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TUNNEL SURFACE CURRENT IN GaAs—AlGaAs P-N JUNCTIONS, DUE TO AMMONIA MOLECULES ADSORPTION

The influence of ammonia vapors on *I-V* characteristics of forward and reverse currents and kinetics of surface currents in GaAs-AlGaAs p-n junctions with degenerated p^+ region was studied. It is shown that ammonia molecules adsorption, under sufficiently high NH_3 partial pressure, forms in p-AlGaAs a surface conducting channel with degenerated electrons. P-n junctions with degenerated p^+ region have higher gas sensitivity at reverse bias than at forward bias. This effect is explained by tunnel injection of electrons into the conducting channel from the degenerated p^+ region at a reverse bias. The rise time of the surface current in an ammonia vapor atmosphere of ~20s is due to filling up deep electron traps.

1. INTRODUCTION

P-n junctions as gas-sensitive devices [1, 2] have some advantages in comparison with structures, based on oxide polycrystalline films [3, 4] and Shottky diodes [5, 6]. P-n junctions have high potential barriers for current carriers, which results in low background currents. Sensors on p-n junctions [1, 2] have crystal structure, high sensitivity at room temperature

In previous papers the gas sensitivity of p-n structures on GaAs and GaAs—AlGaAs [1, 2], GaP [7], InGaN [8], and Si [9, 10] was investigated. . It was shown that the gas sensitivity of all these p-n junctions is due to forming of a surface conducting channel in the electric field induced by the ammonia ions adsorbed on the surface of the natural oxide layer. The gas-sensitivity of the forward current in p-n junctions is limited by strong rise of the injection current with the bias voltage. The voltage-limit for the reverse current is substantially higher. Therefore, under some conditions, the gas-sensitivity of the reverse current can be higher than the forward one.

The aim of this work is a study of the influence of ammonia vapors on the forward and reverse currents in a GaAs—AlGaAs p-n heterostructure with a degenerated p^+-GaAs layer. It is shown that, at high enough concentration of ammonia in the ambient atmosphere, a surface conducting channel with degenerated electrons is formed and tunnel forward and reverse currents are observed.

2. EXPERIMENT

The measurements were carried out on p+-GaAs(Zn) — p-$Ga_{0.45}Al_{0.55}$(Ge) — p-$Ga_{0.65}Al_{0.35}$(Ge) — n- $Ga_{0.45}Al_{0.55}$(Ge) structures with a degenerated p^+ layer.

I-V characteristics of the forward and reverse currents were measured in air with various concentrations of ammonia vapors. The current kinetics at the change of the ambient atmosphere was observed.

Fig.1 represents *I—V* characteristics of the forward current in a p-n structure in air (1) and in air with ammonia vapors of various partial pressures. The forward current increases with enhanced NH_3 concentration. At an ammonia pressure P>1000Pa a pronounced peak in the *I-V* curve is observed witch can be ascribed to electron tunneling between the c—band in the surface conducting channel and the v— band in the degenerated p^+ region. It means also that electrons in the channel are degenerated.

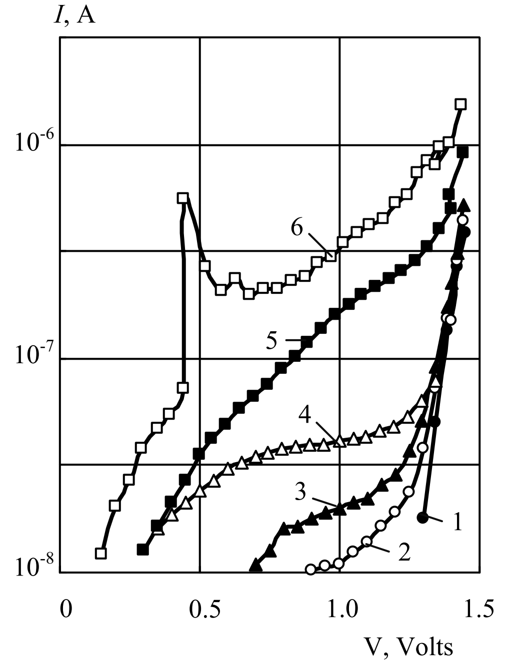

Fig. 1. *I—V* characteristics of the forward current in a p-n structure in air (1) and in ammonia vapors of a pressure: 2 — 50 Pa; 3 — 100 Pa; 4 — 200 Pa; 5 — 1000 Pa; 6 — 4000 Pa

Curves 1— 4 in Fig. 2 delineate the *I—V* curves of he forward and reverse currents in a p—n junction, placed in air with various ammonia partial pressures. It is seen that the reverse current is greater than forward one at the same ammonia pressure. It is characteristic for tunnel currents in tunnel- and inverted diodes.

