Effect of Surface Roughness on the Properties of Ohmic Contacts to GaAs

N. L. Dmitruk, O. Yu. Borkovskaya, V. P. Kladko, R. V. Konakova, Ya. Ya. Kudryk, O. S. Lytvyn, V. V. Milenin

Abstract - Au/Ge/TiB_x/Au ohmic contacts to n-GaAs with textured surface have been developed and investigated. Two types of microrelief morphology (quasi-grating and dendrite-like), that are perspective for Solar Cell and sensor application, have been obtained by wet chemical anisotropic etching. The surface morphology and structural perfection were studied by AFM technique and x-ray diffractometry measurements. The effect of surface roughness on the value of contact resistivity and its lateral distribution has been investigated. The qualitative model for nonuniformity of ohmic contact formation caused by the dependence of intrinsic stresses on the interface roughness has been drawn to explain experimentally observed spread of electrical parameters.

I. INTRODUCTION

The actual metal-semiconductor contacts are practically always nonuniform to an extent. Generally these nonuniformities are related to interface imperfection, presence of oxide layers on etched surfaces, structure of a metallized layer or reactions in metal-semiconductor contacts [1]-[3]. The above sources of nonuniformities result from drawbacks of technological processes used in production of contact structures. These drawbacks lead to uncontrolled spread of the electrophysical parameters of contact structures. In this connection investigation of the properties of metal-semiconductor junctions at purposeful formation of nonuniformities at their interfaces becomes of special importance. Many of such nonuniformities may be exemplified by a purposefully formed microrelief on a semiconductor surface [4], [5].

II. SAMPLE PREPARATION AND CHARACTERIZATION

Investigated structures with flat and textured surfaces were fabricated on (100) oriented n-GaAs substrate with $N_d \approx 2 \cdot 10^{17}$ cm^{-3} (300 μm thick). Nearly flat polished surfaces were obtained by chemical etching in $3H_2SO_4$:$1H_2O_2$:$1H_2O$ solution. Two types of textured surfaces which are promising for solar cell and photodetector applications [5], [6] were prepared by wet chemical anisotropic etching. Dendrite-like microrelief was formed in concentrated HNO_3(65%) at etching conditions: $T=20^0C$, t≈ 45 s. To obtain quasi-grating-like microrelief as a set of oriented along [110] V-grooves whose period varies along the surface over some range, we used $1H_2SO_4$:1HF:$0,5H_2O_2$ mixture with etching temperature 24^0C and etching duration 1÷3 min. Varying the etching conditions allows one to change both the depth of microrelief and its geometrical and statistical parameters.

The investigated multilayer ohmic contacts to GaAs were fabricated by magnetron sputtering of Au (180 nm), Ge (30 nm) TiB_x (100 nm), Au (200 nm) films on prepared substrates [7]. The oxide layers that were formed on GaAs surface during chemical texturing were etched off before the sputtering. The set of circular contacts having a diameters from 20 to 400 μm was formed on the front surface of wafer. The contact to its back side was continuous. Formation of nonrectifying contacts was performed using thermal annealing in hydrogen at 500^0C for 1 min.

The microrelies morphology investigation and determination of its parameters were performed with the help of AFM technique using a Nanoscope IIIA AFM (Digital Instruments, USA) in the tapping mode with Si_3N_4 tip.

To investigate how texturing treatments affect structural perfection of the wafer studied, we used methods of x-ray topography and x-ray diffractometry (XRD) measurements of the radii of curvature of wafers and full width at half-maximum (FWHM) of the rocking curve.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Figures 1–3 present the results of our studies of contact resistivity ρ_c of the GaAs–Au(180 nm)–Ge(30 nm)–TiB_x(100 nm)–Au(200 nm) ohmic junctions. They were prepared on the semiconductor surfaces of different morphologies; the contact diameter was d_c = 400 μm. Formation of nonrectifying contacts was performed using thermal annealing in hydrogen at 500 °C for 1 min.

