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ЭЛЕКТРОНИКА

FROM MICRO - TO NANOELECTRONICS

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The main results in the development of nanotechnology achieved at BSUIR are presented. Two ways of the NE development are described.

Keywords: nanoelectronics, nanotechnology, nano self organized structures.

Nanoelectronics (NE) is an emerging technology that will play a vital role in the development of the new generations of the information and telecommunication systems. There are two ways of the NE development — the transition to NE from the conventional Microelectronics (ME) by diminution the size of the microelectronic components to the nanoscale dimensions (top down approach) and the utilization of molecules and biological substances which are leading to the molecular- and bioelectronics (bottom up approach). The most appropriate way will be somewhere in between- the combination of the molecular and biological objects with the conventional ME technology.

Government of Belarus is paying a strong attention to the NE development. **A subprogram (SP) "Nanoelectronics**" have been elaborated as the part of the national program "Nanomaterials and Nanotechnologies". This SP contains a number of original practical projects mostly based on the long time experience in ME and high-level scientific results in basic science- physics, chemistry and biology. In the world practice just at the beginning of this century ME is transferring to NE-100 nm technology is in production in 2004, while a decade later the 35 nm technology node should became available. If in the μm region of the ME technology the mode of the transistors functioning does not depend on their size (principle of scaling), in the nm region the quantum effects are becoming dominant in the functioning of the devices and scaling may trigger the breakthrough of nanoelectronic devices such as e.g. single electron transistors (SETs), resonant tunneling diodes (RTDs), spin controlled devices (SCDs), rapid single quantum flux logic (RSQF) etc.

Because big gap in ME development with the industrial countries it is not reasonable for Belarus to follow directly the "top down" way, developing technology for the nanoscale devices production. But a number of the projects of SP are devoted to the **modeling nanoscale devices** taking into account first of all the quantum affects such as dimensional quantization, confinement, interference of electronic states etc.. There is a number of another theoretical projects which are dealing with the super lattices; atomic clusters; quantum wells, filaments, dots and contacts; structures with tunnel transparent barriers (systems of quantum walls and super lattices); photonic crystals; two dimensional structures of nanothickness films, including magnetic, especially using the giant magneto resistance; quantum computation, cryptography and teleportation [1, 2].

Design of specific devices based on **single molecules** is at the initial stage of the investigations in the world despite that really nanoscaled effects are expected in these objects. The dynamic molecular relays, energy transporters, information saving and recognition devices, molecular nanomashines and nanomotors (rotors), nanorobots are under the construction.

A number of the projects in SP are devoted to the **modeling of single molecules** such as DNA, proteins etc. [1].

But most projects of the SP are bearing a very practical character and are based on the original experience of Belarusian scientists in ME. The point is that long time (more than 20 years) they were carrying on the investigations of the very specific materials - porous silicon (Si-por.) and porous oxide of aluminum ($Al_2 0_3$-por.) and successfully implemented them into the ME technology. These materials in terms of nanotechnology can be considered as the **nano self organized structures** (NSOS) with the unique properties for the NE application.

Porous Silicon (Si-por.) is a special morphological form of Si, obtained under the anodic treatment of Si in the HF solutions and composed by the network of pores of the micro- and nanodimentions in the crystal lattice of Si. By the doping, pores filling and layers deposition different types of the composite structures can be obtained (Fig.1).