3. DISCUSSION

Curves 1 and 2 in Fig. 2 were obtained at ammonia pressures of 20 Pa and 100 Pa, respectively. As seen from the *I–V* curves sections, corresponding to $V>0$, the tunnel forward current under these pressures is small. And the reverse currents are remarkably higher than forward ones. It is characteristic of inverted diodes and argues that tunneling of electrons at reverse biases occurs from the degenerated p$^+$ region.

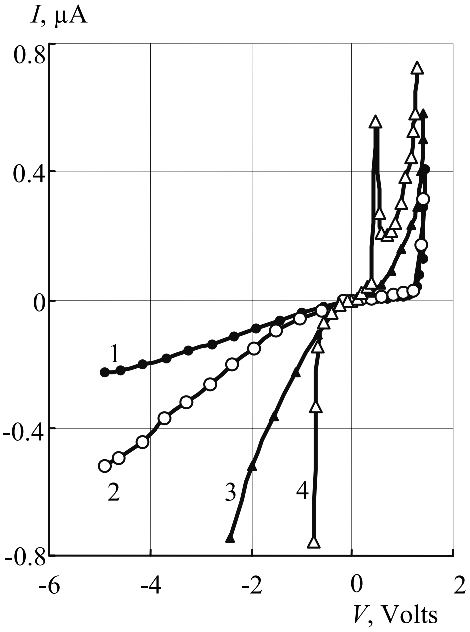

Fig. 2. *I–V* characteristics of a p-n structure in ammonia vapors of a pressure: 1 — 20 Pa; 2 — 100 Pa; 3 — 1000 Pa; 4 — 4000 Pa

Fig. 3 shows a simplified band diagram of the p-n junction with degenerated p$^+$ region. The Fermi level *F* is located in the v-band in p$^+$ region. The occupied states area is dashed. However the Fermi level lies by ΔE below c-band in n-region. In our case n-region corresponds to the conducting surface channel. Depending on the ammonia partial pressure, ΔE change can be estimated from the expression

$$n_s = N_c \exp(-\Delta E / kT)\,, \tag{1}$$

where n_s is the electrons concentration in the channel at the surface; N_c is the effective density of states in c-band; *k* is the Boltzmann constant; *T* is temperature. It is evident from Fig. 3, that the strong rise of the current with reverse bias voltage V_r must begin at

$$V_r = V_0 = \Delta E / q\,, \tag{2}$$

where *q* is the electron charge. Therefore the cutoff reverse bias voltage V_0 must logarithmic depend on the electrons concentration in the conducting channel, formed by the electric field of ammonia ions:

$$V_0 = kT / q \ln(N_c / n_s)\,. \tag{3}$$

Fig. 4 represents low-bias sections of *I–V* characteristics of the reverse current in a p-n structure, situated in ammonia vapors of various partial pressures. The cutoff voltage was estimated as the intersection of linearly extrapolated *I-V* curve with the abscise.

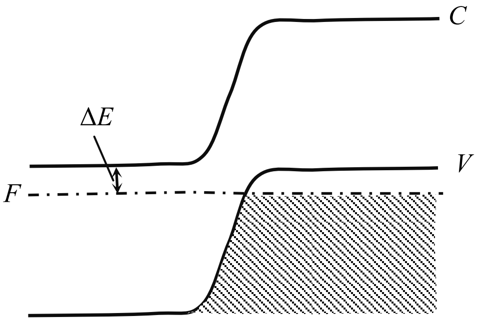

Fig. 3. Band diagram of an inverted diode at thermal equilibrium

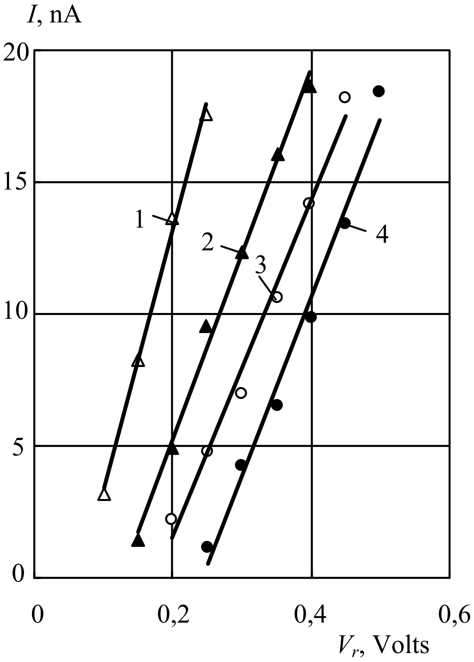

Fig. 4. Low-bias sections of *I–V* characteristics of the reverse current in a p-n structure in ammonia vapors of a pressure: 1 — 20 Pa; 2 — 50 Pa; 3 — 100 Pa; 4 — 4000 Pa

The dependence of the cutoff voltage on the ammonia partial pressure *P* is shown in Fig. 5. This dependence is logarithmic, however, the proportionality coefficient is $n_p kT / q$ with n_p=1.4 — 1.5 instead kT / q.

