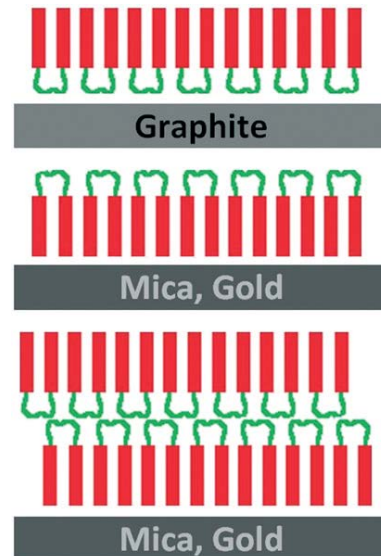


**Fig. 8.** Scheme of energy levels in structure metal-DPT composite-metal, illustrating the occurrence of negative differential conductivity.

During the synthesis of gold NPs in solution, stabilization of NPs surface occurs due to the adsorption of ionized carboxyl groups. Moreover, they may form various types of adsorption bonds with the surface of gold NPs (bridged, mono and bidentate, etc.). The formed Au-COO<sup>-</sup> bonds can create energy levels in the band gap of the peptide composite, which may capture charges. The filling of these levels depends on the sign and magnitude of the applied voltage. As already noted, the nature of CVCs of peptide layers is best consistent with the model of currents limited by the space charge. It involves the capture of electrons by traps that arise in the dielectric layer at the interfaces. As a result, a space charge region may appear at the interfaces and in the bulk of the Au-DPT layer. In this case, one must also take into account the surface states at the substrate–DPT–nAu interface. When the polarity of the applied voltage changes, the space charge region may expands or contracts.

There may be another explanation for this effect. Given that gold NPs are in the form of flat disks with a height of  $\leq 4$  nm, there is a possibility of dimensional quantization of the energy levels in height. For NPs, that are distributed along this height. Even if the distance between the levels in vacuum may seem too large ( $\sim 1$  eV), inside peptide matrix, this distance increases in proportion to the ratio of the effective masses of electrons in the NPs and matrix [20]. However, the absence of exact values of the effective masses of the electron in DPT does not allow the corresponding calculations and so to confirm or deny such possibility.

The most significant differences, in addition to the structure and morphology of layers, were also found in the shape of LTCVCs when comparing composite layers on graphite and gold. It follows that the interaction of the DPT with the substrate not only leads to a change in the conformation of the molecule in the adsorption layer [7], but also determines the final structure of DPT



**Fig. 9.** Possible scheme of orientation of DPT monolayers on graphite, gold, and mica surfaces.

multilayers hundreds of nanometers thickness. It is a very interesting result that awaits its further study. Similar to solid DPT-0 and DPR-1 layers, the effect of bipolar resistive switching is also observed in DPT-nAu layers. It can find practical application in the manufacture of DPT memristors.

The materials we studied differed not only in their structure and chemical composition, but also in the surface charge. Indeed, the surfaces of graphite is electrically neutral, and on the surface of gold a positive charge arises only when DPT-1 is adsorbed (electric image force). Therefore, when DPT-0 and DPT-1 are deposited on the surfaces of these materials, the nature of their interaction will be significantly different. Among all the substrates studied, the surface of graphite is the most inert and hydrophobic. After DPT deposition, it becomes hydrophilic in contrast to gold,

Previously, the scheme of their orientation in the adsorption layer was proposed [7]. This scheme diagram is shown in Figure 9. From this scheme, it follows that the functional groups of PTs (antenna) are oriented perpendicular to the surface of the mica and gold. Wherein, the hydrophobic bridges form the outer layer of the adsorbate. Differences in the nature of adsorbate–adsorbent interactions on the surface of gold and graphite lead to differences in the growth lead to a significant change in the electrical properties of solid layers, for example, the appearance of residual polarization in DPT-nAu and DPT-1 on the surface of gold and its absence on the surface of graphite.

#### 4. Conclusion.

The results demonstrate that the structure and morphology of DPT thin layers depend significantly on the molecule charge (neutral or anion) and the nature of the substrate–layer interface. It was possible to control the structure and properties of the formed solid layers by

changing the pH of the solution (the charge of the DPT molecule). Bipolar resistive switching was observed in thin peptide layers on graphite and gold surfaces. The crystallization of anions on the surface of gold unlike graphite led to the formation of a ferroelectric.

A strong dependence of the morphology of the DPT composite layers on the nature of the substrate and the state of its surface is revealed. It indicates the important role of interfacial interactions in the crystallization processes of the DPT layers. The electrical properties of layers also depend on the interaction of DPT with the substrate. An increase in the thickness of the layers significantly affects the morphology and value of the tunneling current. Similar to crystallization of the salt of the peptide on a gold surface, crystallization of DPT-nAu composite also leads to the formation of a ferroelectric. Such differences in the structure of composite layers on graphite and gold surfaces can be explained if we assume that the structure of the second and all subsequent layers is completely determined by the structure of the first adsorption layer in DPT-substrate interface. So this layer serves as a template for the growth of all other layers.

The results can find practical application in 3D printing technologies. The presence of NDC on CVCs of peptide composites is of great practical importance when used as active elements for amplifying current and power, memory cells. Investigated DPT has rather good memristive characteristics, including good endurance, satisfying ON/OFF current ratio, long retention time and reproducible write-once read-many times (WORM) memory behavior. All this allows us to consider the DPT as a perspective material of memristor organic electronics. Since it is also a drug, the polymorphism and its dependence on pH can also find application in the pharmaceutical industry.

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