JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. **14** No 1, 01027(5pp) (2022)

ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том **14** № 1, 01027(5cc) (2022)

Advanced Micron Sized Gunn Diode Based on Graded-Gap GaPAs – GaInAs

Ihor Storozhenko[1,*], Sergey Sanin[2]

[1] *V.N. Karazin Kharkiv National University, 4, Svobody Sq., 61077 Kharkiv, Ukraine*
[2] *O.Ya. Usikov Institute for Radiophysics and Electronics NASU, 12, Ac. Proskura St., 61085 Kharkiv, Ukraine*

(Received 27 October 2021; revised manuscript received 22 February 2022; published online 28 February 2022)

The paper studies the characteristics of Gunn diodes based on graded-gap GaInPAs semiconductor. Gunn diodes are active elements for generating electromagnetic waves in the millimeter and submillimeter ranges. Nowadays, providing modern equipment with active sources of the subterahertz range is an urgent task. It can be implemented by increasing Gunn diodes power and cutoff frequencies of generation. One of the means to increase the cutoff frequency of Gunn diodes is the use of graded-gap semiconductors. The dependence on the coordinate of many parameters of a graded-gap semiconductor affects the processes that occur in the Gunn diode based on the graded-gap semiconductor. Therefore, it is very important to optimize the diode structure by both the doping level and varying the fraction parts of the graded-gap alloy. The paper presents the results of modeling the operation of Gunn diodes with an active zone length of 1 μm based on graded-gap GaPAs – GaInAs alloy at different lengths of the graded-gap layer, different fraction parts of In and P and different electron densities in the active zone. The power spectra of self-oscillations (in the absence of a resonator) of Gunn diodes are obtained, the analysis of physical processes is performed, the optimal lengths of the graded-gap semiconductor layer and optimal mole fractions of In and P are found to obtain the highest power and oscillation frequency. For diodes with an electron density in the active zone of 6×10^{16} cm^{-3}, $Ga_{0.67}P_{0.33}As$ – $Ga_{0.5}In_{0.5}As$ has the greatest oscillation power at the layer length of the graded-gap compound equal to 0.2 μm. This diode provides an RF power of 11.28 mW at 102.5 GHz for the fundamental harmonic and 49 μW (307.5 GHz) for the third harmonic.

Keywords: Gunn diode, Transferred electron device, Graded-gap semiconductor, Heterojunction, Subterahertz range, Millimeter wave, Oscillations, GaInPAs.

DOI: 10.21272/jnep.14(1).01027 PACS numbers: 85.30.Fg, 73.40.Kp, 73.40. – c

1. INTRODUCTION

Gunn diodes are increasingly becoming the optimal solid-state mm-wave active source which can be used in various applications of submillimeter waves [1, 2]. However, the Gunn diode has a number of physical processes that cut off the frequency of these devices from above. Various special cathodes and new materials are used to reduce the negative influence of ‘dead space’.

A diode with AlGaAs/GaAs heterojunction in combination with a thin undoped layer in front of the transit zone has become widespread [3, 4]. Such a contact acts as a ‘hot electron injector’, increases intervalley electron transfer and reduces the ‘dead space’. However, research of the diode operation with graded-gap AlGaAs alloy in the transit zone showed even better microwave characteristics than with AlGaAs/GaAs heterojunction [5, 6]. The dependence on the coordinate of many electrophysical parameters of a graded-gap semiconductor has a strong effect on the physical processes occurring in a graded-gap diode [6].

The results of the research [7] have shown that $n^+ - n - n^+$ Gunn diodes of 1 μm length based on graded-gap GaPAs – $Ga_{0.5}In_{0.5}As$ and GaInP – $Ga_{0.5}In_{0.5}As$ have the highest power and frequency of oscillations. However, optimization of the length and mole fractions of the graded-gap semiconductor layer at different concentrations of ionized impurities in the active zone remains an open question. In the paper, I present the results of studies on microwave oscillation in a diode based on graded-gap GaPAs – GaInAs alloy at different graded-gap layer length and different concentration of ionized impurities in the transit zone. The goal of my research is to optimize the structure of graded-gap diodes to obtain the maximum power and frequency of oscillations.

