RESONANT FREQUENCIES, ELECTRICAL NOISE AND DEGRADATION PHENOMENA IN CNT-BASED SENSORS

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The report is devoted to the investigating of the possibility of using auto emitters based on carbon nanotubes (CNT) as a basis for biosensors.

Nowadays Carbon Nanotubes are very much popular as a basis for building biosensors. It is conditioned by a developed surface of nanotubes' array, or putting it by other words, by a high absorption coefficient of the array.

Taking into consideration wonderful autoemission properties of CNT and mentioned above aspect we've got an opportunity of successful realization of autoemission reading regime.

Particularly, a model of biosensor based on CNT-emitters may be interesting.

A reading component of sensor's diagnostic unit is a diode structure: autocathode based on CNT and inert anode. The reading process is based on the transformation of the proper mechanical oscillations of the emitting CNTs (caused by ponderomotive and resilient forces) into electric current in the external circuit. An adsorption of diagnosticating molecular fragments leads to the decreasing of self-frequencies of mechanical oscillations and, as a result, to the changing of alternative current's constituent in the external circuit, and thus, to the decreasing of the good quality of the oscillation system. Summing it up, a problem of the calculation of mechanical self-frequencies of CNT autoemitters and their electrical properties is of current importance.

So the calculations of self-frequencies of mechanical oscillations have been made. Also we have estimated possible values of electrical noises of CNT's auto emitters and investigated degradation phenomena of the CNTs.

Analyzing small transversal oscillations of thin cylindrical shanks we can write an oscillation equation for single CNT.

The point we are interested in is autoemitters' arrays based on CNTs. They are similar to the shanks with a fixed end. Making a proposal that CNTs are independent separately arranged objects and taking into consideration boundary conditions we can get the solution of the equation and estimate self-frequencies of the CNT.

We suppose every tube as oscillation system to be independent. A value of physical constant a is changing during a work cycle. Actually, due to adsorption of molecular fragments effective Yung module, moment of inertia of a section, and mass of CNT changes. And hence the resonance frequency changes.

As a Yung module of CNT is greater than the Yung module of biological fragment the self-frequencies of CNTs with adsorbent and a good quality of a system decrease.

In the case of using of biosensors based on CNT's arrays the adsorption of molecular fragments leads to the substitution of the oscillations of independent CNTs by the oscillations of the CNTs' locally connected by the biomolecular fragments.

Using a resonance system for detecting we've got an opportunity to study the dynamics of changing of the spectrums of the oscillations of the current's alternative constituent in the external circuit. This gives us an opportunity to study an adsorption of biological fragments. Also it's important to estimate a ratio signal-noise. So the estimations have been done. The results are shown in the tables.

Besides fluctuation noise, temperature noise and thermal noise have been calculated.

As autoelectronic emission is taken into consideration, and there are no nonlinear activation mechanisms, temperature noise is not able to influence on the spectrum of electrical noises of sensors. Thermal noise is less than fluctuation noise, too. And the fluctuation noise is dominating.

It is important to study the degradation phenomena of autoemitters based on CNT. Two different mechanisms of degradation have been studied – local overheating and tearing off the CNT's caused by ponderomotive force.
It's important to write a balance equation to study the phenomena of overheating. There are two main mechanisms of energy isolation by the heat exchange between two ends of the nanotube and radiation. Pointing out the parameters of double layer, which is made by ions of cathode lattice and emitted electrons, it is possible to find out the working voltage and appropriate pick temperature.
Now we may estimate possible overheating of CNT's base connected with the diffusion of the heat from the pick of CNT to the end, and spreading of the heat from spherically symmetric source in the substrate. The balance equation is written again, and simple calculations give temperature value equal to 300,01K.
Thus the local overheating is impossible.
The estimations of ponderomotive force and mechanical voltages tightly connected with it has been done. The voltage appears on the contact of the CNT catalytic layer of the substrate.

The force which acts on CNT is $F = 4 \cdot 10^{-7} N$ and mechanical stress is ~ 1234.89MPa, what is much more then possible yield stress of the used catalytic materials. Possible yield stress for nickel is $\sigma_{Ni} = 400 \frac{MN}{m^2}$ for iron is $\sigma_{Fe} = 290 \frac{MN}{m^2}$. Hence, the pressure limit for the system doesn't have to exceed 15V for Ni catalytic layer and 8V for iron catalytic layer.

Typical parameters of CNT used for making calculations:

$$E = 10^{12} \frac{N}{m^2},\ l = 5\mu m,\ \rho = 2000 \frac{kg}{m^3},\ S = \pi(r_{ex}^2 - r_{in}^2) = 3.06 \cdot 10^{-17} m^2,\ m = V \cdot \rho = 3.06 \cdot 10^{-19} kg.$$

To sum it up, the most probable reason for degradation of emission characteristics of CNT is a high value of ponderomotive force connected with applied voltage. The necessity of applying such voltages is caused by high threshold value of autoemission, in other words by tubes unsoundness.

All in all, self-frequencies and electrical noises have been calculated. It was found out that self-frequencies values are the tenth and hundredth part of Giga Hertz.