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Effect of microwave radiation on *I–V* curves and contact resistivity of ohmic contacts to *n*-GaN and *n*-AlN

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Abstract. We studied ohmic contacts Au-Pd-Ti-Pd-*n*-AlN and Au-TiB$_2$-Al-Ti-*n*-GaN with contact resistivity $\rho_c = 0.18\ \Omega\cdot\text{cm}^2$ and $1.6\cdot10^{-4}\,\Omega\cdot\text{cm}^2$, respectively, and the effect of microwave treatment on their electrophysical properties. After microwave treatment for time *t* up to 1000 s, the contact resistivity dropped by 16% (60%) in the contact to AlN (GaN). This seems to result from increase of the number of structural defects in the semiconductor near-contact region caused by relaxation of intrinsic stresses induced by microwave radiation.

Keywords: ohmic contact, contact resistivity, microwave treatment, intrinsic stresses.

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1. Introduction

Interest in III–N compound semiconductor devices has quickened in the last few years. Along with the development of light-emitting diodes, power devices and various microwave diodes and transistors, the above materials are considered for production of solar blind photodetectors operating in UV [1-5]. Efficient application of all the above-mentioned devices and facilities cannot be achieved without high-reliability thermostable low-resistance ohmic contacts. However, the development of ohmic contacts to wide-gap III–N semiconductors still remains a complicated physico-technological problem. Even in the present-day manufacturing technology of gallium-nitride light-emitting diodes and field-effect transistors with high mobility of charge carriers in the channel based on GaN/AlGaN heterostructures, fabrication of ohmic contacts is the most vulnerable technological process that often does not enable one to predict parameter reproducibility.

A number of contact systems are applied now to GaN [1, 4-6], while ohmic contacts to AlN remain practically unexplored. The authors of [7, 8] inform on linear *I–V* curves in an alloyed ohmic contact In-AlN [6] and Ni-AlN [7]. There are no other data on parameters of ohmic contacts to AlN in the above papers. In [9, 10] a possibility of formation of ohmic contact to high-resistance *n*-AlN film grown on a heavily doped n^+-4H-SiC substrate was shown as well as temperature dependence of contact resistivity, $\rho_c(T)$, was measured. A high density of structural defects was observed in the near-contact region of *n*-AlN grown on a n^+-4H-SiC substrate, just as in ohmic contacts to *n*-GaN grown on sapphire. Such objects are of interest for studying the effect of various radiation actions (in particular, microwave one) on their properties.

2. Specimens and methods of investigation

We prepared test structures Au(100 nm)-Pd(70 nm)-Ti(50 nm)-Pd(30 nm)-*n*-AlN-n^+-4H-SiC and Au(100 nm)-TiB_2(100 nm)-Al(60 nm)-Ti(30 nm)-*n*-GaN-Al_2O_3. The contact metallizations were formed on substrates (heated to 350°C) by using layer-by-layer vacuum deposition of metal films in a single technological cycle (*n*-AlN) and magnetron sputtering (*n*-GaN). After this, the specimens were made using templates with radial or linear geometry for measurements of contact resistivity with the transmission line method [11].

The *n*-AlN films were grown using chloride vapor phase epitaxy on n^+-4H-SiC substrates. A standard horizontal reactor setup was used [12]. The *n*-AlN films (thickness of ~3.5 μm) were of high-resistance and compensated, with the donor impurity concentration $\geq 10^{17}\,\text{cm}^{-3}$. The GaN films were grown on the sapphire substrate by using metal-organic chemical vapor deposition [13]. These films (thickness of ~1 μm) were doped with silicon (concentration up to $\sim 10^{17}\,\text{cm}^{-3}$). The density of growth dislocations in *n*-AlN was $\sim 10^{10}\,\text{cm}^{-2}$, while in *n*-GaN it was lower by two orders of magnitude.