2. DIODE STRUCTURE AND SIMULATION MODEL

A diode with an $n^+ - n - n^+$ doping profile based on graded-gap $Ga_{1-x(z)}In_{x(z)}P_{y(z)}As_{1-y(z)}$ alloy was simulated with the following parameters: active zone length $l_a = 1.0$ μm, electron densities in it 4×10^{16}, 5×10^{16} and 6×10^{16} cm^{-3}, length of the cathode and $l_c = 0.4$ μm, electron density 3×10^{17} cm^{-3}. The mole fractions of In and P in $Ga_{1-x}In_xP_yAs_{1-y}$ were given by S-dependences as in [6, 7]. The graded-gap alloy layer was placed in such a way that the beginning of the change in the semiconductor composition corresponded to the cathode $n^+ - n$ contact. The length of the graded-gap layer was from 0.1 to 0.9 μm. The diode had a cross section of $S = 400$ μm^2. The crystal lattice temperature T_0 was considered to be constant and equal to 300 K.

The actual research was carried out by means of a three-level model of the intervalley electron transfer effect in graded-gap semiconductors based on the solution of the Boltzmann equation for the case of a displaced Maxwellian distribution of electrons [7-9]. This model represents a system of equations consisting of continuity equations, current density equations and energy balance equations for each of the three non-equivalent valleys of the semiconductor conduction band, as well as the Poisson equation [7].

---

[*] prof.igor.storozhenko@gmail.com

2077-6772/2022/14(1)01027(5)

3. RESULTS OF THE RESEARCH AND ITS ANALYSIS

3.1 Current Oscillations in a Graded-Gap Diode

Generation of continuous microwave oscillations does not occur in short (less than about 3 μm in length) Gunn diodes based on GaAs or GaInAs with $n^{+}-n$ cathode in the absence of a resonator. To make continuous microwave current oscillations occur in the diode, it is necessary to increase the electron density in the side valleys in the active zone near the cathode. It can be done using a layer of a graded-gap alloy, when the energy gap between the G-valley and side valleys in the $n^{+}-n$ cathode is smaller than in the active zone. For example, continuous current oscillations occur in a 2.5 μm diode based on graded-gap GaAs – GaInAs alloy [10]. These current oscillations exist due to the appearance and drift of electric field domains. The domains themselves in the GaAs – GaInAs layer of the graded-gap alloy occur due to the energy gap between the Γ-valley and side valleys, which increases towards the anode contact. Domains stop to form when the length of the active zone decreases. As shown in this study, continuous oscillations no longer arise in 1 μm GaAs – GaInAs diodes. For oscillations to occur, it is necessary to further reduce the energy gap between the Γ-valley and side valleys in the cathode. This can be realized, for example, using AlGaAs – GaInAs [6, 11] or GaPAs – GaAs [7] alloys.

Continuous oscillations occur in the GaPAs – $Ga_{0.5}In_{0.5}As$ diode, starting from the minimum level of the P mole fraction, which is 0.19. This value turned out to be the same for different electron densities in the transit zone (4×10^{16}, 5×10^{16} and 6×10^{16} cm^{-3} in this research and 9×10^{16} cm^{-3} in [7]) and different lengths of the graded-gap semiconductor layer.

The reader's attention should be drawn to the fact that the power and frequency of oscillations depend on the applied voltage. If the voltage applied to the diode is increased, then the oscillation frequency increases, and the average oscillation power has a maximum. Such dependences are of the same type for these diodes. For example, as seen in Fig 1, the $GaP_{0.38}As_{0.62}$ – $Ga_{0.47}In_{0.53}As$ diode, when the electron density in the active zone is 4×10^{16} cm^{-3}, has an RF power in the range from 0.7 to 3.2 V. The frequency range is from 79.6 to 124.9 GHz. The average peak power is 2.48 mW at 108 GHz when the applied voltage is 1.7 V.

