International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

June 2023 | Issue 55 | Volume 15 | Number 2 | Pages 302-306

EXCITATION OF UNSTABLE WAVES IN SEMICONDUCTORS SUCH AS GaAs MAGNETIC FIELDS

E.R. Hasanov [1,2] S.G. Khalilova [2] G.M. Mammadova [2] E.O. Mansurova [2]

1. Baku State University, Baku, Azerbaijan, egasanov065@gmail.com
2. Institute of Physics, Azerbaijan National Academy of Sciences, Baku, Azerbaijan
shahlaganbarova@gmail.com, gizbesmamedova@gmail.com, esmira85mansurova@gmail.com

Abstract- Using the Boltzmann kinetic equation, the frequency of the current oscillation in multi-valley semiconductors, in an external electric and strong magnetic fields, has been calculated. It has been proven that for the excitation of current oscillations in multi-lobe semiconductors, the sample size must be certain. It was found that the critical value of the electric field when the current oscillation appears almost does not differ from the value of the electric field obtained by the experiment of Gunn. It is shown for the first time that the appearance of unstable oscillations in two-valley semiconductors of the type GaAs size along the coordinate axes of the sample must have a certain value. Application of the Boltzmann kinetic equation leads to consistent values for the electric field and the frequency of current oscillations in the specified semiconductor. The obtained theoretical formulas were evaluated using the Gunn experiment in a semiconductor GaAs and numerical values were obtained for the current frequency and the critical value of the electric field.

Keywords: Oscillations, Frequency, Distribution Function, Electric Field, Magnetic Field, Current-Voltage Characteristic, Multi-Line Semiconductors.

1. INTRODUCTION

In theoretical works, current oscillations in two-valley semiconductors of the GaAs type in an external electric field, and in an external electric and strong magnetic fields are investigated by solving the Boltzmann kinetic equation. In these works, the critical values of the electric and magnetic fields were calculated from the condition

$$\frac{dj}{dE} = \sigma_d = 0 \tag{1}$$

The j is the current flux density, E is the electric field, σ_d is the differential conductivity. However, from condition (1) it is impossible to determine the frequency of the current oscillation.

Therefore, it is of great interest to determine the current fluctuation in the presence of condition (1). In this theoretical work, we will calculate the frequency of current oscillation and the critical value of the electric and magnetic fields by applying the Boltzmann kinetic equation [1-4].

2. THEORY

Let's develop a mathematical model of three-phase two-pole synchronous motors with permanent magnets, which is shown in Figure 1. Here, there is a falling section on the current-voltage characteristic.

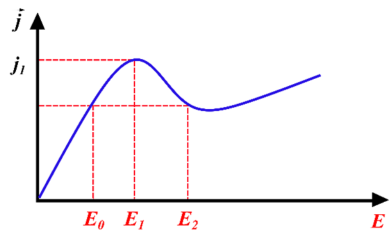

Figure 1. The dependence of the current density on the electric field in two-valley semiconductors of GaAs type is an N-shaped characteristic

The field strength is a multivalued function of the current density at certain range of currents $j_2 < j < j_p$. In this current range, the system can be in one of three spatially homogeneous states. The Gunn effect is associated with an N-shaped characteristic. With negative differential conductivity, electric charges in the system are distributed unevenly, i.e., spatial regions with different values of charges appear in the system (i.e., electrical domains appear). One of the mechanisms for the appearance of domains is the Ridley-Watkins-Hillsum mechanism. In electronic gallium arsenide GaAs, the dispersion law is as follows [5, 6].

Since the energy distance between the minima is relatively large ($\Delta = 0.36$ eV, $\Delta >> T_p$, T_p is the lattice temperature) under conditions of thermodynamic equilibrium, the presence of upper valleys (minima) practically does not affect the statistics of electrons.

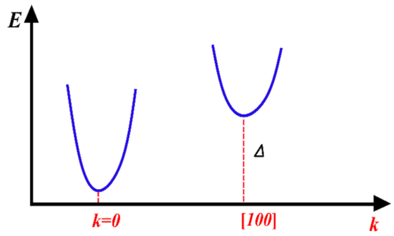

Figure 2. Electron energy versus wave vector in GaAs

Some of the electrons go to the upper minimum when heated sufficiently. In this case, the effective mass of electrons in the lower valley m_a is much less than the mass of electrons in the upper valley m_b. Therefore, the electron mobilities in the corresponding valleys are related by the relation

$$\mu_b >> \mu_a \quad (2)$$

If we designate the concentrations in the valleys n_a, n_b we can write an expression for the current in the form;

$$\vec{j} = en_a\mu_a\vec{E} + en_b\mu_b\vec{E} \quad (3)$$

$$n = n_a + n_b = const \quad (4)$$

The diffusion current due to $eEl >> k_0T$, where e is the elementary charge, as the electron mean free path which are neglected.

