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TUNNEL SURFACE CURRENT IN GaAs P-N JUNCTIONS INDUCED BY AMMONIA MOLECULES ADSORPTION

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The effect of a treatment in concentrated wet ammonia vapors on I-V characteristics of GaAs p-n junctions, measured in air and in ammonia vapors, was studied. Such a treatment strongly enhances the sensitivity of the surface current to the water- and ammonia vapors. In ammonia vapors of high enough partial pressure, a maximum in the forward branch of I-V characteristic appeared. The treated p-n junctions have higher gas sensitivity at reverse bias than at forward bias. This suggests that ammonia molecules adsorption, under sufficiently high NH3 partial pressure, forms in the p-n junction a surface conducting channel with degenerated electrons. And the observed maximum in the I-V characteristic is explained by tunnel injection of electrons from the conducting channel to the degenerated p+ region.

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 mostly interest for gas sensors on p-n junction are Si and GaAs. The Si p-n junctions can be combined in a transistor, which has much higher gas sensitivity than a single junction [11]. They can be easy integrated into microelectronic circuits. And GaAs p-n junctions can have very high gas sensitivity [12].

Some tunnel effects on *I-V* characteristics of the surface current, due to ammonia molecules adsorption, were observed on AlGaAs-GaAs p-n junctions under high, of 4 kPa ammonia partial pressure [13]. 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. And the treated GaAs p-n junctions have a threshold ammonia vapors partial pressure of 0,1 Pa [12]. Therefore the tunnel effects must be observed on these junctions under lower NH_3 pressures.

The aim of this work is a study of the influence of ammonia vapors on the forward and reverse currents in a GaAs p-n structures after a treatment in wet ammonia vapors of high partial pressure.

2. EXPERIMENT

The measurements were carried out on GaAs p-n structures, described in the previous paper [12]. The junctions were treated by durable exposure in wet ammonia vapors under an NH_3 partial pressure of 12 kPa. *I-V* characteristics of the forward and reverse currents were measured in air with various concentrations of ammonia vapors.

Fig.1 represents *I–V* characteristics a p-n structure, measured in air and in air with wet ammonia vapors of various partial pressures. The forward and reverse currents increased with enhanced NH_3 concentration. At an ammonia pressure of P=100Pa a pronounced peak in the *I-V* curve was 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 at the contact. 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

The experimental results can be explained with the model, depicted in fig. 2. Ionized ammonia molecules 2 are located on the natural oxide surface. Their electric field bend the depletion layer 3 and forms a n- conducting channel 4. The forward current consists of two components. Arrow *a* corresponds to the through component I_t of the current in the channel. And arrow *b* represents the current component I_i due to electron injection from the channel into the p^+ layer at the contact. The *I-V* curves, measured under ammonia pressures P<100 Pa, are monotonous and correspond to the case of

$$I_t > I_i. \qquad (1)$$

At $P \geq 100$ Pa a clear maximum in the *I-V* curve apiers. And, at low enough voltages, the forward and reverse currents are equal. This is characteristic for tunnel current in p-n junction.

It is remarkable, that the current in the minimum of the *I-V* curve, measured at P=100 Pa, is lower than currents, meaeured at the same voltage under P= 50 Pa and P=20 Pa. It can be explained as a result of the quantization of electron energy in the channel [14]. There is a triangular potential well for the electrons in the channel. For the electron energy levels in this well one can write [14]

$$E_n = \left[\frac{3}{2}\pi\left(n-\frac{1}{4}\right)\right]^{2/3}\left(\frac{e^2F^2\hbar^2}{2m^*}\right)^{1/3}, \qquad (2)$$

where F is the slope of the wall; m^* is the electron effective mass; n=1, 2, ... Electrons in the cannel are located on the lowest level of the triangular well and, at corresponding voltages, resonantly tunnel to the empty states in the p^+ layer. And the lateral mobility of the electrons on this level is lower than without quantization. Therefore the current in the minimum in the *I-V* curve at P=100 Pa is lower than current, measured at P=20 Pa.

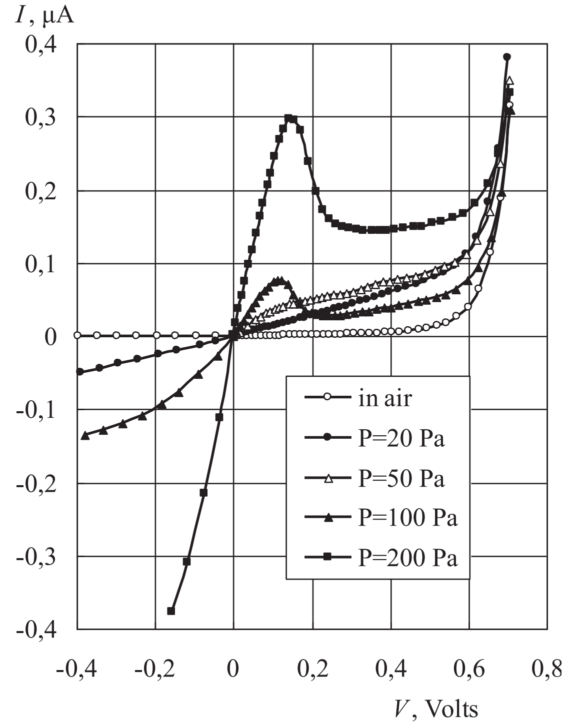

Fig. 1. *I–V* characteristics of a p-n structure in ammonia vapors of various pressureѕ *P*.

