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Admittance Spectroscopy of Charge Traps of FET Based on Nanotubes

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***Abstract* — Investigation of electrical properties of FET based on polymer wrapped nanotubes, namely charge carrier transport and trap appear mechanisms. Model of carrier transport in the device was performed. Local traps states activation energies were obtained.**

Keywords* — *FET; CNT; bandgap; carrier transport

I. INTRODUCTION

In the current research we studied the transistor with the semiconductor channel material consisting from a network of chaotic located single-walled carbon nanotubes (SWCNT). Up-to-date and there are many types of similar devices [1,2] that use carbon nanotubes as a semiconductor material for the channel of the FET. Similar devices are suitable for work on high frequencies - due to the ballistic transport of the charge carriers in SWCNT [3]. However, there are not solved problems for instance of impurity influence on the electrical properties (appearing of charge traps) of the device. Actual research provide to determinate and estimate those charge traps (activation energies obtaining in particular).

II. TRANSISTOR

The creation of such systems is very tightly connected do the whole range of specific technological processes, which in resolved defined the physical features and peculiarities of the obtained transistors [4-5]. In the current research we observed the transistor which consists of preliminarily selected (by the method of polymer wrapping) nanotubes. The transistor fabricated experimentally in the current research is depicted on Fig.1. It consists of gold Source and Drain electrodes, which are located on the substrate.

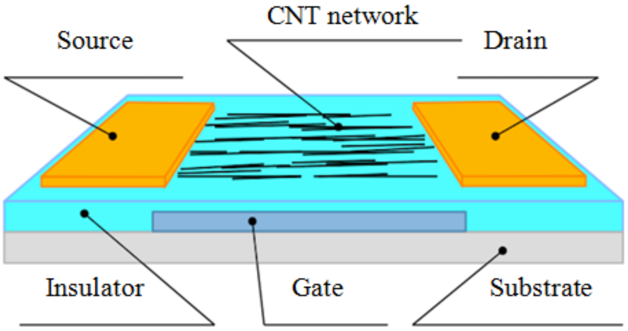

Fig. 1. The device - FET based on nanotubes network.

Between the contacts there is a network, consisting of the nanotubes' pieces. Gate plate locates under the network and behind the insulator. The network is depicted on Fig.2. The nanotube network represent the randomly located nanotubes with the hole conductivity. The schematic contact of two nanotubes is depicted on Fig.3.

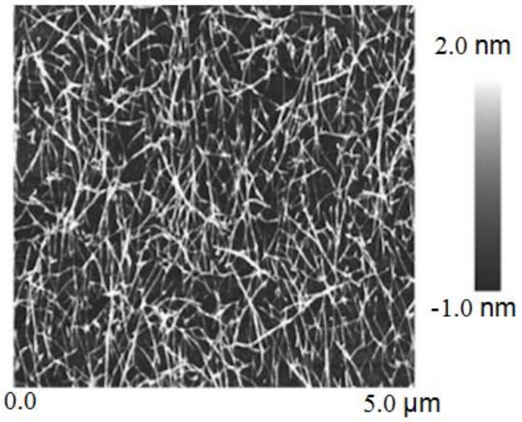

Fig. 2. Photo of FET channel (CNT network).

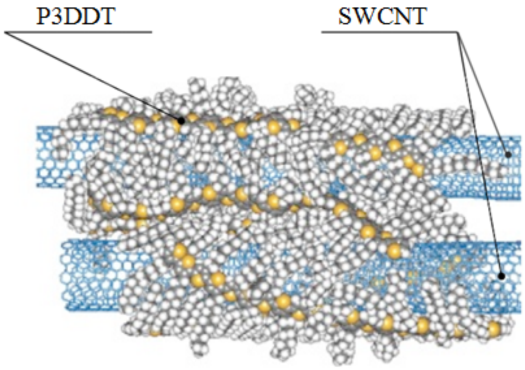

Fig. 3. Contact of two nanotubes (polymer is located between nanotubes).

The selection of nanotubes was conducted with the help of polymer-wrapping method [6-9]. As a selecting polymer thew P3DDT (poly (3-dodecylthiophene-2.5-diyl)) was chosen. Selection by this method allows to separate the nanotubes according to their chirality parameters, wish literally determines the variety of their qualities by the conductivity type and also by their diameter, which in its turn defined their

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bandgap width. Such a polymer allowed to select only the semiconductor nanotubes [7]. Usually in this way the selected nanotubes show hole conductivity [8] - which was already proven by the current experiment. The presence of polymer on each of the tubes determines the appearance of polymer bandgap between touching nanotubes. The approximate band diagram of the obtained structure is depicted on Fig.4.