3.2 Dependence of the Average Power and Oscillation Frequency on the Length of the Graded-Gap Layer

Fig. 2 shows the dependences of the average power of oscillations (solid lines) of the fundamental harmonic in the graded-gap $GaP_{y}As_{1-y}$ – $Ga_{0.5}In_{0.5}As$ diode on the graded-gap layer length when the mole fraction of P and applied voltage are optimal for different electron densities in the active zone. It can be seen from the figure that these dependences are of the same type for different electron densities. Current oscillations in such diodes occur if the graded-gap semiconductor length is greater than a certain minimum value. This minimum length increases with an increase in the electron concentration in the active zone and is approximately from 0.09 to 0.12 μm.

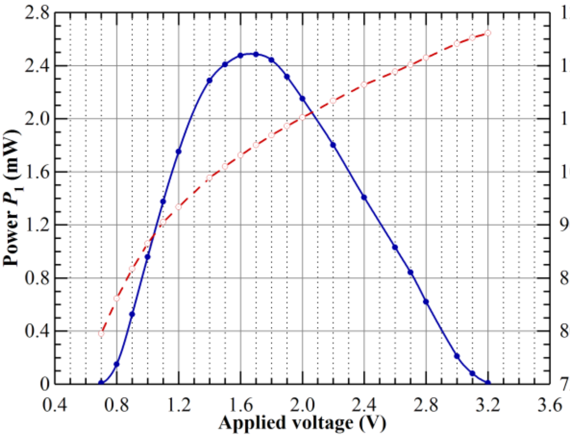

Fig. 1 – Dependences of the average power (solid lines) and frequency (dashed lines) of oscillations for the fundamental harmonic in the graded-gap $GaP_{0.38}As_{0.62}$ – $Ga_{0.47}In_{0.53}As$ diode on the applied voltage when the electron density in the transit zone is 4×10^{16} cm^{-3}

The curves of the dependence of the average power on the graded-gap layer length have two maxima. The first maximum of the power exists if the length of the graded-gap layer is from 0.2 to 0.24 μm and the second maximum exists when the length is from 0.8 to 0.9 μm, that is, approximately equal to the length of the transit zone. The optimal mole fraction of P increases as the length of the graded-gap layer increases.

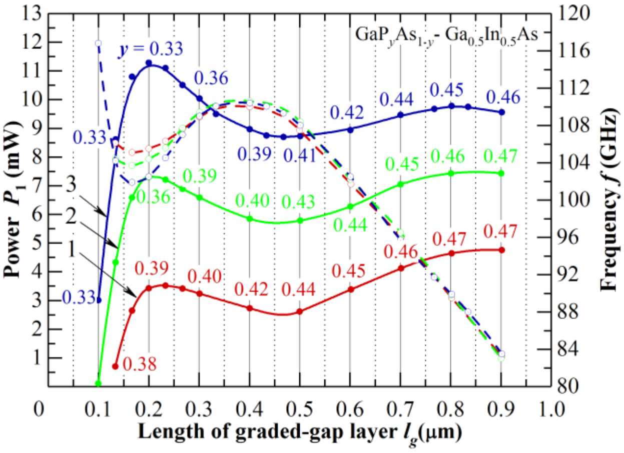

Fig. 2 – Dependences of the average power (solid lines) and frequency (dashed lines) of oscillations for the fundamental harmonic in the graded-gap $GaP_{y}As_{1-y}$ – $Ga_{0.5}In_{0.5}As$ diode on the graded-gap layer length, when the mole fraction of P and the applied voltage are optimal for the maximum RF power at different electron densities in the transit zone: $n = 4\times10^{16}$ cm^{-3} (1), $n = 5\times10^{16}$ cm^{-3} (2) and $n = 6\times10^{16}$ cm^{-3} (3). The numbers above the dots represent the optimum mole fraction of P in the alloy that is optimized for the maximum average oscillation power

Fig. 2 shows the dependences of the oscillation frequency (dashed lines) of the fundamental harmonic in the graded-gap $GaP_{y}As_{1-y}$ – $Ga_{0.5}In_{0.5}As$ diode on the graded-gap layer length when GaP fraction and applied voltage are optimal for different electron densities in the transit zone. If the length of the graded-gap layer is greater than 0.25 μm, then the oscillation frequency does not depend on the electron density in the transit zone. The oscillation frequency is maximum and is equal to approximately 110...111 GHz, if the length of the graded-gap layer is equal to 0.4 μμm.