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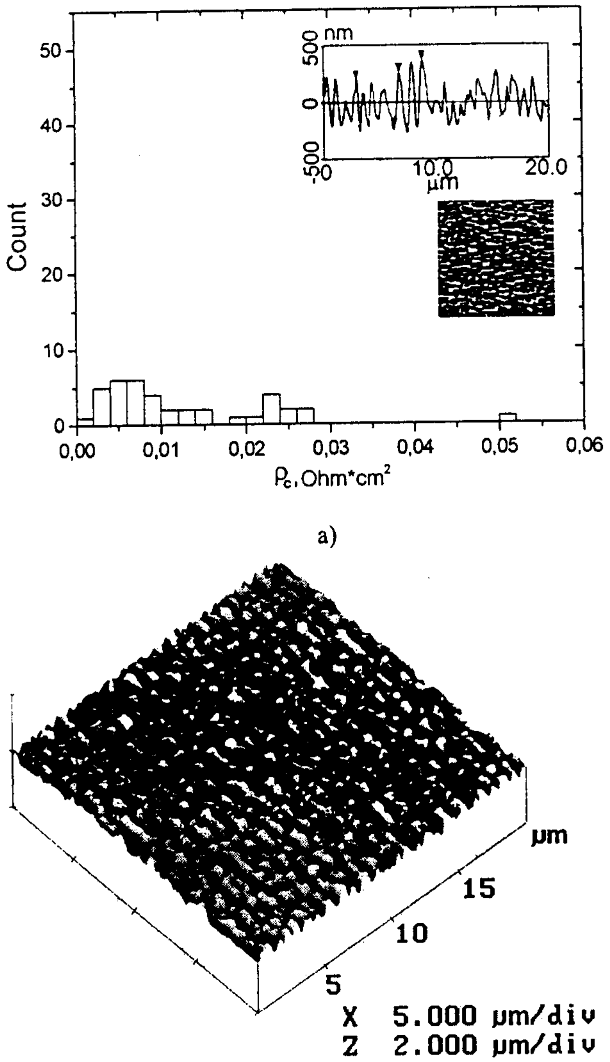


a)

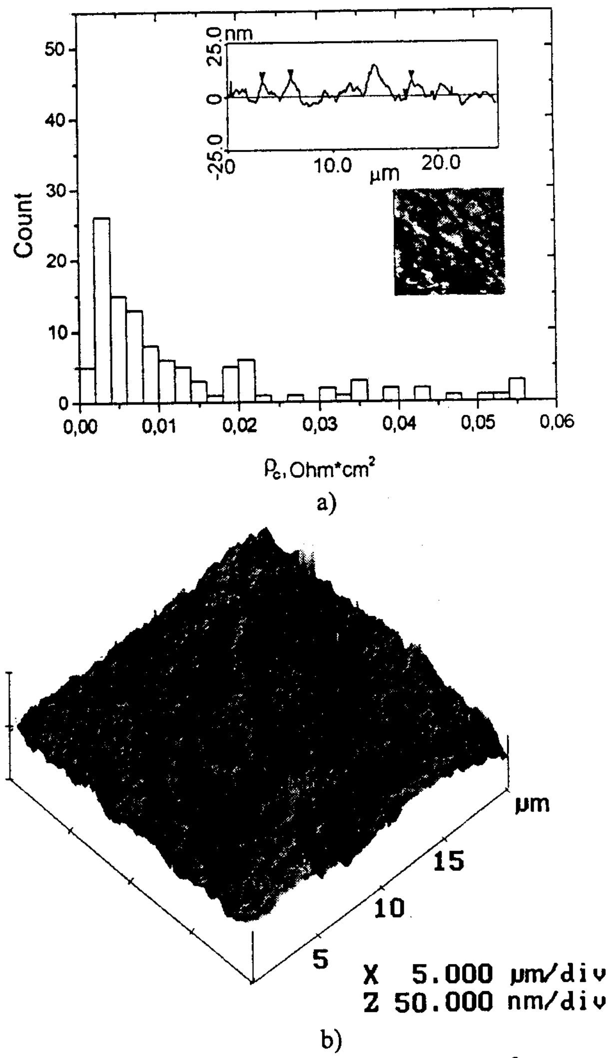
b)

Fig.1. The results of studies of contact resistivity ρ_c of GaAs–Au (180 nm)–Ge (30 nm)–TiB_x (100 nm)–Au(200 nm) ohmic transitions on quasi-grating-like semiconductor surface (a) and AFM surface pattern (b).

Our measurements of the sample curvature showed that the samples were rather strained, with nonuniform lateral distribution of strain over the wafer area. Depending on the surface treatment, this characteristic varies from sample to sample. The main data on the radii of curvature for four samples are presented in Table I.

TABLE I
RADII OF CURVATURE FOR GAAS SAMPLES WITH DIFFERENT SURFACE MICRORELIEFS

Type of surface microrelief	Radius of curvature, m
dendrite-like	14.9-25
quasi-grating-like (etching for 1 min. at 30^0 C)	6.3-8.5
quasi-grating-like (etching for 3 min. at 24^0 C)	0.63-2.17
polishing etching	77-150



a)

b)

Fig.2. As in Fig.1 but for flat semiconductor surface.

