PACS: 73.20.Hb, 73.25.+I; UDC 621.315.592

O. O. Ptashchenko[1], F. O. Ptashchenko[2], V, R.Gilmutdinova[1]

EFFECT OF DEEP CENTERS ON THE TIME-RESOLVED SURFACE CURRENT INDUCED BY AMMONIA MOLECULES ADSORPTION IN GaAs P-N JUNCTIONS

[1]I. I. Mechnikov National University of Odessa, Dvoryanska St., 2, Odessa, 65026, Ukraine
[2]Odessa National Maritime Academy, Odessa, Didrikhsona St., 8, Odessa, 65029, Ukraine

The time-dependence of the surface current in GaAs p-n structures after placing in concentrated wet ammonia vapors was studied. It is sown that the slope of measured current-time curves is non-monotonous. This effect is explained with taking into account presence of deep surface levels, which are filled, when the quasi-Fermi level is moving to the conduction band. An analysis of time-resolved measurements of surface current in GaAs p-n structures in wet ammonia vapors enabled to estimate depths of some surface levels. The depths of the main revealed surface levels are 0,206 eV, 0,185 eV, and 0,176 eV from c-band. In the interval of depths 0,176 eV – 0,185 eV surface levels are continuously distributed with practically constant density.

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. The lowest size of these sensors in a classical variant is limited by the space-charge layer thickness and is of the order of 100 nm.

The mostly interesting for gas sensors on p-n junction are Si and GaAs. The gas sensitivity of GaAs p-n junctions is remarkably higher than that of Si sensors, due to higher electron mobility [1, 2, 7, 8].

GaAs p-n junctions as ammonia vapors sensors have a non-monotonous dependence of the sensitivity to the NH_3 partial pressure due to deep surface centers. This dependence was used for an estimation of corresponding levels depth [9].

The aim of this work is to study the influence of deep surface centers on the time-dependence of the surface current in GaAs p-n structures in ammonia vapors.

2. EXPERIMENT

The measurements were carried out on GaAs p-n structures, described in the previous paper [9]. 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. The time-dependence of the surface current and the open-circuit voltage was analyzed in ammonia vapors.

Fig.1 represents the time-dependence of the direct current in a p-n structure at V=0,3 Volts after placing in wet ammonia vapors with an NH_3 partial pressure of 12 kPa.

It is seen that the slope of $I(t)$ curve non-monotonously changes with the time. The characteristic changes in the slope occur practically at the same currents in different samples.

The current-dependence of $I(t)$ derivative, obtained from the curve in fig. 1, is presented in fig. 2. Curve $dI/dt(I)$ has distinct minimums at current values of 1,086 μA, 2,386 μA, and 3,353 μA. The values for different samples differ mostly by

5%. The presence of these minimums can be explained by filling of deep surface centers in p-region due to electrical field of adsorbed ammonia molecules, which are donors in GaAs.

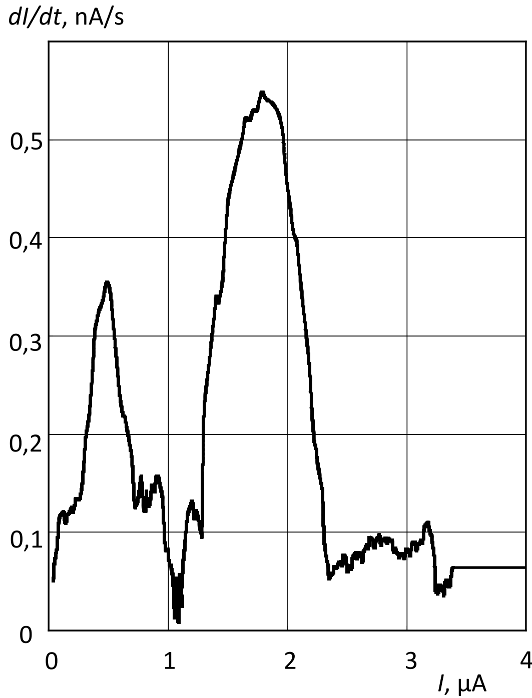

Fig. 1. Current-dependence of dI/dt, obtained from the curve I(t) in fig. 1.

