[3] Manipulation system of robots / A.A. Kobrinsky and A.E. Kobrinsky. – Moskva : Nauka, 1985. – 343 p. [in russian]
[4] Robot Analysis. The Mechanics of Serial and Parallel Manipulators / L.W. Tsai. – John Wiley & Sons, Maryland, 1999.
[5] Robotics / K. Foo, R. Gonsalez and K. Li. – Moskva : Mir, 1969. – 624 p. [in Russian]
[6] Computer modelling of actuating parallel kinematics' mechanism with 6 degrees of freedom / E.A. Litvinov // Mechanics of machines, mechanisms and materials. − 2010. − № 4(13). − P. 45−48. [in russian]
[7] Modelling of dynamics of parallel mechanism with 6 degrees of freedom in MATLAB/Simulink environment / E.A. Litvinov // Theoretical and applied mechanics. – 2009. – No. 24. – P. 267–272. [in russian]
[8] Ben-Horin, R. Kinematics, Dynamics and Construction of a Planarly Actuated Parallel Robot / R. Ben-Horin, M. Shoham, S. Djerassi // Robotics and Computer Integrated Manufacturing. – 1998. – Vol. 14. – No. 2.
[9] Automatic assembling of integrated circuits / E.E. Onegin, V.A. Zenkovich and L.G. Bitno. – Minsk : Vysheyshaya shkola, 1990. – 382 p. [in russian]
[10] Automatic control of topology of planar structures / S. M. Awakaw. – Minsk : FUAinform, – 2007. – 168 p. [in russian]
[11] Precision displacement systems of equipment for manufacturing of microelectronics products / S.E. Karpovich, V.V. Jarski and I.V. Dainiak // Doklady BGUIR. – 2014. – No 2(80). – P. 60–72. [in russian]

EMISSION PROPERTIES OF AN ARRAY OF SILICON NANOCONES

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I. INTRODUCTION

At the present time, nanoelectronics expands its capabilities; new directions are developing and traditional areas are improving, such as vacuum electronics. In recent years, has developed such area as vacuum nanoelectronics which is directed to application of nanostructures with vacuum spacing, containing emitters for field emission [1, 2]. The advantages of such nanostructures are that it is not necessary to create a vacuum by airpumping, and there is no need for cathodes heating. In addition, a high speed of electrons in vacuum gaps permits to increase significantly the operating frequency of devices. The technological possibilities of creating nanoelectronic vacuum devices are determined by silicon technology. On its basis, it is possible to create vacuum silicon nanostructures, functionally analogous to traditional vacuum tubes (triodes, pentodes, etc.). For the implementation of devices of vacuum nanoelectronics in industry some problems remain to be solved, related to increasing of the efficiency of field emission of semiconductor (silicon) cathodes, the reproducibility of the formation of nanostructures, and the stability of their functioning, associated mainly with degradation of pointed cathodes.

In this paper the emission properties of an array of silicon nanocones containing cobalt nanoparticles at their vertices are investigated. Nanocons are formed on a silicon substrate by depositing a cobalt film, its processing to producing of an array of nanoparticles with a diameter of 20-30 nm, and subsequent silicon etching. Nanoconuses of silicon are separated from the conductive substrate by a layer of silicon oxynitride SiO_xN_y 8 nm in thickness. The purpose of this work is the simulation the current transfer in n-Si(Sb)/SiO_xN_y/Co nanoconesand the evaluation of their autoemission properties.

II. MODEL

To model the current transfer in the n-Si(Sb)/SiOxNy/Co heterostructure, we assume that the current transfer is monopolar, and the main mechanism of electron transport in SiO_xN_y is the capture on trap centers and subsequent ionization of such centers in a strong electric field. This mechanism is valid for the case of carrier transport in wide-gap semiconductors and dielectrics in strong electric fields at a high concentration of trap centers [3]. SiO_xN_y is characterized by a relatively high concentration of traps. To increase it, an electric breakdown can be carried out, which results in a prebreakdown condition characterized by an increase in the trap concentration almost up to 10^{20}cm^{-3} [4]. In this case, the current-transfer equation and the Poisson's equation, taking into account trapping and ionization in the stationary case, reduce to a system of equations of the form of [5]:

$$n_t(F) = N_t[1 + (q/J\sigma)P(F)]^{-1} \quad (1)$$

$$\frac{\partial F(x)}{\partial x} = q\frac{n_t(F)}{\varepsilon\varepsilon_0} \quad (2)$$