The reasons for the two maxima in the dependence of the average oscillation power on the length of the graded-gap layer and the maximum in the dependence of the oscillation frequency on the length of the graded-gap layer remain unclear. In general, this is due to the presence of a large number of factors affecting the processes in the diode. Oscillations in the Gunn diode based on graded-gap semiconductors depend strongly on the distribution of mole fractions in ternary or quaternary semiconductor compounds along the diode. When the length of the graded-gap layer changes, the significance of these factors changes both in general and for each factor separately [10]. For example, the dependence of the electron affinity on the coordinate is more significant than the decreasing dependence of the energy gap between the Γ-valley and satellite valleys at a graded-gap layer length of less than 0.1...0.2 μm.

3.3 Optimal Fractional Composition of GaPAs

Let us consider the characteristics of the devices in more detail at the points of maximum power and frequency of oscillations in Fig. 2 on the example of a device whose electron density in the transit zone is 6×10^{16} cm^{-3}. The inset in Fig. 3 shows the dependence of the frequency and average power of oscillations for the fundamental harmonic on the mole fraction of P in GaPAs – $Ga_{0.5}In_{0.5}As$ if the graded-gap layer length is 0.2 μm and the applied voltage is optimal for RF power.

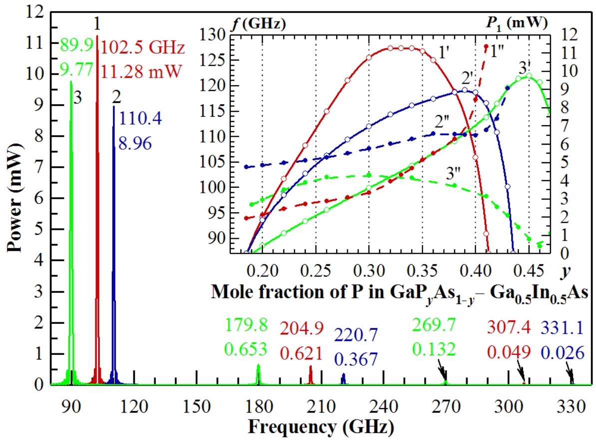

Fig. 3 – Power spectrum of oscillations in the diode based on graded-gap GaP_yAs_{1-y} – $Ga_{0.5}In_{0.5}As$ when the mole fraction of P is $y = 0.33$, the graded-gap layer length is $l_g = 0.2$ μm and the applied voltage is $U = 2.5$ V (1); $y = 0.39$, $l_g = 0.4$ μm and $U = 2.4$ V (2); $y = 0.45$, $l_g = 0.8$ μm and $U = 2.4$ V (3). The inset represents the dependence of the frequency (dashed lines) and average power (solid lines) of oscillations for the fundamental harmonic on the mole fraction of P in GaPAs – $Ga_{0.5}In_{0.5}As$ semiconductor when the graded-gap layer length is $l_g = 0.2$ μm (1' and 1"), 0.4 μm (2' and 2") and 0.8 μm (3' and 3") at the optimum applied voltage for maximum RF power

In such devices, oscillations occur if the mole fraction of P in the GaPAs cathode is in the range from 0.19 to 0.41. The RF power of the GaPAs – $Ga_{0.5}In_{0.5}As$ diode is maximum when P mole fraction is about 0.33 and the applied voltage is 2.5 V. The power spectrum of the $GaP_{0.33}As_{0.67}$ – $Ga_{0.5}In_{0.5}As$ diode is shown in Fig. 3. The fundamental harmonic power of such oscillations is 11.3 mW at a frequency of 102.5 GHz. The oscillation spectrum contains the second and third harmonics, which are well distinguishable. The power of the second harmonic is 621 μW and of the third harmonic is 49 μW. The DC power in such a diode is 1668.5 mW. The oscillation frequency in the GaPAs – $Ga_{0.5}In_{0.5}As$ diode increases with an increase in the mole fraction of P in the GaPAs cathode.