The discrepancy between the model prediction and the experimental data can be ascribed to a variety of factors. The most important of them are: a) dependence of the effective channel width on the surface electrons concentration n_s; b) non-linearity of the dependence $n_s(P)$, caused by deep traps in the channel.

A strong influence of trapping processes on the surface current in studied p-n structures is evident from a comparison between the rise- and decay curves of the surface current after let in- and off ammonia vapor in the container with the p-n structure.

Fig. 6 illustrates the kinetic of the surface current in a p-n structure after let in and removal of ammonia vapor from the container with the sample. The rise curve is exponential, i. e.

$$I(t) = I_{st}[1 - \exp(-t / \tau_r)]\,, \tag{4}$$

where I_{st} is the stationary value of *I*; the rise time τ_r=19.5 s. The decay curve is not exponential, with the 90% decay time τ_{90}=4s. This time is comparable with the time of changing the atmosphere in the container. Therefore the true value of the surface current decay time τ_d<4s.

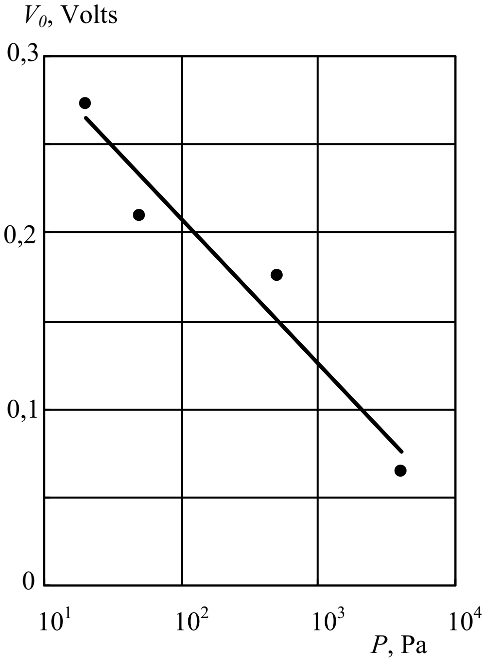

Fig. 5. Cutoff voltage of the reverse current in a p-n structure as a function of the ammonia vapor pressure

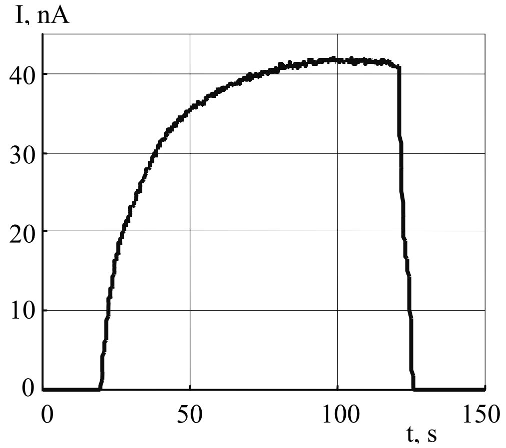

Fig. 6. Reverse current kinetics at let in- and out of ammonia vapor with a partial pressure of 100 Pa

In the simplest case, the adsorption–desorption process can be described by the equality

$$\frac{dN_s^m}{dt} = \alpha F_m - N_s^m / \tau_{des}\,, \qquad (5)$$

where N_s^m is the surface density of adsorbed molecules (ions); F_m is the density of the molecules incoming flow at the surface; α is the probability of adsorption of a molecule, dropping on the surface; τ_{des} – the desorption time of a molecule. For F_m and the vapor partial pressure P a relation can be written

$$P / F_m = 2mv\,, \qquad (6)$$

where m is the molecular mass; v is the thermal velocity of molecules. For ammonia molecules at room temperature and P= 100Pa, $F_s \approx 2.2 \cdot 10^{20}$ sm^{-2}s^{-1}.

The estimations show that, in non-degenerated case, the surface density of free electrons in conducting channel is negligible comparing to the surface states density which in GaAs is $N_s \sim 3 \cdot 10^{12}$ cm^{-2}.