where q is the electron charge, J is the current density, P is the ionization probability of the trap center, F is the electric field intensity, Nt is the concentration of the trap centers, σ is the capture cross section of the electron per trap, ε, ε0 are the relative dielectric constant of SiO_xN_y and the permittivity of vacuum. After the transformations, we obtain a system of equations characterizing the distribution of the electric field intensity and the current density [5]:

$$J = \frac{(q/\sigma)\int_{F_0}^{F_d} P(F)FdF}{(q/\varepsilon\varepsilon_0)N_tU_g + (1/2)(F_d^2 - F_0^2)} \quad (3)$$

$$\frac{\int_{F_0}^{F_d} P(F)dF}{\int_{F_0}^{F_d} P(F)FdF} = \frac{(q/\varepsilon\varepsilon_0)N_td + (F_d - F_0)}{(q/\varepsilon\varepsilon_0)N_tU_g + (1/2)(F_d^2 - F_0^2)} \quad (4)$$

Here F_0, F_d are the electric field intensity at the Si/ SiO_xN_y and SiO_xN_y/Co interface, d is the SiO_xN_y thickness, and U_g is the voltage drop at SiO_xN_y.

To perform calculations using the system (3,4), it is necessary to determine the dependence of the ionization probability P on the electric field strength F. It is determined by the ionization mechanism and depends on the parameters of the trap center. Three mechanisms of ionization of traps under these conditions of current transfer are considered, namely: the Poole-Frenkel mechanism, the mechanism of tunnel ionization of charged centers, and the mechanism of multiphonon tunneling ionization of neutral centers [5,6]. Equations for the ionization probabilities by means of these mechanisms are given in [5]. By specifying the functions P (F) and the corresponding parameters of the traps, one may calculate the distribution of field intensity in SiOxNy and the current density in it, depending on the applied external bias.

III.RESULTS AND DISCUSSIONS

Structure parameters: the thickness of SiO_xN_y is 8 nm, the traps concentration in SiO_xN_y, N_t=(2-10)10^{19} cm^{-3}, the flat-band voltage is 0.15 V, the capture cross section of the electron per trap is $5\cdot10^{-13}$ cm^2, The energy of the traps wt= 0.4-0.5 eV, the frequency of traps oscillations is 1010 Hz, the effective temperature in the Poole-Frenkel ionization mechanism is 380-420 K. The dielectric constant ε = 5. With the help of a method of measuring of the injection of electrons from silicon to SiO_xN_y by the Fowler-Nordheim mechanism in [7] the barrier for electrons at the Si/SiO_xN_y interface was estimated, which was 2.9 eV. The results of the calculations are shown in Fig. 1, 2.

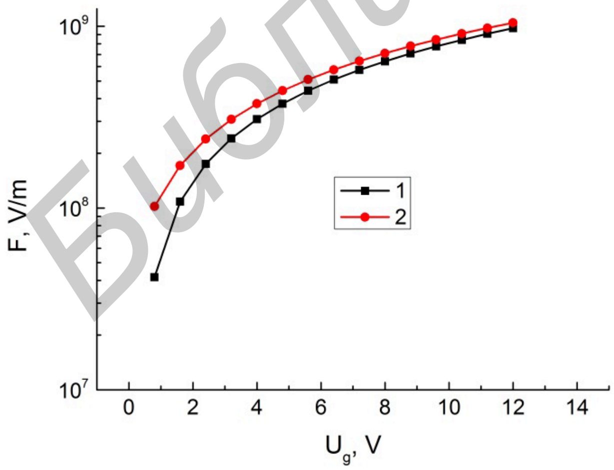

Figure 1 – Dependence of the electric field intensity on the SiO_xN_y interface on the external bias: F_0 – (curve 1), F_d - (curve 2).

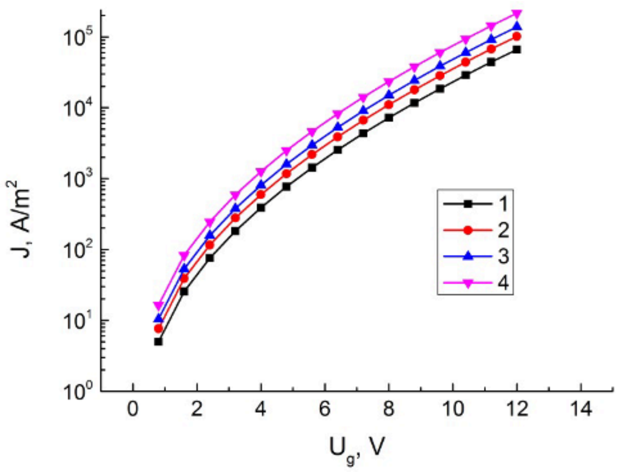

Figure 2. Current density through silicon oxynitride as a function of external bias at different concentrations of trap centers N_t at the energy w_t = 0.5 eV: N_t (cm^{-3}) = $5\cdot10^{19}$ (1), $3\cdot10^{19}$ (2), $2\cdot10^{19}$ (3), $1\cdot10^{19}$ (4).