Let us consider a device with a length of the graded-gap layer of 0.4 μm. The peculiarity of the dependence of the average power and frequency of oscillations on the mole fraction of P in the GaPAs cathode remained the same as in the diode in which the graded-gap layer length is 0.2 μm. If the length of the graded-gap layer is 0.2...0.23 μm, then the device has high values of RF power and of oscillation frequency at the fundamental harmonic. The optimal mole fraction of P ranges from 0.33 to 0.39.

However, there are some changes. The range of mole fractions of P, in which continuous oscillations occur, increases from the side of large values and a section of mole fractions of P appears, at which the oscillation frequency decreases. The average power is maximum when the mole fraction of P in the GaPAs cathode is 0.39, that is, it increases as compared with the case when the length of the graded-gap layer is 0.2 μm. If the graded-gap layer length is increased even more, then the tendencies described above are more pronounced. The oscillation frequency is maximum when the mole fraction of P is 0.30 and is minimum when it is 0.46. If the mole fraction of P is 0.45, the oscillations have the highest RF power, but almost the lowest frequency. If the length of the graded-gap layer is greater than the length of the transit zone of the device, then continuous self-oscillations gradually cease as the gradients of all parameters of the graded-gap semiconductor decrease. So, the graded-gap diode has the maximum average oscillation power when the fractional composition of GaPAs is optimal. The optimal mole fraction of P in GaPAs increases if the length of the graded-gap layer increases.

3.4 Optimal Fractional Composition of GaInAs

Let us consider the processes in a graded-gap diode based on GaPAs – GaInAs from the point of view of the dependence on the fraction of In. Continuous current oscillations do not occur in a homogeneous GaInAs diode when the transit zone length is 1 μm for any mole fraction of In. But if the fraction of P in the cathode increases, the GaPAs – GaInAs diode has RF power. Fig. 4 shows the dependences of the average power of oscillations (solid lines) of the fundamental harmonic in the graded-gap GaP_yAs_{1-y} –$Ga_{1-x}In_xAs$ diode on the mole fraction of In when the mole fraction of P and the applied voltage are optimal for different electron densities in the transit zone. Current oscillations in the diode occur at any mole fraction of In. If the mole fraction of In is greater than 0.6, then the intervalley electron transfer effect is overlapped by impact ionization [12-14]. Impact ionization is considered a negative effect for transfer electron devices. However, research [14] shows that if impact ionization occurs only in the anode contact, then the oscillation frequency increases. A diode with an active zone length of 0.64 µm based on the graded-gap GaAs – $Ga_{0.2}In_{0.8}As$ alloy has a peak of efficiency at 210 GHz with impact ionization and at 150 GHz without impact ionization.

If the mole fraction of In grows, then the following changes occur: i) the optimal composition of the mole fraction of P for RF power increases; ii) the average power of oscillations is maximum when the mole fraction of In is 0.3…0.5; iii) the oscillation frequency is minimum when the mole fraction of In is 0.15…0.25.