The contact *I–V* curves and contact resistivity were measured at the temperature close to 300 K both before and after microwave treatment for 1–1000 s in non-heating mode (frequency of 2.45 GHz, emittance of 7.5 W/cm^2). The radius of curvature *R* of test structures Au-TiB_x-Al-Ti-*n*-GaN-Al_2O_3 with continuous metallization was measured with a profilometer-profilograph П104.

3. Experimental results and discussion

The *I–V* curves of contacts to *n*-GaN and *n*-AlN were linear both before and after microwave treatment, thus characterizing contact ohmicity (Fig. 1). However, according to the electrophysical parameters of the initial *n*-AlN and *n*-GaN films, the values of contact resistivities for the above contacts differed by about 3–3.5 orders of magnitude (ρ_c of contacts to *n*-AlN was higher than that of contacts to *n*-GaN).

Shown in Fig. 2 are dependences of contact resistivity ρ_c on the time of microwave treatment *t* for contacts to *n*-AlN (curve 1) and *n*-GaN (curve 2). At short times of treatment (below 100 s), ρ_c in contacts to *n*-AlN grows with time, while ρ_c in contacts to *n*-GaN decreases at times of microwave irradiation up to 1000 s. The above variations of ρ_c with time in contacts to *n*-GaN can be explained by taking into account relaxation of intrinsic stresses (IS) in that contact system induced by microwave radiation. As the time of microwave treatment grew, the radius of curvature of test specimen increased. To illustrate, in the initial (before microwave treatment) specimen $R = 10$ m, while after microwave irradiation for 28 s $R = 45$ m.

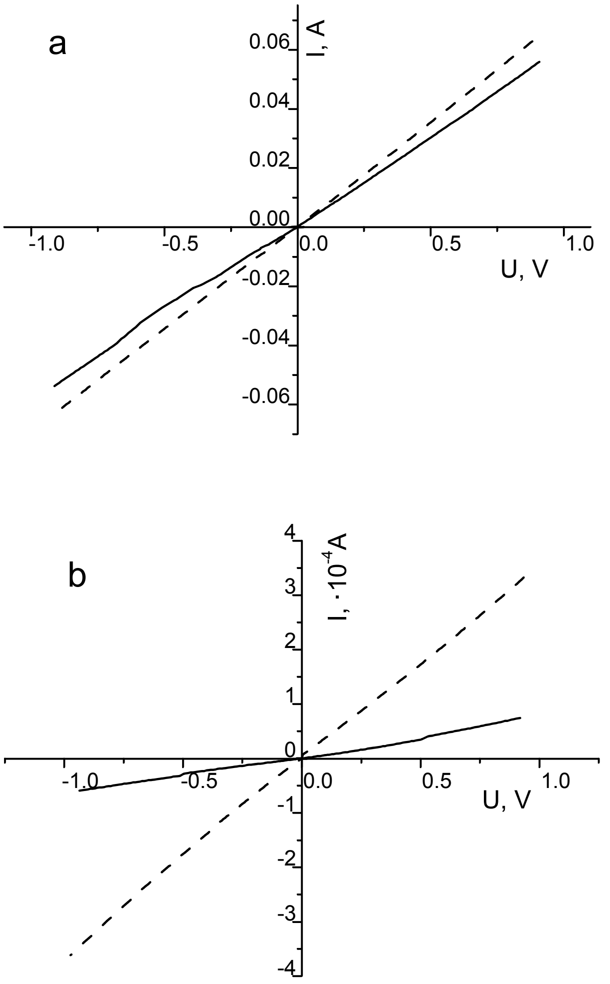

Fig. 1. *I–V* curves for the contact structures Au-TiB_x-Al-Ti-*n*-GaN (a) and Au-Pd-Ti-Pd-*n*-AlN/SiC (b) taken before (—) and after (---) microwave treatment for 750 s.