4. CONCLUSIONS

Ammonia molecules adsorption, under sufficiently high NH_3 partial pressure, forms in p-n GaAs 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. The electron energy in the channel is quantized.

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.

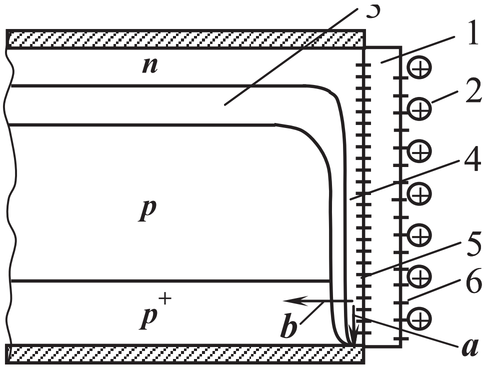

Fig 2. Schematic of a *p-n* structure, placed in a donor gas: 1 – oxide layer; 2 – ions; 3 – depletion layer; 4 – conducting channel; 5 – surface (fast) centers; 6 – states on the oxide surface (slow centers). Arrows: *a* – direction of the electron movement along the channel; b – tunneling from the channel into the p^+ region.

The threshold ammonia vapors partial pressure of 0,1 Pa for GaAs junctions is caused by filling up the surface states at the middle of band gap during the treatment.

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Abstract

The effect of a treatment in concentrated wet ammonia vapors on *I-V* characteristics of GaAs p-n junctions, measured in air and in ammonia vapors, was studied. Such a treatment strongly enhances the sensitivity of the surface current to the water- and ammonia vapors. In ammonia vapors of high enough partial pressure, a maximum in the forward branch of *I-V* characteristic appeared. The treated p-n junctions have higher gas sensitivity at reverse bias than at forward bias. This suggests that ammonia molecules adsorption, under sufficiently high NH_3 partial pressure, forms in the p-n junction a surface conducting channel with degenerated electrons. And the observed maximum in the *I-V* characteristic is explained by tunnel injection of electrons from the conducting channel to the degenerated p^+ region.

Key words: p-n junction, gas sensor, surface current; conducting channel, tunneling.

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ТУНЕЛЬНИЙ ПОВЕРХНЕВИЙ СТРУМ В P-N ПЕРЕХОДАХ НА ОСНОВІ GaAs, ІНДУКОВАНИЙ АДСОРБЦІЄЮ МОЛЕКУЛ АМІАКУ

Резюме

Досліджено вплив обробки у концентрованих вологих парах аміаку на ВАХ p-n переходів на основі GaAs, виміряних у повітрі та в парах аміаку. Така обробка різко підвищує чутливість поверхневого струму до парів води та аміаку. В парах аміаку достатньо високого парціального тиску з'являється максимум на ВАХ. Оброблені p-n переходи мають більш високу газову чутливість при зворотному зміщенні, ніж при прямому зміщенні. Це свідчить, що адсорбція молекул аміаку , при достатньо високих значеннях парціального тиску NH_3, створює в p-n переході поверхневий провідний канал з виродженими електронами. І наявність спостереженого максимуму на ВАХ пояснюється тунельною інжекцією електронів із провідного каналу у вироджену p^+ область.

Ключові слова: p-n перехід, газовий сенсор, поверхневий струм, провідний канал, тунелювання.

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ТУННЕЛЬНЫЙ ПОВЕРХНОСТНЫЙ ТОК В P-N ПЕРЕХОДАХ НА ОСНОВЕ GaAs, ИНДУЦИРОВАННЫЙ АДСОРБЦИЕЙ МОЛЕКУЛ АММИАКА

Резюме

Исследовано влияние обработки в концентрированных влажных парах аммиака на ВАХ p-n переходов на основе GaAs, измеренных в воздухе и в парах аммиака. Такая обработка резко повышает чувствительность поверхностного тока к парам воды и аммиака. В парах аммиака с достаточно высоким парциальным давлением появляется максимум на ВАХ. Обработанные p-n переходы имеют более высокую газовую чувствительность при обратном смещении, чем при прямом смещении. Это свидетельствует, что адсорбция молекул аммиака , при достаточно высоких значениях парциального давления NH_3, создает в p-n переходе поверхностный проводящий канал с вырожденными электронами. И появление максимума на ВАХ объясняется туннельной инжекцией электронов из проводящего канала в вырожденную p^+ область.

Ключевые слова: p-n переход, газовый сенсор, поверхностный ток, проводящий канал, туннелирование.