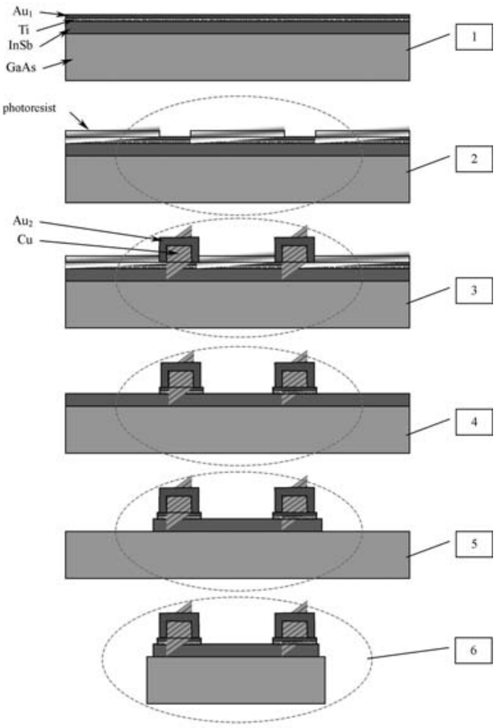


Fig. 1. Stages of the process for Hall sensor chip fabrication. 1 – Ti-Au$_1$ contact system sputtering in vacuum. 2 – Layout formation for local growth of contact pads. 3 – Local growth of contact pads (Cu, Au$_2$). 4 – Removal of photoresist from the wafer and etching the Au$_1$ and Ti layers. 5 – Photolithography and etching off sensor layout on InSb. 6 – Wafer slicing into chips; presorting.

Table. Roughness height range Z_r and simple average roughness R_a of the surfaces of *n*-InSb–GaAs(*i*) and Au–Ti–*n*-InSb–GaAs(*i*) structures.

Type of sample	Type of treatment	Z_r, nm	R_a, nm
n-InSb–GaAs(*i*)	starting sample	19.84	2.25
Au–Ti–*n*-InSb–GaAs(*i*)	starting sample	10.35	1.24
	RTA (300 °C, 60 s)	30.66	3.19
	RTA (360 °C, 30 s)	16.71	1.81

Note. A surface area of 1×1 μm was analyzed.

It should be noted, however, that such changes of the surface are rather insignificant and cannot affect the phase and structural states of the system and interfaces (this was proved by further investigations). Table contains the characteristic roughness parameters of front surfaces in the samples studied.

The reduced contact resistance measured for test structures after RTA at $T = 300$ °C (for 60 s) and 360 °C (for 30 s) did not exceed 10^{-5} Ohm·cm. This is indicative of a rather stable near-contact region, where an ohmic contact is formed. The AES studies of concentration depth profiles inherent to contact components in the test structures (Fig. 4) showed that both the starting samples and those after RTA retain their layered metallization structure; noticeable mass transfer at the interfaces of metal-metal (Au–Ti) and metal-semiconductor (Ti–InSb) was not revealed.

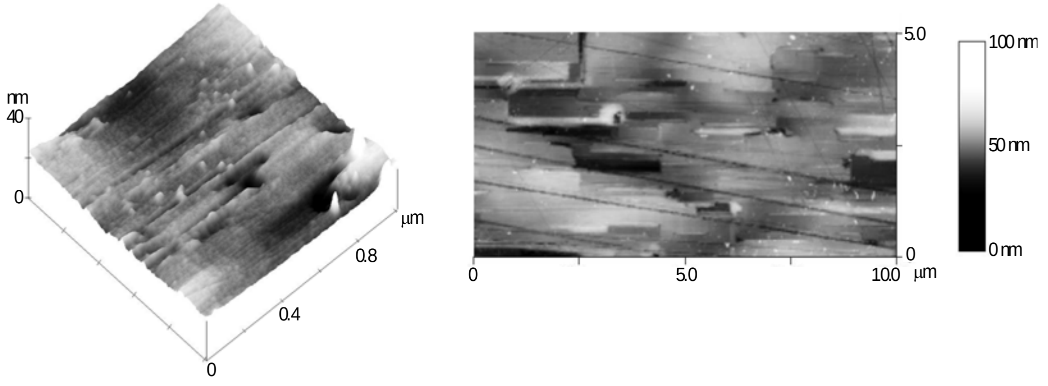
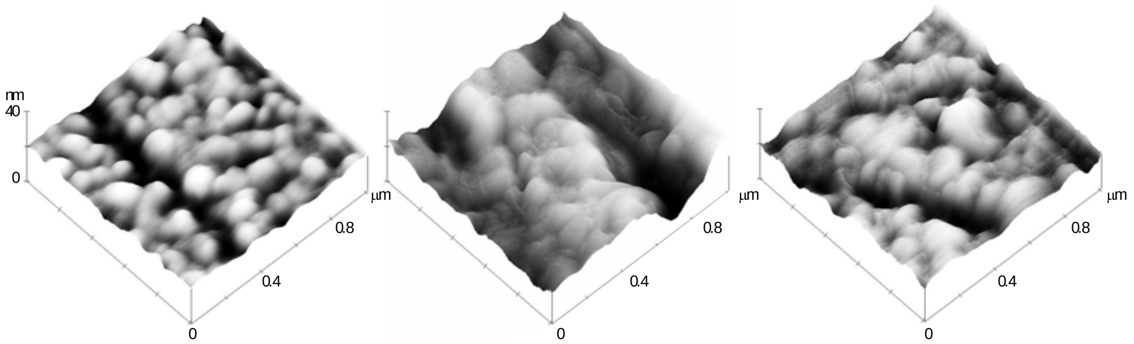


Fig. 2. 3D and 2D images of surface of the starting InSb film.



a *b* *c*

Fig. 3. AFM images of Au films surfaces before (a), after annealing at 300 °C for 60 s (b) and 360 °C for 30 s (c).