In works, without taking into account the intervalley scattering (it is considered small in comparison with the intravalley one), by solving the Boltzmann equation, more specific conditions for the appearance of current oscillations were obtained. In the scientific literature, there are no works devoted to theoretical studies of the Gunn effect taking into account the intervalley scattering based on the solution of the Boltzmann kinetic equation. We will theoretically analyze the influence of a strong magnetic field on the Gunn effect, taking into account the above [5-6].

3. BASIC EQUATIONS OF THE PROBLEM

Under the action of external forces, the state of charge carriers is described by the distribution function $f\left(\vec{k},\vec{r}\right)$, the value that is necessary when considering transport phenomena, $f\left(\vec{k},\vec{r}\right)$ is the probability that an electron with a wave vector $\vec{k}$ (quasi-momentum $h\vec{k}$) is located near the point $\vec{r}$. We consider stationary processes, then $f\left(\vec{k},\vec{r}\right)$ is clearly independent of time. The distribution function is found from the kinetic Boltzmann equation. It is known that the distribution function changes under the influence of external factors and under the influence of collisions with lattice vibrations (phonons) and crystal defects. In the considered stationary state, the influence of these factors mutually compensates each other.

$$\left(\frac{\partial f}{\partial t}\right)_{external} + \left(\frac{\partial f}{\partial t}\right)_{coll} \quad (5)$$

In external electric and magnetic fields, Equation (5) has the form [7]

$$\vec{\vartheta}\nabla_{\vec{r}} f + \frac{e}{h}\left\{\vec{E} + \frac{1}{c}\left[\vec{\vartheta}\vec{H}\right]\right\}\nabla_{\vec{k}} f = \left(\frac{\partial f}{\partial t}\right)_{coll} \quad (6)$$

where, $\vec{\vartheta} = \frac{1}{h}\nabla_k\varepsilon\left(\vec{k}\right)$ is the electron velocity, $\nabla_{\vec{k}}$ and $\nabla_{\vec{r}}$ is the wave vectors and the gradient in the space of coordinates.

When solving the problem, we neglect the anisotropy. The fact that no orientation dependence was found in studies of the Gunn effect on GaAs samples speaks in favor of this assumption. We will assume that for the lower valley the intervalley scattering prevails over the intravalley one, and for the upper valley, the intravalley scattering prevails over the intervalley one. Then the Boltzmann equation for the lower valley can be written in the form

$$\left(\frac{\partial f^a}{\partial t}\right)_{internal} + \left(\frac{\partial f^a}{\partial t}\right)_{intervalley} \quad (7)$$

And for the upper valley in the form

$$\left(\frac{\partial f^b}{\partial t}\right)_{internal} + \left(\frac{\partial f^b}{\partial t}\right)_{intervalley} \quad (8)$$

Davydov [8] showed that in a strong electric field the distribution function has the form:

$$f = f_0 + \frac{\vec{p}}{p}\vec{f}_1 \quad (9)$$

where, f_0 is the equilibrium distribution function, is the momentum of charge carriers. It is clear that you can write

$$f^a = f_0^a + \frac{\vec{p}}{p}\vec{f}_1^a, \; f^b = f_0^b + \frac{\vec{p}}{p}\vec{f}_1^b \quad (10)$$

Distribution function f^b found from Equation (8) in [8]

$$f_0^a = Be^{-\alpha_a(\varepsilon-\Delta)^2} \quad (11)$$

$$f_1^a = -\frac{em_bl_b}{p}\vec{p}\frac{\partial f_0^b}{\partial p} \quad (12)$$

where,

$$l_b = \frac{\pi h^4\rho u_0^2}{D^2m_b^2k_oT} \quad (13)$$

$$\alpha_a = \frac{3D^4m_b^5k_0T}{e^2\pi^2h^8\rho^2u_0^2} \quad (14)$$

It is clear that for the valley "a" you can write similar Equations (13) and (14) replacing "a" with "b". The l_b is the mean free path, D is the deformation potential, T is the temperature of the lattice, ρ is the density of the crystal, and u_0 is the speed of sound in the crystal.