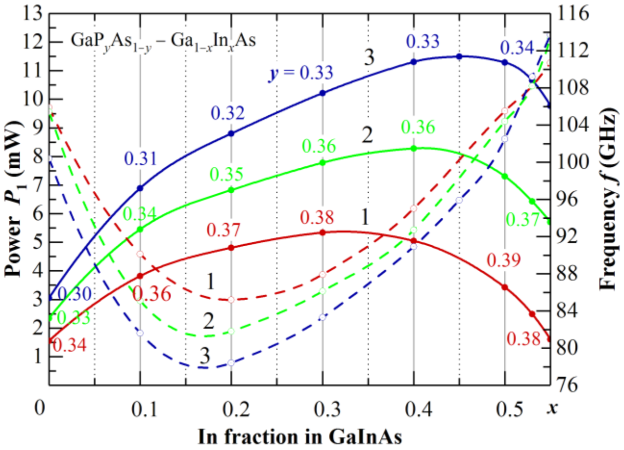

Fig. 4 – Dependences of the average power (solid lines) and frequency (dashed lines) of oscillations for the fundamental harmonic in the graded-gap GaP_yAs_{1-y} – $Ga_{1-x}In_xAs$ diode on the mole fraction of In when the mole fraction of P and applied voltage are optimal for maximum RF power at a graded-gap layer length of 0.2 µm and different electron densities in the transit zone: $n = 4\times10^{16}$ cm^{-3} (1), $n = 5\times10^{16}$ cm^{-3} (2) and $n = 6\times10^{16}$ cm^{-3} (3). The numbers above the dots represent the optimum mole fraction of P in the alloy that is optimized for the maximum average oscillation power

3.5 Analysis of Results

Thus, the results show that in devices based on graded-gap GaPAs – GaInAs alloy, continuous oscillations in the mm-wave range are possible. The average power and frequency of self-oscillations in devices based on graded-gap GaPAs – GaInAs alloy depend on the mole fraction of P and In in GaInPAs, on the length of the graded-gap layer, on the electron density in the transit zone, and on the applied voltage. Table 1 shows the results of optimization of GaP_yAs_{1-y} – $Ga_{0.5}In_{0.5}As$ devices for RF power.

There are three optimal lengths of the graded-gap GaPAs – $Ga_{0.5}In_{0.5}As$ layer. If the length of the graded-gap layer is 0.4 µm, then the device has the highest values of the oscillation frequency at moderate RF power. The optimal mole fraction of P ranges from 0.39 to 0.42. If the length of the graded-gap layer is 0.8...0.9 µm, the device has a high RF power, the lowest DC power and the lowest oscillation frequency. The optimal mole fraction of P ranges from 0.45 to 0.47. Extrapolation of the dependence curve of the oscillation power on the electron density in the transit zone shows that self-oscillation is possible if the electron density is greater than 3.0×10^{16}… 3.5×10^{16} cm^{-3}.

Table 1 – Power spectrum peaks

y	l_g µm	U V	f_1 GHz	P_1 mW	P_2 µW	P_3 µW	P_0 mW
$n = 4\times10^{16}$ cm^{-3}							
0.39	0.20	1.8	105.5	3.42	61.2	0.8	803.6
0.42	0.40	1.7	110.2	2.72	48.3	1.4	656.6
0.47	0.80	1.9	89.5	4.64	251.1	2.1	547.2
$n = 5\times10^{16}$ cm^{-3}							
0.36	0.20	2.2	101.4	7.30	336.6	13.7	1275.3
0.40	0.40	2.1	110.6	5.84	188.0	9.6	1017.4
0.46	0.80	2.2	89.8	7.43	437.5	74.0	752.6
$n = 6\times10^{16}$ cm^{-3}							
0.33	0.20	2.5	102.5	11.28	621.0	49.4	1668.5
0.39	0.40	2.4	110.4	8.96	367.3	26.2	1336.3
0.45	0.80	2.4	89.9	9.77	652.6	131.7	971.0

Minimization of the DC power is of interest, too. The research results show that the highest DC power occurs at low values of the mole fraction of P, and the lowest DC power at large values of the mole fraction of P. However, the dependence of the DC power at a fixed length of the graded-gap layer on the mole fraction of P is not monotonic, but has a local maximum, which is observed at the same values of the mole fraction of P as the maximum RF power. The dependence of the DC power at a fixed mole fraction of P on the graded-gap layer length is also non-monotonic and has a local maximum, when the length of the graded-gap layer is 0.2 µm. The maximum oscillation efficiency is observed at the same values of the mole fraction of P as the maximum RF power.

