NANO SEMICONDUCTOR DEVICES, INCLUDING MOLECULAR SEMICONDUCTORS

Rostislav Pavlov Rusev (1), Boris Petkov Atanasov (2), Tihomir Borisov Takov (1), Marin Hristov Hristov (1)

(1) ECAD Laboratory, FETT, Technical University of Sofia, 8 Kliment Ohridski Str., 1797 Sofia, Bulgaria, rusev@ecad.tu-sofia.bg, mhristov@ecad.tu-sofia.bg,takov@ecad.tu-sofia.bg
(2) Biophys. Chem. Proteins Lab, Institute of Organic Chemistry, Bulgarian Academy of Science, Acad. G,Bonchev Str., Bl.9, rm 405, BG-1113-SOFIA, Bulgaria, Tel:(+359) 2 9606123, boris@orgchm.bas.bg

New types of semiconductors for microelectronics needs are proposed. In the first part of the article single electron transistors, their physical characteristics, constructive features and problems related to its V-PADOX technology construction are described. In the second part colloidal semiconductors in photo-conversion devices are presented. In the third part of the article a description of monolayer chemical technology for construction of organic semiconductors is made. Different organic diodes and transistors, constructed on the base of monolayers, their designs and their physical foundations are shown. A comparison between advantages and disadvantages of known devices and of the new types of semiconductors is made.

Keywords: SET – single-electron transistor, V-PADOX - Vertical Pattern-Dependent Oxidation method, OLED - organic light-emitting diode, SAMFET - self-assembled monolayer (SAM) field effect transistor

1. INTRODUCTION

The process of globalization requires faster data transfer, faster and easier access to information, which requires more complex machines. The modern engineers are challenged to construct new microelectronic elements, which have faster performance, little power consumption, little size, and the elements have to be implemented in VLSI. In the present day, the engineers solve this problem, and the number of transistors integrated in IC is doubled every 12-24 months. The fast progress of microelectronics is due to Si-technology introduction. When the elements scale down to nano-metters size, they are affected by disadvantageous effects (1) such as: non uniform density of doping elements, tunnel effects, short channel effects, large leakage currents, parasitic capacity.

Deriving from theoretical calculations, the technology has limited possibility to cope with engineering demands. In the future, scientists and engineers from different universities and companies have to find alternative technologies and exploitations. The base directions of develop are: nano-technologies which use known materials like Si, carbon and etc., or principally new technologies based on new methods and new materials.

2. PROBLEM STATEMENT

2.1. Single-electron transistor

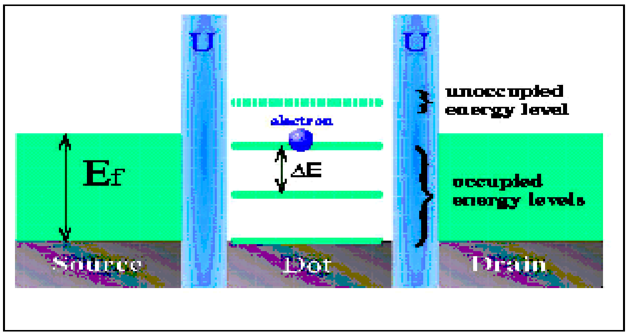

Fig. 1 Scheme of single-electron transistor

One of the future elements is single-electron transistor. It is shown on the figure 1. Kay part of this transistor is little island (quantum dot), which is built from conducting material. The island is separated from both electron donor (source) and electron acceptor (drain) by potential barriers. These barriers are constructed from non conducted materials. The electron can occupy only quantified energy levels on the island. The gate electrode on the island changes the energy state of the island and specifies the conditions for electron tunneling. The electron must have energy equal or bigger than e2/2C to hop from source to island, or hop from island to drain. This energy is named Coulomb energy, and it depends on the size of the island and the number of electrons on it. The size of quantum dot is usually 1-3 nm. If the bias of source and drain are equal to zero, the electrons do not have enough energy to cross barriers, i.e. there is no electrical current passing through the transistor. With the increasing of source-drain voltage, the energy of the electrons also increases. When their energy becomes bigger than Coulomb energy, the pass through the island is possible. This effect is known as Coulomb blockade and it is base phenomenon in all single-electron transistors.

The first SET is accidentally produced in 1989 year from Scott-Thomas et al. pinch Si- field effect transistor. Later, Meirav et al. (2) develop transistors with heterogenic structures on the base of GaAs/AlGaAs. The quantum effects are easier observed in these and similar elements. Only in the last years a sufficiently small SET with observed quantum effects is made.

In most cases the potential confining the electrons in a SET is of sufficiently low symmetry that one is in the regime of quantum chaos: the only quantity that is quantized is the energy. For this case, there are good approaches for predicting of distributions and height of conduction spikes as a function of gate bias.

Big disadvantage is transistor sensibility toward surrounding charges. Transistor's parameters are strongly influenced by charges from impure dielectric materials, which require the development of new or more precise technologies. Takahashi and other authors exploit Pattern-Dependent Oxidation (PADOX) method for constructing of Si-single electron transistors at high temperatures. This method shows good control of the batch, and good reproducibility of parameters from each element.