Let's calculate the total current;

$$\vec{j} = \vec{j}_a + \vec{j}_b \quad (15)$$

$$\vec{j} = \frac{2e}{(2\pi)^3}\int_0^\infty \frac{\vec{p}}{p}\vec{f}\vec{\vartheta}d\vec{k} \quad (16)$$

Davydov [8] showed that in the case of intravalley scattering f_1^b in an external electric and magnetic field f_1^b has the following form

$$f_1^b = -\frac{el_b m_b}{p}\frac{\partial f_0^b}{\partial p}\cdot\frac{\vec{E}+\left(\frac{el_b}{cp}\right)\left[\vec{E}\vec{H}\right]+\left(\frac{el_b}{cp}\right)^2\vec{H}\left(\vec{E}\vec{H}\right)}{1+\left(\frac{el_b}{cp}\right)^2\vec{H}^2} \quad (17)$$

$$\alpha_a = \frac{3D^4 m_b^5 k_0 T\left[1+\left(\frac{el_b}{cp}\right)^2\vec{H}^2\right]}{e^2\pi^2 h^8\rho^2 u_0^2\left[E^2+\left(\frac{el_b}{cp}\right)^2\left(\vec{E}\vec{H}\right)^2\right]} \quad (18)$$

where, f_1^a and α_a are obtained if we replace "b" with "a" in (17)-(18). After an easy calculation of the current density j_a and j_b from (16) we get:

$$\vec{j}_a = \frac{e^2 l_a\alpha_a A}{12\pi^2 h^2 m_a^2}\left\{\vec{E}\frac{c^2}{e^2 l_a^2 H^2}\left(\frac{4m_a^2}{\alpha_a}\right)^2+\right.$$
$$\left.+\left[\vec{E}\vec{H}\right]\frac{c\Gamma\left(\frac{7}{4}\right)}{el_a H^2}\left(\frac{4m_a^2}{\alpha_a}\right)^{\frac{7}{4}}+\vec{H}\left(\vec{E}\vec{H}\right)\frac{\Gamma\left(\frac{3}{2}\right)}{H^2}\left(\frac{4m_a^2}{\alpha_a}\right)^{\frac{3}{2}}\right\} \quad (19)$$

After calculating the total current by the formula;

$$\vec{j} = \vec{j}_a + \vec{j}_b \quad (20)$$

$$j_z' = \frac{8nc^2 m_a^{\frac{1}{2}}}{3\sqrt{2}\Gamma\left(\frac{3}{2}\right)l_a}\cdot\frac{E_z'}{H^2}\cdot\frac{\alpha_a^{-\frac{1}{4}}}{1+\gamma^{-\frac{3}{2}}Z^{\frac{3}{4}}\beta}\left\{1+t\gamma_z^{-2}\beta+\right.$$
$$\left.+\frac{e^2 l_a^2\alpha_a^{\frac{1}{2}}}{2c^2 m_a}H^2\Gamma\left(\frac{3}{2}\right)\left[1+t\gamma^{-1}z^{\frac{1}{2}}\beta\right]\right\} \quad (21)$$

where, $A = t\gamma^{-1}z^{-\frac{1}{2}} = \frac{m_b}{m_a}$, $\gamma = \frac{m_a}{m_b}$, $z = \frac{\alpha_a}{\alpha_b}$, $t = \frac{l_b}{l_a}$,

$$e^{-a}\alpha^{\Delta^2} = e^{-\left(\frac{E_x}{E}\right)^2} = \left(1-\frac{E_x}{E}\right)^2;$$

$$E_x^2 = \frac{3D^4 m_0 m_a^3 k_0 T}{e^2\pi^2 h^8\rho^2 u_0^2} \quad (22)$$

We write (21) in the following form

$$\vec{j} = \sigma\vec{E}+\sigma_1\left[\vec{E}\vec{h}\right]+\sigma_2\vec{h}\left[\vec{E}\vec{h}\right] \quad (23)$$

where, $\vec{h}$ is unit vector in the magnetic field. Comparing (23) with (21), one can easily write the expressions $\sigma+\sigma_1$, σ_1, σ_2.