As can be seen from the results obtained, the electric field intensity in SiO_xN_y is 10^8-10^9 V/m. The current density varies in the rangeof 10^2-10^5 A/m^2 with the increasing of voltage drop and depends on the parameters of the traps and their concentration.

Estimation of emission characteristics. To obtain the current density of the field emission of 100 A/m^2, taking into account the value of the SiO_xN_y/cobalt surface barrier and the cobalt work function (4.4 eV), the current density in SiOxNy should be above 10^4A/m^2. To obtain an emission current density of 100 A/m^2 at a field intensity between cobalt and vacuum of about (2-5)107V/m, the current density of $2\cdot10^7 - 1.1\cdot10^4$ A/м^2 is required in SiO_xN_y. As preliminary estimates have shown, this can be achieved by the trap concentration of (2-5)10^{19}cm^{-3} and their energy of 0.4-0.5 eVover conduction band bottom of SiO_xN_y.

IV. CONCLUSIONS

Simulation of current transfer in the array of silicon nanocones, presenting the n-Si(Sb)/SiO_xN_y/Co nanostructure, is performed. It is established that at concentrations of traps in SiO_xN_y of the order of (2-5)10^{19} cm^{-2} and their energy of 0.5 eV, is possible to reach a current density up to 10^5 A/m^2, which will allow to obtain an emission current density of 100 A/m^2.

REFERENCES

[1] J.-W. Han, J.S. Oh, M. Meyyappan. Appl. Phys.Lett. 100, 213505 (2012).
[2] T. Grzebyk, A. Gorecka-Drzazga. Vacuum 86, 39 (2011).
[3] K.C. Kao, W. Hwang, Electrical Transport in Solids.Pergamon Press, Oxford, 1981.
[4] K.L. Pey, C.H. Tung, R. Rajanetal. Int. J. Nanotechnol. 4, 347 (2007).
[5] A.L. Danilyuk, D.B. Migas, M.A. Danilyuk et al. Physica Status Solidi 210-A, 361 (2013).
[6] S.D. Ganichev, W. Prettl, I.N. Yassievich. Phys. Solid State 39, 1703 (1997).
[7] V.A. Gritsenko, H. Wong, R.W.M. Kwok, J.B. Xu. J. Vac. Sci. Technol. 21-B, 241 (2003).

SURFACE PLASMONS IN GRAPHENE HETEROSTRUCTURE

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I. INTRODUCTION

Over the past decades, it was discovered that it is possible to get the surface plasmons on the conductor/dielectric interface with the same frequency as external electromagnetic waves, but with a much shorter wavelength. This will allow to use plasmons in nanostructures to transfer the information inside the chip. In that case plasmon interconnects would be a real breakthrough in the area of increasing the operating frequencies of integrated circuits [1]. Thus, a promising way for solving this problem is the use of the effect of plasmonic oscillations in the terahertz frequency range, in particular, using graphene on a dielectric substrate [2]. However, a number of technological and physical problems for the excitation, propagation and detection of plasmonic oscillations with controlled parameters need to be solved before that.

In this paper, we present the results of simulation of plasmon effects in a single-layer graphene nanostructure, depending on the chemical potential μ and temperature in the terahertz range.

II.MODEL

A key role is played by the dynamic conductivity of graphene. As a conductivity model for graphene, the following expression was used [3]:

$$\sigma(\omega) = \left(\frac{e^2}{4\hbar}\right)\left\{\frac{8kT\tau}{\pi\hbar(1-i\omega t)}\ln\left[1+\exp\left(\frac{\mu}{kT}\right)\right] + \tanh\left(\frac{\hbar\omega-2\mu}{4kT}\right) - \frac{4\hbar\omega}{i\pi}\int_0^\infty \frac{G(\varepsilon,\mu)-G(\hbar\omega/2,\mu)}{(\hbar\omega)^2-4\varepsilon^2}\,d\varepsilon\right\} \quad (1)$$

where τ is the electron relaxation time, $\hbar$ is the reduced Planck constant, k is the Boltzmann constant, T is the temperature, c is the speed of light, ω is the angular frequency, functions