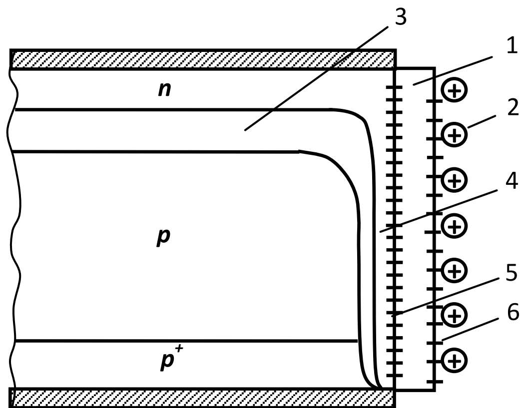

Fig 2. Schematic of a p-n structure, placed in a donor gas: 1 – oxide layer; 2 – ions; 3 – depletion layer; 4 – conducting channel; 5 – surface (fast) centers; 6 – states on the oxide surface (slow centers).

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. After adsorption and ionization of donor molecules the slow centers are filling and after that electrons are captured by fast centers. And only after filling of surface centers the surface depletion layer is widened and the n-channel is forming. During this process the Fermi quasi-level for electrons is moving to the conduction band. In a quasi-stationary approach the electrons surface concentration is defined as

$$n_S = N_c \exp\left[-(E_c - F_n)/(kT)\right], \qquad (1)$$

where N_c is the effective states density in C-band; $E_c - F_n$ is the quasi-Fermi level depth; kT is the Boltzmann factor. And the number of electrons, captured on the surface centers can be calculated as

$$N_S^- = N_S\left\{\exp\left[(E_S - F_n)/(kT)\right] + 1\right\}^{-1}, \qquad (2)$$

where N_s is the density of surface traps; E_s is the corresponding energy level. From (1) and (2) follows that a minimum of dn/dN_S^- corresponds to the equality

$$F_n = E_S. \qquad (3)$$

If , in a limited time, $dN_S^-/dt \approx const$, equality (3) corresponds to minimum dn_s/dt, that corresponds to a minimum dI/dt. Therefore the minimums of curve $dI/dt(I)$ in fig. 2 correspond to crossing the related deep surface levels by the quasi-Fermi level. The minimums of curve $dI/dt(I)$ at current values of 1,086 μA, 2,386 μA, and 3,353 μA yield estimations of surface levels depths 0,206 eV, 0,185 eV and 0,176 eV, respectively.

In the current interval 2,3 – 3,3 μA, that corresponds to

$$0{,}206 \text{ eV} > E_c - F_n > 0{,}176 \text{ eV}, \qquad (4)$$

curve $I(t)$ has a linear section, that corresponds to constant surface states density in the depths interval

$$0{,}206\ \text{eV} > E_c - E_S > 0{,}176\ \text{eV} \cdot \quad (5)$$

The obtained surface levels depths are in agreement with results of previous work [9], where the corresponding estimations were made by an analysis of the dependence of gas sensitivity of GaAs p-n junctions on the ammonia partial pressure.

The surface level with a depth of 0,18 eV was observed with the method of deep levels transient spectroscopy in the GaAs natural oxide layer [10]. This level is one of the main deep levels in the natural oxide layer on GaAs crystals and its concentration increases at a treatment in oxygen plasma [10]. The electrons capture by this level reduces the gas sensitivity of GsAs p-n junctions [9].

4. CONCLUSIONS

The time-dependence of the surface current in GaAs p-n structures after placing in concentrated wet ammonia vapors has a non-monotonous slope. This effect is explained with taking into account presence of deep surface levels, which are filled, when the quasi-Fermi level is moving to the conduction band.

Time-resolved measurements of surface current in GaAs p-n structures in wet ammonia vapors enable to estimate depths of some surface levels. These estimates are in a good agreement with the results of previous works, obtained with different methods.

The surface level in p-GaAs of a depth of 0,18 eV, which is responsible for the non-monotonous slope of $I(t)$ dependence, corresponds to a point defect in the natural oxide, that includes an oxygen atom.