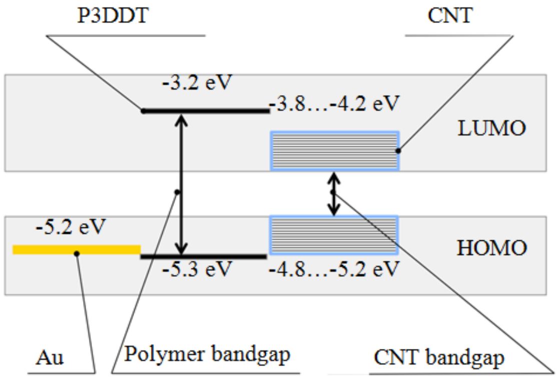

Fig. 4. Energy bands: Au-P3DDT-nanotube (with a bandgap)

Here also illustrated the Source electrode level (Au) and the energy zone of nanotube (that defines the scatter in the bandgap width of nanotubes).

In the experimental structures where only one single nanotube is used as a channel - the transport of carriers is ballistic [3]. Energy band diagram of the FET is depicted on Fig.5. In the case of the network compound from the nanotubes pieces - the mechanism of carrier transport is complicated, which reduces the mobility of such structures.

Carriers also can be captured on the states (capture centers –CC) located outside of nanotubes in the polymers layer. Between the nanotubes occurs carriers scattering and hopping, directed to such a trap (local states of ligands for instance) and charge accumulation also. One of them is the trap for carriers. And actual energy deep of traps is located between polymer and states in nanotubes because of the difference of they energy HOMO levels (see Fig.4). In this way can be expected a local charge accumulation (capacity increase) by those traps.

In the same time due to the prohibited area bandgap width of the nanotubes, it is suspected that on certain areas (pieces of nanotubes chains), in the network of nano tubes the series wiring of nanotubes (for example after the next “i” nanotube) – with the different width of bandgap - inevitably occur the traps for the charge carriers (in this particular case - for the holes). The measurements conducted in the next chapter prove, that the studied structures show the effect of charge accumulation

III. MEASUREMENTS

Conventional methods of FETs analysis usually use DC measuring. They provide basic information about charge carriers mobility and on/off ratio of a FET. Unfortunately, those methods are not informative enough about carriers transport inside the device. In this paper we utilize, the full conduction spectroscopy method, which provides information about a frequency dependences of capacitance-voltage and admittance characteristics. This technique allows to see the charge accumulation, frequency dependence and also allows to calculate the carriers activation energy for capturing and flowing processes. Measurements are carried out at different temperatures, allowing investigate of charge carriers transport in semiconducting materials.

Series of capacitance-voltage (*C-V*) and conductance-voltage (*G-V*) characteristics at different temperatures (down to 77 K) and frequencies (50mV modulation bias voltage) were filmed during the experiment. The graphs were plotted with the constant temperatures and frequencies and variable gate voltage (*Ug*). Fig.6 and Fig.7 demonstrates the graphs of the capacitance-voltage characteristics.

In the current research the different channel length transistors were studied. In the case of the length of the channel of 20mkm - the nanotube network consists in average of crossing the pieces of 5-10 nanotubes (was estimated from a photo of nanotubes network).

In the case of the length of the channel of 2.5mkm (Fig.7) - the nanotube network consists in average of crossing the pieces of 20-40 nanotubes.

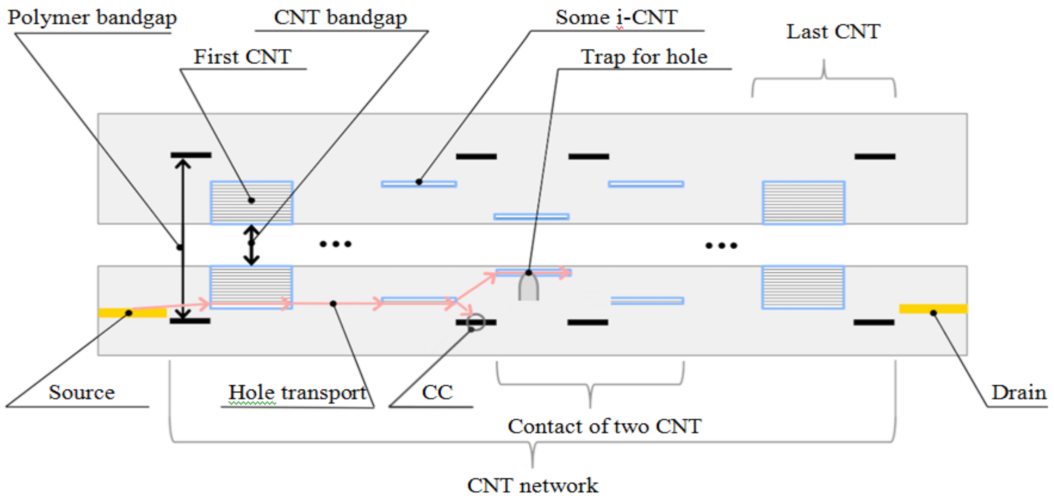

Fig. 5. FET energy band diagram - carriers transport (red line), hopping on trap (gray potential barrier) and capturing on local state (CC level)