The research results are consistent with similar studies [11, 14-20]. In recent years, planar Gunn diodes have shown consistent improvements in frequency [15-19]. A planar Gunn diode made from $In_{0.53}Ga_{0.47}As$ on an InP substrate has a maximum output power of 98 µW (10.1 dBm, 0.64 MW/m^2) with a device geometry of 1.3 µm × 120 µm at 164 GHz [15]. A Gunn diode made from GaAs with the graded-gap AlGaAs cathode, with 1 µm long active zone shows a maximum output power of 23 mW at 98 GHz [16]. Noteworthy is the research [13], in which the inverse distribution of the composition of graded-gap GaInAs was used, namely GaInAs – GaAs for a diode placed in a resonator. The efficiency of such diode was low.

4. CONCLUSIONS

Thus, the results of my research show that continuous self-oscillations do not occur in 1 µm devices based on homogeneous semiconductors GaAs and GaInAs. The use of graded-gap GaAs – GaInAs alloy, in which the energy gap between the Γ-valley and satellite valleys increases along the diode length from the cathode to the anode, and the use of GaAs/GaInAs heterojunction placed in front of the transit zone, which injects 'hot electrons', also do not lead to continuous self-oscillations. It should be noted that, as shown by the research results [6, 10, 14], such devices have RF power when operating in a resonator.

But in devices based on the GaPAs – GaInAs graded-gap alloy, even continuous self-oscillations in mm-wave range are possible. The mole fraction of P in the GaPAs cathode makes it possible to reduce the energy gap between the Γ-valley and satellite valleys in the cathode more than in GaAs.

The average power and frequency of self-oscillations in a device based on the graded-gap GaPAs – GaInAs alloy depend on the mole fractions of P and In in GaInPAs, on the length of the graded-gap layer, on the electron density in the transit zone, and on the applied voltage. Three optimal lengths of a graded-gap semiconductor and the corresponding optimal mole fractions of In and P for the maximum RF power are found. One of the optimized diodes provides 11.28 mW RF power at 102.5 GHz for the fundamental harmonic and 49 μW (307.5 GHz) for the third harmonic at a mole fraction of P of 0.33 and In of 0.50.

To sum up this research, I confidently can say that sub-terahertz oscillations in Gunn diodes based on GaInPAs can be achieved by using graded-gap alloys. Findings of the study extend the knowledge about the physical processes of carrier transfer in complex semiconductor structures and can be used in the technological design of new high-speed devices.

REFERENCES

1. Robert J. Trew, *IEEE Trans. Electron Devices* **52** No 5, 638 (2005).
2. N. Priestley, N. Farrington, A*RMMS UK Automated RF & Microwave Measurm. Soc. Conf.*, 1 (London: 2010).
3. A. F'orster, M.I. Lepsa, D. Freundt, J. Stock, S. Montanari, *Appl. Phys. A.* **87**, 545 (2007).
4. Sanjeev K. Sharma, Deuk Young Kim, *J. Korean Phys. Soc.* **67** No 4, 619 (2015).
5. John Kevin Twynam, Pat. US6,111,265 A, USA (2000).
6. I.P. Storozhenko, M.V. Kaydash, *Telecommun. Radio Eng.* **75** No 16, 1495 (2016).
7. I. Storozhenko, *J. Nano- Electron. Phys.* **12**, 01015 (2020).
8. Wei Feng, *Chin. Phys. B* **29** No 4, 047302 (2020).
9. I. Storozhenko, *2021 IEEE 2nd KhPI Week on Advanced Technology (KhPIWeek),* 553 (2021).
10. Yu.V. Arkusha, E.D. Prokhorov, I.P. Storozhenko, *J. Commun. Technol. Electron.* **51** No 3, 352 (2006).
11. A.B. Gnilenko, Y.N. Lavrich, S.V. Plaksin, *Telecommun. Radio Eng.* **74** No 13, 1193 (2015).
12. F. Osaka, T. Mikawa, T. Kaneda, *IEEE J. Quantum Electron.* QE-21, 1326 (1985).
13. O.V. Botsula, K.H. Prykhodko, V.A. Zozulia, *J. Nano-Electron. Phys.* **11** No 1, 01006 (2019).
14. O.V. Botsula, K.H. Prykhodko, V.A. Zozulia, *J. Nano-Electron. Phys.* **11** No 2, 01009 (2019).
15. Ata Khalid, C. Li, V. Papageogiou, G.M. Dunn, M.J. Steer, I.G. Thayne, M. Kuball, C.H. Oxley, *IEEE Electron Device Lett.* **34** No 1, 39 (2013).
16. M. Missous, F. Amir, C. Mitchell, *SPIE*, (2009).
17. J.A. Novoa-Lopez, G. Paz-Martínez, H. Sánchez-Martín, Y. Lechaux, *IEEE Electron Device Lett.* **42** No 8, 1136 (2021).
18. S. Pereza, T. Gonzalez, D. Pardo, J. Mateos, *J. Appl. Phys.* **103**, 094516 (2008).
19. B. Li, H. Liu, Y. Alimi, A. Song, *Int. J. Hydrog. Energy* **41** No 35, 15772 (2016).
20. I. Storozhenko, *2021 IEEE Microwave Theory and Techniques in Wireless Communications*, 111 (2021).