When obtaining an expression for the current density j_z' using (21), then we direct the electric field and the magnetic field H_0 as follows

$$\vec{E}_0 = \vec{h}E_0,\ \vec{H}_0 = \vec{h}H_0 \quad (24)$$

The E_x value is obtained from the following condition;

$$\frac{dj_z'}{dE_z'} = 0 \quad (25)$$

when, estimating E_x^2 for GaAs, the value

$$E_x^2 = 43.84\left(\frac{\text{V}}{\text{cm}}\right)^2 \quad (26)$$

For all strong electric fields,

$$E >> E_x \quad (27)$$

It is quite satisfied. Now let's calculate the frequency of the current oscillation. When an alternating electric field E' is excited inside the medium, an alternating magnetic field H' arises, which satisfies Maxwell's Equation (28);

$$\frac{\partial\vec{H}'}{\partial t} = -\text{crot}\vec{E}' \quad (28)$$

The current density in the presence of electric and magnetic fields has the form;

$$\vec{j} = \sigma\vec{E}+\sigma_1\left[\vec{E}\vec{H}\right]+\sigma_2\vec{H}\left[\vec{E}\vec{H}\right] \quad (29)$$

Let us direct the external electric and magnetic field as follows.

$$\vec{E}_0 = \vec{h}E_0,\ \vec{H}_0 = \vec{h}H_0 \quad (30)$$

where, $\vec{h}$ is the unit vector in z. We find the variable value j_x', j_y', j_z' from (29) taking into account (28-30), then we get.

$$j_x' = \sigma\left(1-\frac{\mu k_z E_0}{\omega}\right)E_x'+\sigma_1\left[\left(1+\frac{ck_x E_0}{\omega H_0}\right)-\right.$$
$$\left.-\frac{2\sigma_2 ck_z E_0}{\omega H_0}\right]E_y'+\frac{2\sigma_2 ck_y E_0}{\omega H_0}E_z' \quad (31)$$

$$j_y' = -\sigma_1 E_x'+\left(\sigma-\frac{\sigma_1 ck_z E_0}{\omega H_0}\right)E_y'+\sigma_1\left(1+\frac{ck_y E_0}{\omega H_0}\right)E_z' \quad (32)$$

$$j_z' = \left(\sigma+\sigma_2\right)E_z'-\frac{2\sigma_2 ck_y E_0}{\omega H_0}\left(E_x'+E_y'\right) \quad (33)$$

Equating $j_x' = 0$ and $j_y' = 0$ to zero, we find E_z' and E_y' from (31)-(32) and supplying E_z', E_y' in (33), we obtain for j_z' the following expressions.

$$j_z' = \left[\sigma_2+\frac{2\sigma_2 ck_x E_0}{\omega H_0}\left(1+\frac{c}{\mu H}\frac{ck_z\mu E_0}{\omega}+\right.\right.$$
$$\left.+\frac{c}{\mu H_0}\frac{ck_y k_z\mu E_0}{\omega^2}\cdot\frac{E_0}{H_0}-\frac{ck_y}{\omega}\frac{c}{\mu H_0}\right)+$$
$$\left.+\frac{2\sigma_2 ck_y E_0}{\omega}\cdot\frac{E_0}{H_0}\left(\frac{ck_y}{\omega}+\frac{ck_y k_z c\mu E_0}{\omega^2}\right)\frac{E_0}{H_0}\right]E_z' \quad (34)$$

When deriving expression (34), we used the conditions of a strong magnetic field $\mu H_0 \gg c$. Equating expressions (34) and (21), we obtain the following dispersion equation for determining the frequency of current oscillation.

$$\left(\sigma_2-\tilde{\sigma}\Phi\right)\omega^3+\frac{2\sigma_2 ck_x E_0}{H_0}\left(1+\frac{E_0}{H_0}\right)\omega^2+\frac{2\sigma_2 ck_x E_0}{H_0}\omega+$$
$$+\frac{\sigma_2 ck_x E_0}{H_0}ck_y\mu k_z E_0\left(\frac{c}{\mu H_0}\cdot\frac{E_0}{H_0}+2\frac{E_0}{H_0}\right)=0 \tag{35}$$

where, $\tilde{\sigma}=\dfrac{8nc^2 m_a^{\frac{1}{2}}\alpha_a^{-\frac{1}{4}}}{3\sqrt{2}\Gamma\left(\frac{3}{2}\right)l_a H^2}$,

$$\Phi=\frac{1}{1+\gamma^{-\frac{3}{2}}Z^{\frac{9}{4}}\beta}\left[1+t\gamma^{-2}Z\beta+\right.$$
$$\left.+\frac{e^2 l_a^2 H^2\alpha_a^{\frac{1}{2}}}{2c^2 m_a}\Gamma\left(\frac{3}{2}\right)+\left(1+t\gamma^{-1}Z^{\frac{1}{2}}\beta\right)\right] \tag{36}$$