In the stationary case, from (5) we obtain for estimation of τ_{des}

$$\tau_{des} = N_s^m / (\alpha F_m)\,. \qquad (7)$$

Putting $N_s^m \approx N_s$ and $\tau_{des} \approx$ 1s, we obtain for the probability of adsorption of a molecule $\alpha \sim 1.4 \cdot 10^{-8}$, which corresponds to a potential barrier for the molecule adsorption $\Delta E_m \approx 0.48$eV.

It is evident from Fig. 6 that

$$\tau_r \gg \tau_d\,. \qquad (8)$$

This strong inequality suggests that during the conducting cannel forming the electron traps of high concentration must be filled up. It agrees with results [11], that a decrease in surface states density enhances the gas sensitivity of p-n junctions on GaAs.

4. CONCLUSIONS

Ammonia molecules adsorption, under sufficiently high NH_3 partial pressure, forms in p-AlGaAs a surface conducting channel with degenerated electrons. I–V curve of the p-n junction with such channel, having a pronounced peak, is characteristic of a tunnel diode.

P-n junctions with degenerated p^+ region have higher gas sensitivity at reverse bias than at forward bias. This effect is due to tunnel injection of electrons into the channel from the degenerated p^+ region at a reverse bias.

The threshold ammonia vapors partial pressure of 5 Pa for GaAs–AlGaAs p-n junctions is caused by filling up the surface states at the middle of band gap.

The rise time of the surface current in an ammonia vapor atmosphere of ~20s is due to filling up deep electron traps.

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Abstract

The influence of ammonia vapors on *I-V* characteristics of forward and reverse currents and kinetics of surface currents in GaAs-AlGaAs p-n junctions with degenerated p^+ region was studied. It is shown that ammonia molecules adsorption, under sufficiently high NH_3 partial pressure, forms in p-AlGaAs a surface conducting channel with degenerated electrons. P-n junctions with degenerated p^+ region have higher gas sensitivity at reverse bias than at forward bias. This effect is explained by tunnel injection of electrons into the conducting channel from the degenerated p^+ region at a reverse bias. The rise time of the surface current in an ammonia vapor atmosphere of ~20 s is due to filling up deep electron traps.

Key words: tunnel surfeace current, adsorbption, junctions.

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ТУННЕЛЬНЫЙ ПОВЕРХНОСТНЫЙ ТОК В P-N ПЕРЕХОДАХ НА ОСНОВЕ GaAs–AlGaAs, ОБУСЛОВЛЕННЫЙ АДСОРБЦИЕЙ МОЛЕКУЛ АММИАКА

Резюме

Исследовано влияние паров аммиака на ВАХ прямого и обратного токов и на кинетику поверхностных токов в p-n переходах на основе GaAs-AlGaAs с вырожденной p^+ областью. Показано, что адсорбция молекул аммиака при достаточно высоком парциальном давлении NH_3 создает в p-AlGaAs поверхностный проводящий канал с вырожденными электронами. P-n переходы с вырожденной p^+ областью имеют более высокую газовую чувствительность при обратном смещении, чем при прямом смещении. Этот эффект объясняется туннельной инжекцией электронов в проводящий канал из вырожденной p^+ области при обратном смещении. Время нарастания поверхностного тока ~20 с в парах аммиака связано с заполнением глубоких электронных ловушек.

Ключевые слова: туннельный поверхностный ток, адсорбция, переход.

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ТУНЕЛЬНИЙ ПОВЕРХНЕВИЙ СТРУМ В P-N ПЕРЕХОДАХ НА ОСНОВІ GaAs–AlGaAs, ОБУМОВЛЕНИЙ АДСОРБЦІЄЮ МОЛЕКУЛ АМІАКУ

Резюме

Досліджено вплив парів аміаку на ВАХ прямого і зворотного струмів та на кінетику поверхневих струмів у p-n переходах на основі GaAs-AlGaAs з виродженою p^+ областю. Показано, що адсорбція молекул аміаку при достатньо високому парціальному тиску NH_3 створює в p-AlGaAs поверхневий провідний канал з виродженими електронами. P-n переходи з виродженою p^+ областю мають вищу газову чутливість при зворотному зміщенні, ніж при прямому зміщенні. Цей ефект пояснюється тунельною інжекцією електронів в провідний канал із виродженої p^+ області при зворотному зміщенні. Час наростання поверхневого струму ~20 с в парах аміаку пов'язаний із заповненням глибоких електронних пасток.

Ключові слова: тунельний поверхневий струм, адсорбція, перехід.