On the base of this technology, Takahashi introduces the improved Vertical Pattern-Dependent Oxidation (V-PADOX) (3) method. The Si-pattern in V-PADOX is constructed as Si-wire crossed by thick region from the substrate (fig. 2).

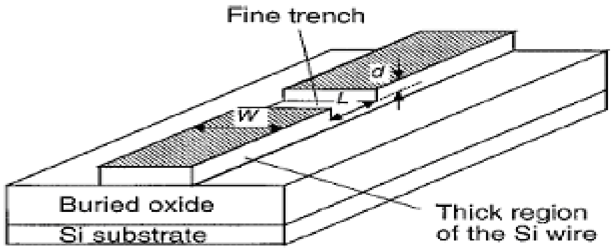

Fig. 2 V-PADOX technologiy Si-pattern; a Si wire with a fine trench on a silicon-on-insulator substrate. W, L, and d are the wire width, trench length, and trench depth, respectively.

Although there are many problems, the scientific development of SET for different areas continues. Ionescu produces hybrid methods for integration of both SET and CMOS transistors (4). Other authors try to construct logical elements and memories based on single–electron transistors.

2.2. Colloidal semiconductors

Colloidal semiconductors have several advantageous features that make them attractive candidates to be used as light-harvesting units in solar energy devices. The idea of using colloidal semiconductors in photo-conversion devices has been discussed by Nozik. This is the possibility for modification of semiconductor's surface by chemisorptions, or catalyst deposition to achieve light-induced charge separation (5) and subsequent fuel-generating dark reactions. On the figure 3 is present design of similar light-harvesting system, which consist TiO_2 particles dispersive in aqueous solution in conjunction with the amphiphilic redox relay. They demonstrate inclination of charge storages and proton generations.

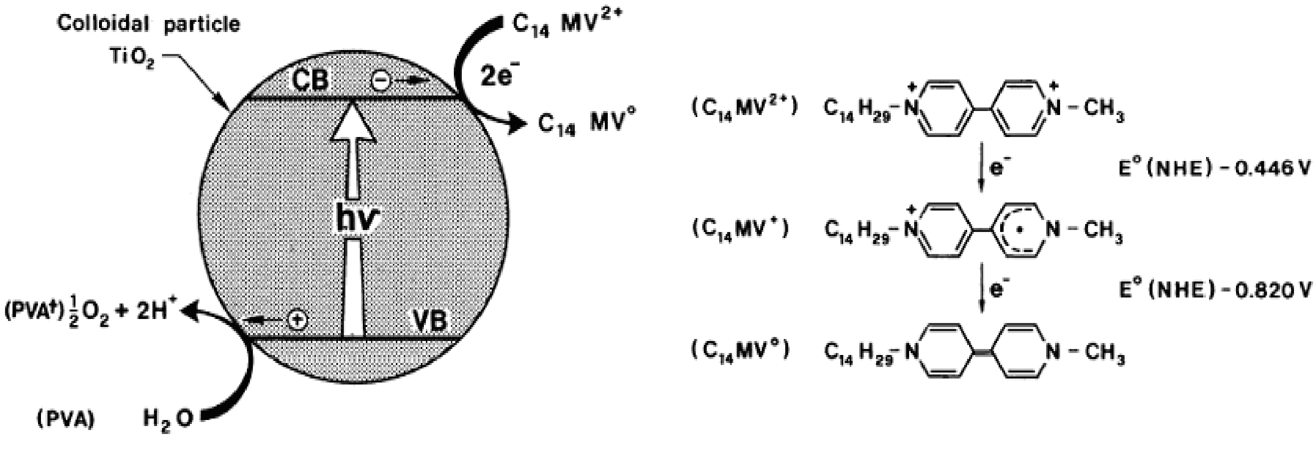

Fig. 3 Scheme for two-electron reduction of $C_{14}MV^{2+}$. MV^{2+} - methylviologen, CB – conduction band, VB – valence band, NHE – normal hydrogen electrode

Illumination of an aqueous TiO_2 sol containing $C14MV^{2+}$ in blue diapason can be attributed to formation of viologen cation radicals ($C14MV^{+}$). The fast change of blue to intensive blue due to reduction of $C14MV^{+}$ to $C14MV^{0}$ is follow.

2.3. Development of molecular organic semiconductors

The construction of self-organized molecules is a new, exciting target of contemporary chemistry. There is big interest in every area, where materials with principally new characteristics are required. The characteristics depending on précised localization of molecular components are attractive for microelectronics, optics, etc.

Technically, there is big interest to construct simple supramolecule systems based on simplest molecules. It is very important that the paradigm of molecule and supramolecule engineering is observed, and on the other hand, a demonstration is needed that simple molecule devices can be made, and the designed principles of self-organized molecular complexes should be understood.