Equating $\sigma_2=\tilde{\sigma}\Phi$, $\left(\dfrac{H_x}{H_0}\right)^0=1$.

$$H_x=H_0=\left[\frac{8c^2 m_a^{\frac{1}{2}}\alpha_a^{-\frac{1}{4}}}{3\sqrt{2}\Gamma\left(\frac{3}{2}\right)l_a e\mu}\right]^{\frac{1}{2}} \tag{37}$$

is obtained. Putting the values of $\alpha_a^{-\frac{1}{4}}$ in (37)

$$H_0=\left[\frac{8}{3\sqrt{2}\Gamma\left(\frac{3}{2}\right)}\right]^2\cdot\left(\frac{k_0 T}{3m_0 u_0^2}\right)^{\frac{1}{8}}\cdot\left(\frac{c^2 m_a^{\frac{1}{2}}}{\mu}\right)^{\frac{1}{2}}\times\left(\frac{1}{el_a}\right)^{\frac{1}{4}}E_0^{\frac{1}{4}} \tag{38}$$

are obtained.

From (38), we get;

$$E_0=\left(\frac{\mu}{c^2 m_a^{\frac{1}{2}}}\right)^2 el_a\left(\frac{H_0}{\varphi}\right)^4$$
$$\varphi=\left[\frac{8}{3\sqrt{2}\Gamma\left(\frac{3}{2}\right)}\right]^{\frac{1}{2}}\cdot\left(\frac{k_0 T}{m_0 u_0^2}\right)^{\frac{1}{8}} \tag{39}$$

Thus, the value of the electric field is obtained during current fluctuations in the above two-valley semiconductors of the GaAs type. In [8], it was obtained that taking into account (26).

$$E_0=E_{kr}=1500\ \frac{\text{V}}{\text{cm}} \tag{40}$$

Supplying (40) to (39), it is easy to see that $\mu H_0 >> c$, from the solution of the dispersion Equation (35), we easily obtain.

$$\omega_{1,2}=-\frac{ck_z E_0}{2H_9}\pm i\frac{ck_z E_0}{H_0}\left(\frac{L_z}{L_y}\right)^{\frac{1}{2}} \tag{41}$$

For growing fluctuations;

$$\omega=-\frac{ck_z E_0}{2H_0}+i\frac{ck_z E_0}{H_0}\left(\frac{L_z}{L_y}\right)^{\frac{1}{2}}=\omega_0+i\gamma \tag{42}$$

From (42), it is seen that in the crystal.

$$L_y>4L_z\quad,\quad \gamma<<\omega_0 \tag{43}$$

Thus, with the size (43) (L_x can be any), current oscillations (i.e., instability) are excited under an electric field (39) In the calculation, we direct E_0 along H_0. Of course, any orientation of the electric and magnetic fields could be chosen. For other orientations, it is necessary to obtain expressions (21) and (34) in the same orientations, and then find the vibration frequencies in the same orientations.

4. CONCLUSION

In valley semiconductors of the GaAs type, current oscillations occur under the influence of an external electric and strong ($\mu H_0 >> c$) magnetic field. The frequency of this oscillation ω_0 (42) is close to the frequency of the Gunn effect, i.e., $\omega_0\sim 10^7\div 10^9$ Hz. This proves that the application of the Boltzmann equation is quite valid, although the Boltzmann equation in strong fields is not always applied. By directing $E_0=\vec{i}E_0$, $E_0=\vec{j}E_0$, $H_0=\vec{i}H_0$, $H_0=\vec{j}H_0$ one can carry out a theoretical calculation and determine the critical value of the electric field (including the magnetic field) and the frequency of current oscillation. Of course, with such calculations, conditions (43) will most likely change. Theoretical analysis of current fluctuations in multi-valley semiconductors of the GaAs type shows that the sample size at current fluctuations is significant. This fact was confirmed in the experiment of Gunn.

REFERENCES

[1] E.R. Hasanov, A.R. Hasanova, S.G. Khalilova, R.K. Mustafayeva, "Current Oscillations in Semiconductors with Deep Traps in Strong Electric and Magnetic Fields", IOSR Journal of Applied Physics, Vol. 11, Issue 1, No. 1, pp. 13-18, India, 2019.