Our measurements and analysis of quasi-forbidden reflection (QFR) intensities (which are sensitive to the stoichiometry parameter) showed that there exists a certain correlation between the general structure perfection level and stoichiometry parameter [8]. From such parameters as FWHM of rocking curve and integral reflectivity for QFR one can conclude that in the crystal dislocation regions both basic components and impurity atoms are redistributed as compared to the situation in the dislocation-free regions.

Investigation of x-ray topography over the GaAs wafer surface before and after the textured etching testifys the laterally nonuniform change of rocking curve FWHM.

This fact testyfys that the strain fields are redistributed during etching. As a result, the intrinsic point defects (impurity atoms) diffuse in these fields.

The effect of strains seems to be the most probable mechanism for changing rocking curve half-width, since it is rather difficult to assume that dislocation density can change essentially, even in local regions.

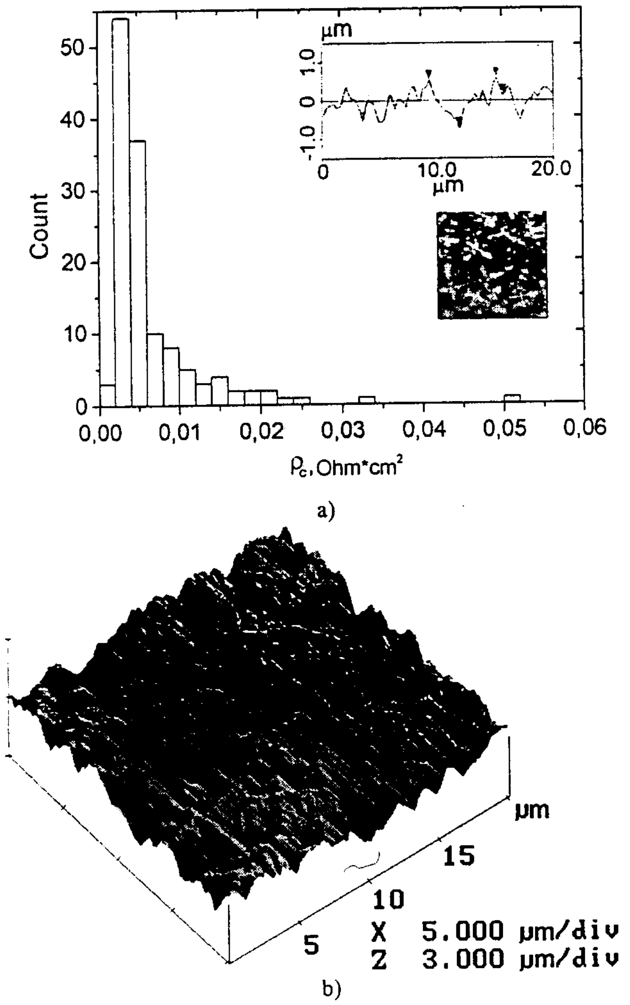


Fig. 3. As in Fig. 1 but for dendrite-like semiconductor surface.

Contact resistivity ρ_c was defined as

$$\rho_c = \left(\frac{\partial J}{\partial V}\right)^{-1}_{V=0} \qquad (1)$$

where J is the current density. Being determined in such a way, this quantity should not depend on the contact area; this conclusion is in contradiction with the results presented in Fig 4.

Thus the results shown in Figs. 1–4 indicate at an essential nonuniformity of ρ_c distribution over the wafer area, at both the initial and microrelief surfaces. This spread of ρ_c values depends on the contact area, and for diameter d_c it may be presented in the following sequence: quasi-grating-like surface–flat surface–dendrite-like surface. Whatever the current flow mechanism (thermionic, thermal-field, field), the resistivity ρ_c is proportional to $\exp(q\varphi_b)$ (where φ_b is the effective barrier height), and the Fermi level is pinned due to high density of surface states. Therefore the only way to affect contact resistivity is variation of the doping level in the semiconductor substrate with uniform planar distribution of impurities over the whole area of the contacting layer.