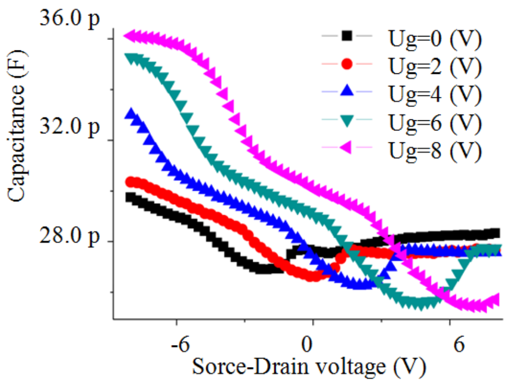

Fig. 6. Capacitance-voltage (*C-V*) characteristics of the structures with 20 mkm channel length measured at different gate voltages and constant 3.14 MHz frequency (T=273 K).

Current-voltage characteristics are shown on Fig.8 and Fig.9. Fig.9 show G-V characteristics for positive gate voltages.

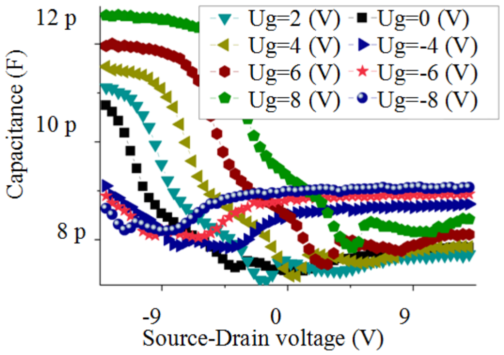

Fig. 7. Capacitance-voltage (*C-V*) characteristics of the structures with 2.5 mkm channel length measured at different gate voltages and constant 3.14 MHz frequency (T=273 K).

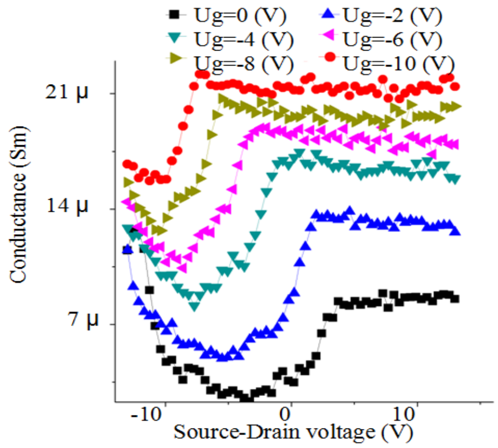

Fig. 8. *G-V* characteristics measured at 3,14 MHz frequency for negative gate voltages (T=233 K)

For clarity of the *G-V* characteristics all the graphs were splitted into two separate plots.

Decreasing temperature leads to increase in charge trapped on local trap states. *C-V* plot, *ln(Q_S)* against 1/*T*, activation energies were calculated. It should be noted that E_{a1}=0,12 eV obtained from temperature dependences of *C-V* curves distinctly differs from E_{a2}=0,02 eV obtained from *G-V* measurements. Interestingly, better plots belong to FETs with smaller channel lengths, that can be explained by better selectivity of nanotubes and fewer amount of various additives (OH groups, ligands etc).

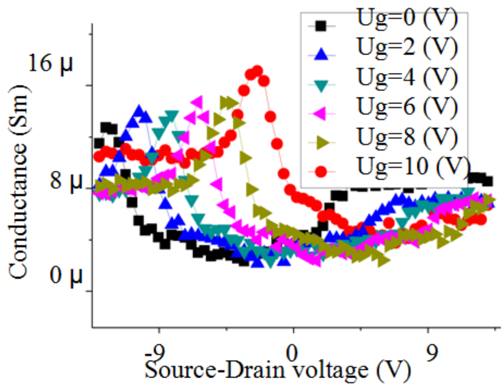

Fig. 9. *G-V* characteristics measured at 3,14 MHz frequency for positive gate voltages (T=233 K).

IV. CONCLUSIONS

Hole conductivity of examined SWCNT mixture was confirmed. Model of carrier transport in the device by energy bands diagram was performed. Local traps states activation energies were obtained (E_{a1}=0,12 eV and E_{a2}=0,02 eV).

Different energies values show that two different processes have been observed and these processes can be separated by using admittance spectroscopy method.

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