[2] E.R. Hasanov, S.G. Khalilova, Z.A. Tagiyeva, S.S. Asadova, "Oscillation of Current in Electric and Magnetic Fields", The 15th International Conference on Technical and Physical Problems of Electrical Engineering (ICTPE-2019), pp. 103-107, Istanbul, Turkey, 14-15 October 2019.

[3] E.R. Hasanov, J.J. Mustafayev, "Non-Linear Fluctuations of Concentration of Charge Carriers and Electrical Field in Semiconductors", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 32, Vol. 9, No. 3, pp. 39-43, September 2017.

[4] E.R. Hasanov, V.M. Hajiyeva, A. Salimi Rikani, "Radiation Doped Semiconductors with Certain Impurities", The 14th International Conference on Technical and Physical Problems of Electrical Engineering (ICTPE-2018), pp. 80-84, Nakhichevan, Azerbaijan, 15-17 October 2018.

[5] B.K. Ridley, T.B. Watkins, "The Possibility of Negative Resistance Effects in Semiconductors", Proc. Phys. Soc., Vol. 78, p. 293, 1961.
[6] C.H. Hilsum, "Transferred Electron Amplifiers and Oscillators", Proc. IRE, Vol. 50, p. 185, 1962.
[7] A.I. Anselm "Introduction to the theory of semiconductors", International Congress of Mathematicians, p. 418, Moscow, Russia, 1962.
[8] A.B. Davydov, "On the Theory of the Motion of Electrons in Gases and in Semiconductors", ZhETF, Issue 7, p. 1069, Russia, 1937.

BIOGRAPHIES

Name: **Eldar**
Middle Name: **Rasul**
Surname: **Hasanov**
Birthday: 13.01.1939
Birth Place: Goykend, Krasnoselo, Armenia
Education: Department of Physics, Faculty of Physics, Azerbaijan State University, Baku, Azerbaijan, 1964
Doctorate: Department of Physics, Faculty of Physics, Institute of Physics and Technology, Leningrad, Russia, 1967
The Last Scientific Position: Prof., Department of Physics of Solids, Baku State University, Baku, Azerbaijan - Leader of Department of Encyclopedia and Terminology, Institute of Physics, Baku, Azerbaijan, Since 2000
Research Interests: Physics of Solids, Classical Mechanics, Thermodynamics and Statistical Physics, Physics of Low-Dimensional Systems
Scientific Publications: 257 Papers, 3 Books
Scientific Memberships: Member of Executive Committee and Scientific Committee of International Conference on "Technical and Physical Problems of Engineering" (ICTPE) and International Journal on "Technical and Physical Problems of Engineering" (IJTPE)

Name: **Shahla**
Middle Name: **Ganbar**
Surname: **Khalilova**
Birthday: 18.11.1977
Birth Place: Baku, Azerbaijan
Bachelor: Department of Physics, Faculty of Physics, Baku State University, Baku, Azerbaijan, 2003
Master: Department of Physics, Faculty of Physics, Baku State University, Baku, Azerbaijan, 2005
Doctorate: Institute of Physics, Baku, Azerbaijan, 2016
The Last Scientific Position: Assist. Prof., Senior Researcher, Institute of Physics, Baku, Azerbaijan, Since 2006
Research Interests: Physics of Solids, Classical Mechanics, Thermodynamics and Statistical Physics, Physics of Low-Dimensional Systems
Scientific Publications: 86 Papers, 5 Projects, 26 Theses

Name: **Gizbes**
Middle Name: **Mammad**
Surname: **Mammadova**
Birthday: 05.05.1964
Birth Place: Barda, Azerbaijan
Education: Physics Faculty, Azerbaijan Pedagogical Institute, Baku, Azerbaijan, 1985
The Last Scientific Position: Lead Engineer, Institute of Physics, Baku, Azerbaijan, Since 2020
Research Interests: Physics of Solids, Classical Mechanics, Thermodynamics and Statistical Physics, Physics of Low-Dimensional Systems
Scientific Publications: 24 Papers

Name: **Esmira**
Middle Name: **Omer**
Surname: **Mansurova**
Birthday: 21.09.1985
Birth Place: Baku, Azerbaijan
Bachelor: Physics, Baku State University, Baku, Azerbaijan, 2003
Master: Physics Baku State University, Physics, Baku, Azerbaijan, 2009
Doctorate: Physics, Institute of Physics, Ministry of Science and Education, Baku, Azerbaijan
Research Interests: Computational Physics, Theoretical Physics
Scientific Publications: 16 Papers