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Single-electron molecular transistors on the base of various types of cluster molecules

E. S. Soldatov†, *A. S. Trifonov*†, S. P. Gubin‡, V. V. Khanin†, G. B. Khomutov†, S. A. Yakovenko†, A. Yu. Obidenov†, V. V. Shorochov† and D. B. Suyatin†

† Faculty of Physics, Moscow State University, 119899 Moscow, Russia

‡ Institute of Generaland Inorganic Chemistry, 119899 Moscow, Russia

Abstract. Effect of single-electron tunneling in double-junction tunnel system based on single molecule was investigated. Molecular single-electron transistor was demonstrated. The comparison of measured characteristics with the similar characteristics of molecular single-electron transistors based on a carborane cluster has shown their qualitative resemblance despite essential differences in a chemical structure and streometry of these molecules.

1 Introduction

The traditional microelectronics schemes construction technologies are limited by resolution of the nanolithography equipment, chemical non-uniformity of layers in which the separate elements are formed and non-uniformity of a substrate. Thereby, searching for new alternate ways of electronics engineering development is actual. One of the perspective solutions for nanotechnology is the use properties of separate molecules, as a rule, organic molecules. The capability of creation a molecular electronics engineering and bioelectronics engineering was motivated [1]. As a simple element for construction of electrical elements the authors offer to use a cluster molecule.

The clusters and cluster molecules differ from other organic and inorganic molecules that they consist of a compact heavy nucleus, as a rule, with spherical symmetry, which is surrounded by ligand from light atoms or elementary molecules [2]. The peculiarities of electron structure of cluster molecule condition on the one hand on occurrence of multiple single-electron reversible transitions [3] and, by the other hand, provide sufficient stability of cluster molecule after addition or removing an electron [4]. The electrochemical properties of many of such molecules are reliably determined enough and vary in rather broad borders.

Main advantage of use a cluster molecules as an element of nanoelectronics:

1. The cluster molecules are synthesized chemically, i.e., all molecules are strictly identical both in electronical structure, and in chemical structure.

2. The size of appropriate for realization a tunnel barrier cluster molecule can be essential less, than in elements formed with classical nanolithography.

3. As chemical and the physico-chemical properties of cluster molecules are already well investigated at the present time, there is a capability to dispose cluster molecules on a substrate not only by physical (deposition), but also by chemical methods.

In our previous activities [5, 6] were demonstrated a double junction single-electron system and single-electron transistor, based on a single carborane cluster molecule. However, the problem is still open: what a minimum set of properties of cluster molecule are enough for possibility of using it as simple element of the single-electron scheme.

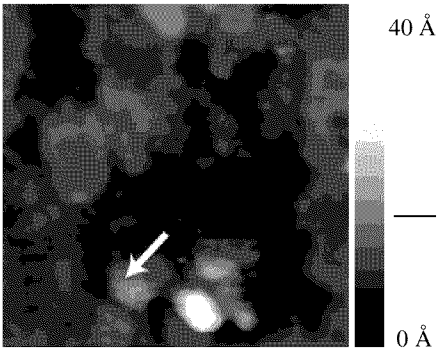

Fig. 1. STM image of $Pt_5(CO)_6[P(C_2H_5)_3]_4$ clusters on graphyte substrate. Arrow point a region where $I-V$ curves and control characteristics was measured. Scan size 550 × 550 Å.

2 Results and discussion

For the comparative analysis of the *SET* — transistor characteristics depending on a type of a cluster molecule, similar [5] experiment was made, where as a working molecule $Pt_5(CO)_6[P(C_2H_5)_3]_4$ was used. Though the molecules $Pt_5(CO)_6[P(C_2H_5)_3]_4$ and the carborane molecule differ entirely by chemical structure, they have a similar structure of energy levels.

For reliability increase of receiving results the samples quantity was increased in comparison with the previous experiments [5, 6], the investigation of measurement regimes influence on the $I-V$ curve and control characteristics (the measure rate, the range of bias voltage, the averaging) was made. The measurements were performed in various characteristic places of a sample (the STM tip above a single cluster on different distances from a gate electrode, above group of clusters and above flat region).

The performed measurements have shown, that

1. The $Pt_5(CO)_6[P(C_2H_5)_3]_4$ molecules have brightly expressed surface — active substance properties, as it forms own (without stearic acid) LB-monolayer.

2. The LB-deposition (at certain parameters) gives a cluster molecules monolayer, and distance between molecules can smoothly be changed over a wide range, for example to do rather large, to consider a separate molecule isolated. (Fig. 1).

3. The $I-V$ characteristics above single clusters differ from $I-V$ curves above flat graphite. (Fig. 2).

4. The control characteristics above single clusters differ from the control characteristics above flat graphite (Fig. 3) by periodicity presence - 2000 ± 200 mV, and this period varies depending on distance between a cluster and a gate electrode.

An observable behavior of $I-V$ curves and control characteristic indicate that in a double junction tunnel system STM tip–cluster–the substrate a regime of single electron tunneling is realized, and the current through this system can be controlled with changing the voltage on a gate electrode.

3 Conclusions

Thus main result of performed research was the realization of the molecular single-electron transistor on the base of a single $Pt_5(CO)_6[P(C_2H_5)_3]_4$ molecule cluster. The comparison of measured characteristics with the similar characteristics of molecular single-electron transistors based on a carborane cluster has shown their qualitative resemblance despite

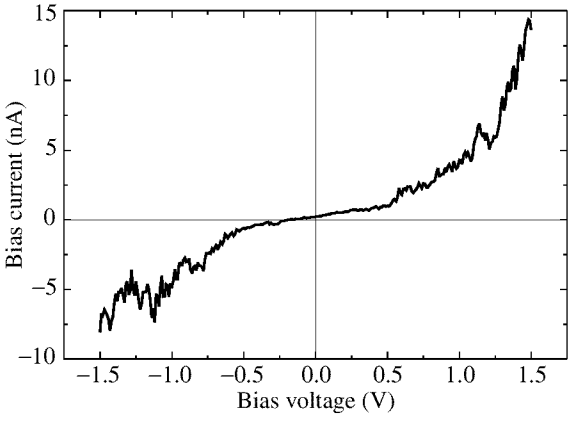

Fig. 2. The typical $I-V$ curve of double junction system STM tip–cluster–substrate.

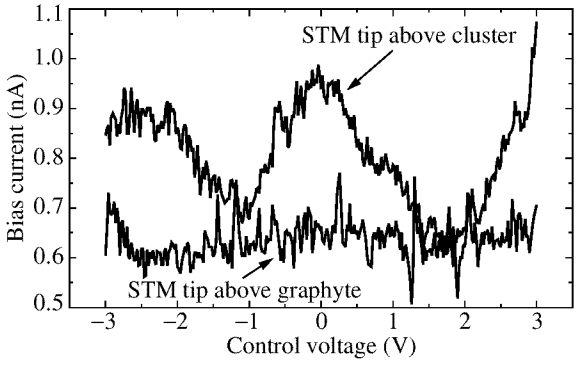

Fig. 3. Control characteristics, measured at STM tip above single cluster molecule and above flat graphite area.

essential differences in a chemical structure and streometry of these molecules.

Acknowledgments

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