Покращений діод Ганна мікронних розмірів на основі варізонного GaPAs – GaInAs

Ігор Стороженко[1], Сергій Санін[2]

[1] *Харківський національний університет імені В.Н. Каразіна, пл. Свободи, 4, 61077 Харків, Україна*
[2] *Інститут радіофізики та електроніки імені О.Я. Усикова НАНУ, вул. Ак. Проскури, 12, 61085 Харків, Україна*

В роботі вивчаються характеристики діодів Ганна на основі варізонного напівпровідника GaInPAs. Діоди Ганна – активні елементи для генерації електромагнітних хвиль міліметрового та субміліметрового діапазонів. Збільшення їх потужності та граничних частот генерації є актуальною задачею у забезпеченні активними джерелами апаратури субтерагерцового діапазону. Один із шляхів збільшення граничної частоти діодів Ганна – це застосування варізонних напівпровідників. На процеси, які відбуваються в діодах Ганна на основі варізонних напівпровідників, впливають залежності від координати великої кількості параметрів варізонного сплаву. Тому дуже важливим є оптимізація структури не тільки за рівнем легування, але й за зміною фракційних часток варізонного сплаву. В статті представлені результати моделювання роботи діодів Ганна з довжиною активної області 1 мкм на основі варізонного сплаву GaPAs – GaInAs при різній довжині варізонного шару, різних мольних частках In і P та різній густині електронів в активній області. В роботі отримані спектри потужності власних (при відсутності резонатора) коливань діодів Ганна, проведено аналіз фізичних процесів, знайдені оптимальні довжини шару варізонного напівпровідника та оптимальні мольні частки In і P для отримання найбільшої потужності та частоти коливань. Для діодів з електронною густиною в активній області 6 10^{16} см$^{-3}$ найбільшу потужність коливань має $Ga_{0.67}P_{0.33}As$ – $Ga_{0.5}In_{0.5}As$ при довжині шару варізонної сполуки рівній 0,2 мкм. Такий діод забезпечує ВЧ-потужність 11,28 мВт на частоті 102,5 ГГц для основної гармоніки та 49 мкВт (307,5 ГГц) для третьої гармоніки. Результати дослідження розширюють знання про фізичні процеси переносу носіїв заряду в складних напівпровідникових структурах і можуть бути використані для технологічних розробок нових швидкодіючих приладів на основі напівпровідників A_3B_5.

Ключові слова: Діод Ганна, Прилад з переносом електронів, Варізонний напівпровідник, Гетероперехід, Субтерагерцовий діапазон, Міліметрові хвилі, Коливання, GaInPAs.