Good opportunities propose the new chemical techniques for producing Langmuir-Blodgett (6) self-organized molecular monolayers (complexes) with isolator and conducting properties, monolayers which can function as sensors and switches, etc. The elaboration of new monolayers with different properties allows creation of new microelectronic elements:

2.3.1. Organic light-emitting diodes (OLEDs)

Organic optoelectronic materials (fig. 4) can be used as new class elements, which can be important for industrial electronics. For example, the organic light-emitting diodes (7) can form the base of ultra-thin, energy effective and mechanically flexible display systems. In addition, miniature devices from micro and nano scale can be used in photonics, biosensors and other areas. There are important technical and scientific problems related to construction of high technology apparatus from this kind, and detailed understanding of their behavior. In particular, the nature of binding between organic semiconductor's surface and metal electrode is critical for performance in these semiconductors.

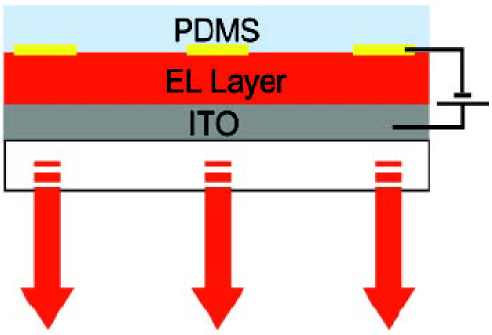

Fig. 4 Scheme of OLED. PDMS – poly(dimethylsiloxane), EL layer – electroluminescent layer, ITO – indium tin oxide

2.3.2. Single-molecule diodes

Historical, this scientific area is explored by physics and chemistry of electron transfer (8) in single molecule. The electron transfer from donor (D) to acceptor (A) via non conjugated σ-bonds is frequently used as a model system. Aviram and Ratner proposed in 1974 (9) a Gedankenexperiment to realize a diode with a D– σ–A molecule connected at both ends to metallic conductor in which the combination of electron system plus leads could support consecution of electron transfer processes, i.e. current. Experimentally, D– σ–A molecular devices are made by using LB layers between two planar electrodes. Lately, self-organized monolayers with D– σ–A structure show rectifier's properties (10). In the future, asymmetric volt-ampere characteristic can be generated by placing of different molecular-electrodes contacts in the both ends (11), by asymmetric displace of resonant level between the electrodes or by using of different metals.

On following figure is presented single-molecule diode.

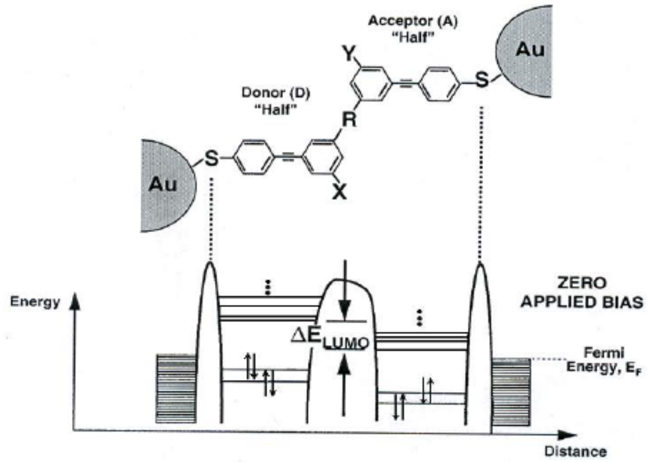

Fig. 5 Schematic illustration of single-molecule diode with energy diagram

For understanding its principles of action, a standard approach for electron transfer though the molecule can be used. The conductance of diode molecules is realized through the resonant interaction of the external electron and neutral molecule (fig. 5). Every event of electron conductance happens when an electron from one of the electrodes tunnels via molecule to appear on second electrode. The asymmetric conductance depends on polarity of bias, i.e. the voltage defines current via diode.

2.3.3. Organic field effect transistors

Scho¨n et al. (12) construct three-terminal device, such as self-assembled monolayer (SAM) field effect transistor (SAMFET), which has possibility for modulation of conductance, and is a good candidate as a base for logical elements. The scheme of SAMFET constructed from 4,4'- biphenyldithiol (BPDT) is shown on the next figure 6, with a SAM connected to source and drain electrodes. The transistor's functionality is similar to that of the molecule diode, rendering into account the controlling action of the gate bias.

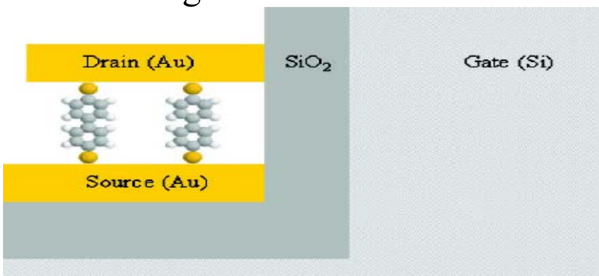

Fig. 6 Scheme of organic field effect transistor

3. CONCLUSIONS

Even though serious technical problems, related to V-PADOX technology for SET construction and manufacture of organic semiconductors based on LB-monolayers are encountered, the research in these areas is in progress. These new elements are good candidates for the future microelectronics requirements, because they have miniature size (amstrong scale), are faster (fento-second scale), and have little power consumption.

4. ACKNOWLEDGMENTS

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