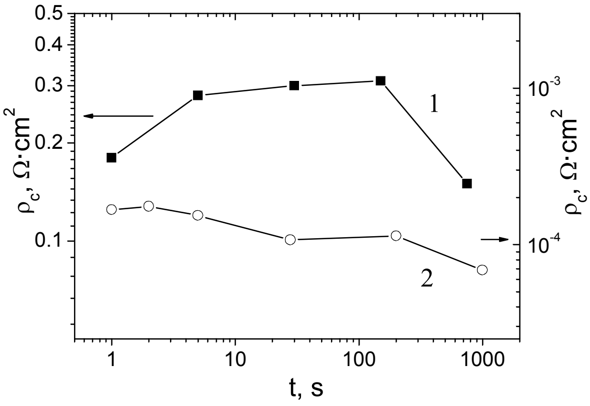

Fig. 2. Dependence of contact resistivity ρ_c on time of microwave treatment *t* for contacts to *n*-AlN (*1*) and *n*-GaN (*2*).

In accordance with the model of ohmic contacts to semiconductor with the high dislocation density [14], ρ_c is

$$\rho_c = \frac{\rho_0 (1+\alpha T) d_D}{\pi r^2 N_{D1}} + \frac{kT}{q} \frac{(1+0.6\beta)}{q(qV_T/4) n e^{y_{c0}} \pi L_\mathrm{D}^2 N_{D1}}. \quad (1)$$

Here ρ_c is the metal resistivity at the temperature $T = 0°\mathrm{C}$, α – its temperature coefficient, r – radius of the metal shunt, d_D – distance that electrons pass through the shunt from the semiconductor bulk to the continuous metal contact, N_{D1} – density of conducting dislocations (i.e., those with which the metal shunts are associated), q – elementary charge, k – Boltzmann constant, V_t – electron thermal velocity, L_D – Debye screening length, n – electron concentration in the semiconductor bulk, $\beta = \frac{V_T L_\mathrm{D}}{4 D_n} e^{y_{c0}}$ – coefficient taking into account current limitation by diffusion supply of electrons, D_n – electron diffusion coefficient, y_{c0} – non-dimensional equilibrium potential at the metal–semiconductor interface.

One can see from Eq. (1) that contact resistivity ρ_c goes down as the density of conducting dislocations N_{D1} increases. This may take place if the IS relaxation process occurs by generation of dislocations. Such a process of IS relaxation correlates with the ρ_c value measured in ohmic contacts to *n*-GaN.

It seems that IS relaxation in the contact to *n*-AlN occurs by annihilation of dislocations at the drains. In that case, the cracks in AlN film caused by aftergrowth IS relaxation serve as drains. Reduction of dislocation density leads to increase of ρ_c, which corresponds to the observed ρ_c dependence on time t of microwave irradiation for 1–150 s. As the irradiation time is increased up to 750 s, then ρ_c goes down to a value smaller than the initial one. We believe that the mechanism of ρ_c decrease in this case is similar to that considered above for contact metallization to *n*-GaN. One can see from Fig. 2 that as the time of irradiation is increased up to 750 s for contacts to *n*-AlN and 1000 s for contacts to *n*-GaN, ρ_c decreases by 16% and 60%, respectively. As was shown in [13] by the example of ohmic contacts to *n*-GaN, these variations remain stable, if the specimens are stored at room temperature for 9 months.

It should be noted that in both types of contacts the interface formed in the course of rapid thermal annealing at $T = 900$ °C followed with cooling is structurally inhomogeneous, since the formed solid solutions and alloys are polyphase. This is related to essential distinction between their structural parameters and compositions [1, 4-6]. The process of relaxation of IS concentrators, which may appear owing to this, is induced by microwave radiation; as a result, a strongly defect interface may be formed in the semiconductor near-contact region. The reality of this process as a general phenomenon in manufacturing technology for semiconductor devices was stressed by the authors of [15] when analyzing defect formation in both heteroepitaxial structures and metal–semiconductor contacts.

4. Conclusion

The experimental studies of contact resistivity ρ_c made before and after microwave treatment of ohmic contacts to *n*-GaN and *n*-AlN for 1–700 s and 1–1000 s, respectively, showed that ρ_c decreased as compared with its initial value. This seems to result from relaxation of intrinsic stresses owing to generation of structural defects induced by microwave radiation.

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