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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.

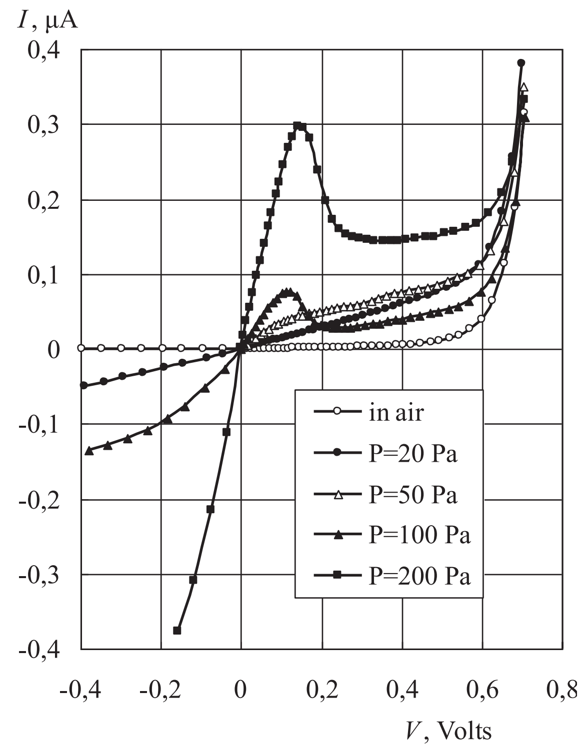

Fig. 1. *I–V* characteristics of a p-n structure in ammonia vapors of various pressures *P*.

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.

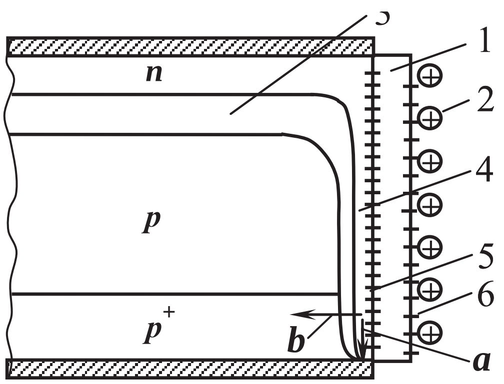

Fig 2. Schematic of a *p-n* structure, placed in a donor gas: 1 – oxide layer; 2 – ions; 3 – depletion layer; 4 – conducting channel; 5 – surface (fast) centers; 6 – states on the oxide surface (slow centers). Arrows: *a* – direction of the electron movement along the channel; b – tunneling from the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

REFERENCES

1. Ptashchenko O. O., Artemenko O. S., Ptashchenko F. O. Vliyanie gazovoi sredy na poverhnostnyi tok v p-n geterostrukturakh na osnove GaAs-AlGaAs // Fisika i khimiya tverdogo tila. – 2001. – V. 2, № 3. – P. 481 – 485.
2. Ptashchenko O. O., Artemenko O. S., Ptashchenko F. O. Vplyv pariv amiaku na poverkhnevyi strum v p-n perekhodakh na osnovi napivprovidnykiv A^3B^5 // Journal of physical studies. – 2003. – V. 7, №4. – P. 419 – 425.
3. Bugayova M. E., Koval V. M., Lazarenko B. I. et al. Gazovi sensory na osnovi oksydu tsynku (oglyad) // Sensorna electronika i mikrosystemni tehnologii. – 2005. - №3. – P. 34 – 42.
4. Russhikh D.V., Rembeza S. I., Shironkin S. Yu. et al. Vysokochuvstvitel'nyi poluprovodnikovyi datchik gazovych sred // Sensors & Systems. 2008. – № 8. – P. 14 – 16.
5. Bomk O. I., Il'chenko L. G., Il'chenko V. V. et al. Pro pryrodu chutlyvosti do amiaku gazovykh sensoriv na osnovi struktur nadtonka tytanova plivka – kremniy // Ukr. fiz. journ. – 1999. – V. 44, №9. – P. 759 – 763.
6. Baluba V. I., Gritsyk V. Y., Davydova T. A. et al. Sensory ammiaka na osnove diodov Pd-n-Si // Fizika i tekhnika poluprovodnikov. – 2005. – V. 39, № 2. P. 285 – 288.
7. Ptashchenko O. O., Artemenko O. S., Dmytruk M. L. et al. Effect of ammonia vapors on the surface morphology and surface current in p-n junctions on GaP. // Photoelectronics. – 2005. – No. 14. – P. 97 – 100.
8. Ptashchenko F. O. Effect of ammonia vapors on surface currents in InGaN p-n junctions. // Photoelectronics. – 2007. – No. 17. – P. 113 – 116.
9. Ptashchenko F. O. Vplyv pariv amiaku na poverkhnevyi strum u kremniyevykh p-n perekhodakh // Ptashchenko F. O. Visnyk ONU, ser. Fizyka.– 2006. – V. 11, №. 7. – P. 116 – 119.
10. Ptashchenko O. O., Ptashchenko F. O., Yemets O. V. Effect of ammonia vapors on the surface current in silicon p-n junctions. // Photoelectronics. – 2006. – No. 16. – P. 89 – 93.
11. Ptashchenko F. O. Characteristics of silicon transistors as gas sensors. // Photoelectronics. – 2010. – No. 19. – P. 18 – 21.
12. Ptashchenko O. O., Ptashchenko F. O., Gilmutdinova V. R. Vplyv poverkhnevogo leguvannya na charakterystyky p-n perekhodiv na osnovi GaAs yak gazovykh sensoriv // Sensorna elektronika i mikrosystemni tekhnologiyi– 2013

– V. 10, № 1. – P. 114 – 123.
13. Ptashchenko O. O., Ptashchenko F. O., Shugarova V. V. Tunnel surface current in GaAs–AlGaAs p-n junctions, due to ammonia molecules adsorption // Photoelectronics. – 2009. – No. 18. – P. 95 – 98.
14. Martinez-Duart J.M., Martin-Palma R.J., Agullo-Rueda F. Nanotekhnologiya dlya mikro- i optoelektroniki. M.: Tekhnosfera, 2007. – 368 p.

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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.