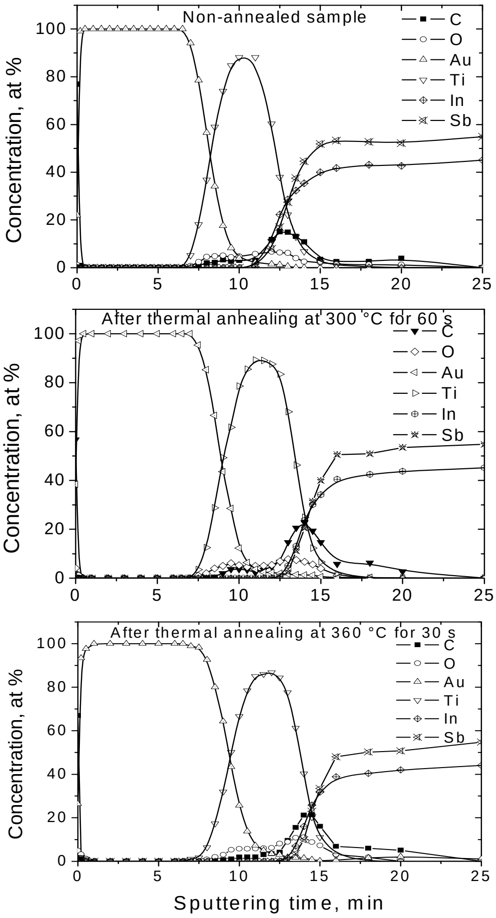


Fig. 4. Concentration depth profiles for the Au–Ti–InSb–GaAs(*i*) contact components.

The above results are confirmed also by the XRD data. They show that, in all the metallized structures studied, the preferred gold crystallite orientation is ⟨111⟩. Probably, the titanium film involves two phases: a principal quasi-amorphous phase (see a broad peak of low intensity at the 20° to 25° angles in Fig. 5) and a small amount of hexagonal polycrystalline titanium (without preferred crystallite orientation). The above phase composition of the Au–Ti–InSb–GaAs system does not change in the course of thermal annealing (Fig. 5, curves 2 and 3).

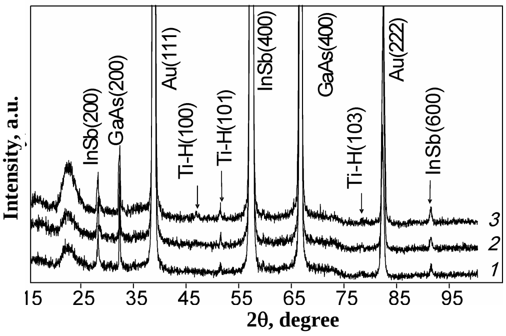


Fig. 5. XRD pattern of the Au–Ti–InSb–GaAs contact before (1) and after annealing at 300 °C for 60 s (2) and 360 °C for 30 s (3).

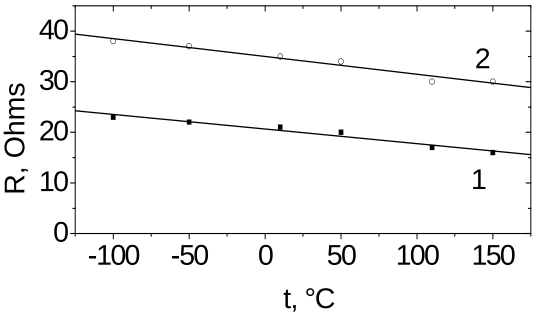


Fig. 6. Temperature dependence of input (1) and output (2) resistances of InSb-GaAs (*i*) Hall-effect magnetic field sensors.

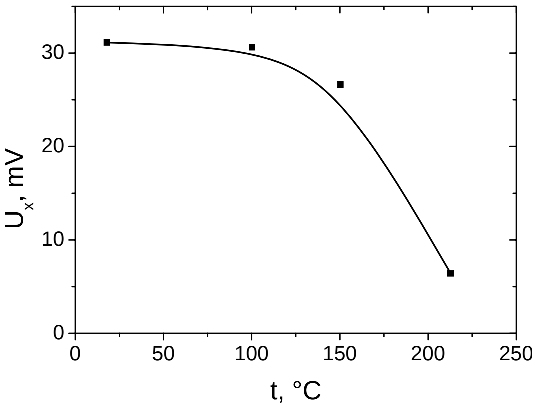


Fig. 7. Temperature dependences of the Hall voltage, U_H, for InSb–GaAs(*i*) magnetic field sensors at direct current 10 mA and magnetic field 0.3 T.

Thus both structure and morphological properties of the Au–Ti–*n*-InSb–GaAs(*i*) contact structures evidence that these structures possess high thermal stability and may serve as a basis for production of Hall sensor elements capable to operate in a wide temperature range. Snown in Figs 6 and 7 the main characteristics of Hall sensors we made.

4. Conclusion

Thus, our studies demonstrated that it is possible to produce the *n*-InSb–GaAs(*i*) Hall sensor elements with Au–Ti contact metallization that can operate within the temperature range from –100 °C up to +150 °C.

References

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