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 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.
8. 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.
9. 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.
10. Fedorov Yu.Yu., Kharlamova T.S., Chikun V.V. Zavisimost' koncentracii glubokikh urovnei ot sposoba okisleniya poverkhnosti arsenida galliya // Elektronnaya tekhnika. Ser. SVCH-tekhnika. – 1993, No 2 (456). – P. 33-35.

This article has been received within 2014.

O. O. Ptashchenko, F. O. Ptashchenko, V, R.Gilmutdinova

EFFECT OF DEEP CENTERS ON THE TIME-RESOLVED SURFACE CURRENT INDUCED BY AMMONIA MOLECULES ADSORPTION IN GaAs P-N JUNCTIONS

Summary

The time-dependence of the surface current in GaAs p-n structures after placing in concentrated wet ammonia vapors was studied. It is sown that the slope of measured current-time curves is non-monotonous. This effect is explained with taking into account presence of deep surface levels, which are filled, when the quasi-Fermi level is moving to the conduction band. An analysis of time-resolved measurements of surface current in GaAs p-n structures in wet ammonia vapors enabled to estimate depths of some surface levels. The depths of the main revealed surface levels are 0,206 eV, 0,185 eV, and 0,176 eV from c-band. In the interval of depths 0,176 eV – 0,185 eV surface levels are continuously distributed with practically constant density.

Key words: surface current, p – n structure, deep centers.

О. О. Птащенко, Ф. О. Птащенк , В. Р. Гільмутдінова

ВПЛИВ ГЛИБОКИХ ЦЕНТРІВ НА КІНЕТИКУ ПОВЕРХНЕВОГО СТРУМУ, ІНДУКОВАНОГО АДСОРБЦІЄЮ МОЛЕКУЛ АМІАКУ В P-N ПЕРЕХОДАХ НА ОСНОВІ GaAs

Резюме

Досліджено кінетику поверхневого струму в p-n структурах на основі GaAs після їх поміщення у концентровані вологі пари аміаку. Показано, що нахил виміряних часових залежностей струму є немонотонний. Дане явище пояснено за врахуванням наявності глибоких поверхневих рівнів, які заповнюються, коли квазі-рівень Фермі рухається в сторону зони провідності. Аналіз кінетики поверхневого струму в p-n структурах на основі GaAs у вологих парах аміаку дав можливість оцінити глибини деяких поверхневих рівнів. Глибини основних виявлених поверхневих рівнів складають 0,206 еВ, 0,185 еВ і 0,176 еВ від с-зони. В інтервалі глибин 0,185 еВ – 0,176 еВ виявлено додаткові поверхневі рівні, розподілені неперервно з практично постійною щільністю.

Ключові слова: глибокі цунтри, p –n переходи, поверхневы центри.

А. А. Птащенко, Ф. А. Птащенко, В. Р. Гильмутдинова

ВЛИЯНИЕ ГЛУБОКИХ ЦЕНТРОВ НА КИНЕТИКУ ПОВЕРХНОСТНОГО ТОКА, ИНДУЦИРОВАННОГО АДСОРБЦИЕЙ МОЛЕКУЛ АММИАКА В P-N ПЕРЕХОДАХ НА ОСНОВЕ GaAs

Резюме

Исследована кинетика поверхностного тока в p-n структурах на основе GaAs после их помещения в концентрированные влажные пары аммиака. Показано, что наклон измеренных временных зависимостей тока немонотонный. Данное явление объяснено с учетом наличия глубоких поверхностных уровней, которые заполняются, когда квази-уровень Ферми движется в сторону зоны проводимости. Анализ кинетики поверхностного тока в p-n структурах на основе GaAs во влажных парах аммиака позволил оценить глубины некоторых поверхностных уровней. Глубины основных обнаруженных поверхностных уровней составдяют 0,206 эВ, 0,185 эВ и 0,176 эВ от с-зоны. В интервале глубин 0,185 эВ – 0,176 эВ обнаружены дополнительные поверхностные уровни, распределенные непрерывно с практически постоянной плотностью.

Ключевые слова глубокие центры, p – n –гетеропереход, поверхностные центры.