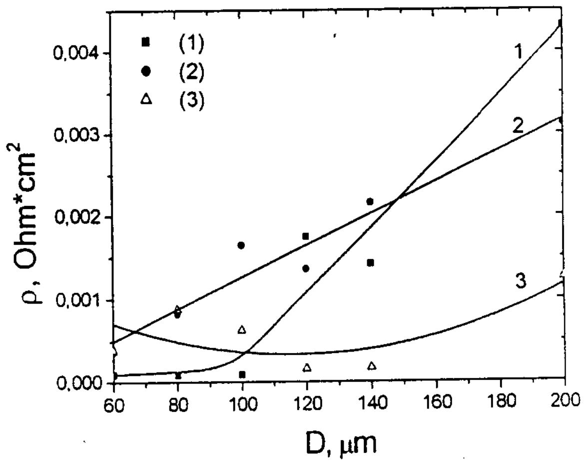
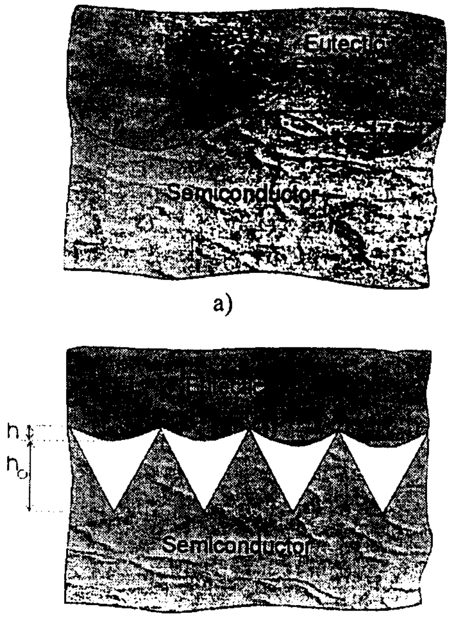


Fig 4. Contact resistivity ρ_c as function of contact diameter d_c: 1 – for dendryte-like surface; 2 – for flat surface; 3 – quasi-grating-surface.

However the structural-phase distinctions at different semiconductor surface areas result in the fact that the actual contact area (disordered sections or those with Ge atoms that have diffused here) differs essentially from the geometrical one. Indeed, it is well known that the eutectic melt AuGe wets poorly the actual GaAs surface. In this case contact formation will depend on composition and thickness of an oxide layer at the metals–semiconductor interface, possibility of its dissolving in the melt, and variation of the wetting angle of the melt due to absorption of Ga(As) atoms and loss of Ge atoms.

From this one can conclude that the geometrical sizes of regions and predominant current flow mechanisms differ essentially for different wafer sections. This leads to the observed spread of ρ_c values. Thus nonuniform oxide layer distribution of at an actual GaAs surface is the reason for nonuniform interdiffusion during thermal treatment and, as a result, for electrical nonuniformity of the interface.

The above model for formation of electrical contact nonuniformities may be applied for analysis of the roughness effect on the properties of nonrectifying contacts. It is known that surface roughness affects wetting of surface by melts. Two limiting cases presented in Fig. 5 may occur, depending on the geometrical parameters of relief (ridge height, width and depth of valleys, as well as wetting angles for surface areas where a relief has been formed).



a)

b)

Fig.5. Wetting of surface with melts: a – the melt fills completely the valleys of a rough surface; b – the case of minimal wetting.

Figure 5 corresponds to the case when a melt fills completely the valleys of a rough surface. At that, as was shown in [9], the actual contact area $S_a = kS_d$, where S_d is the area of a droplet on a flat surface and the coefficient

$$k = \int_0^{r_d} \frac{2\pi\alpha\left[(1+(\frac{\partial z}{\partial x})^2)\right]^{\frac{1}{2}} dx}{\pi r_d^2}. \qquad (2)$$

Here r_d is the radius of a droplet on a flat surface, α is some coefficient, z and x are the variable coordinates which characterize height of ridges and spacing between them.

In an actual situation no complete wetting of valleys occurs, so a case is realized that is intermediate between those presented in Fig. 5. One can show that, as θ grows, h decreases. This fact characterizes eutectic penetration into the valleys of a rough surface (see Fig. 5a).

There exists also another effect affecting S_a. It is due to roughness effect on melt spreading (kinetic factor). Since duration of contact between the melt and semiconductor is finite, presence of ridges serves as a peculiar barrier for spreading; at the same time longitudinal valleys are favorable for melt spreading. Thus the surface morphology features, as well as inhomogeneity of surface composition, affect the character of interactions between phases in metal–semiconductor contacts, i.e., on the electrophysical properties of HJs.

VI. Conclusion

The above qualitative model for nonuniformity formation when fabricating ohmic contacts on rough surfaces makes it possible (i) to explain experimentally observed spread of electrical parameters, and (ii) to show the reasons for their instability (the main of which is appearance of intrinsic stresses). It was shown in [9] that intrinsic stress value in such structures is determined by the roughness parameters and metal film thickness. Depending on the interrelation between the ridge height and metal film thickness, different situations may be realized, when intrinsic stresses are over, equal or below those in contacts formed on flat surfaces.

Acknowledgements

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