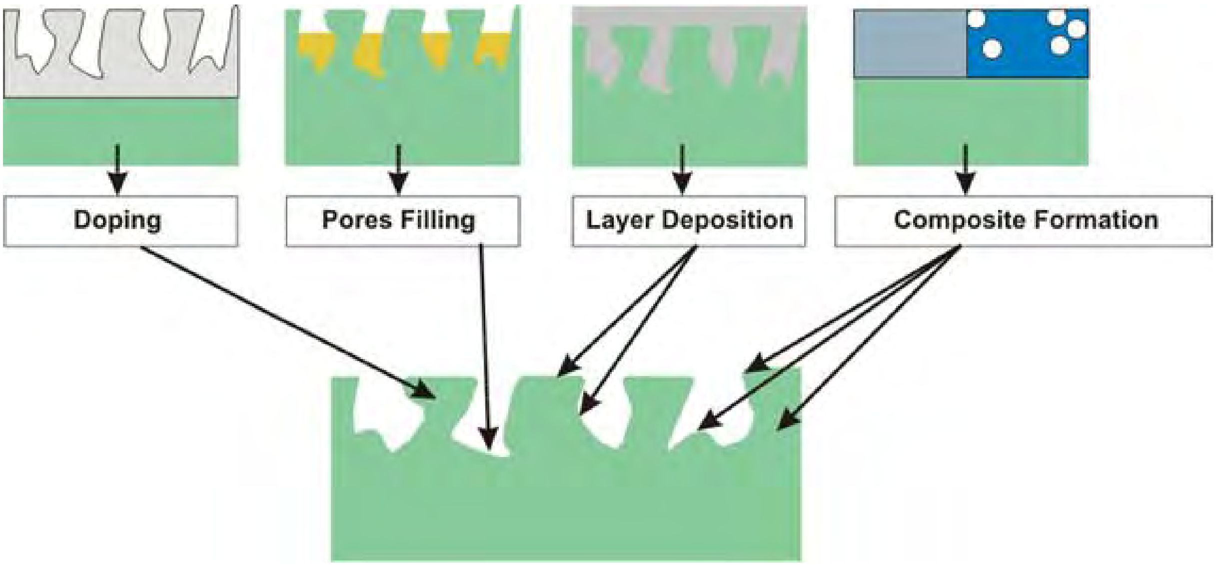


Fig. 1. The types of the composite structures on the basis of Si-por

In the conventional ME Si-por. has received enough wide application. On its basis Belarusian scientists elaborated [3, 4]:

– a high efficiency "Insulation by Porous Oxidized Silicon" of the Integrated Circuits (IC) (Fig.2); the technologies of fast diffusing impurities gettering in the bulk Si ; the thick layers of silicides and epitaxial layers of Si, GaAs (Fig.3), PbS growth on the surface of Si-por. etc..

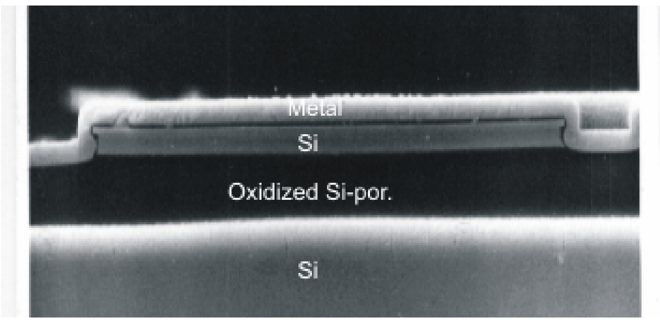


Fig. 2. Insulation by Porous Oxidized Silicon

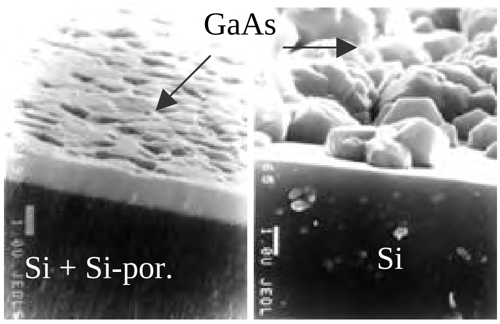


Fig. 3. Perfect GaAs epitaxial layer growth on the Si-por. surface

In 1990 the intensive photoluminescence of Si- por. in the visible light emission range under the room temperature has been discovered [5].

Since that very time Belarusian scientists started to pay the main attention to the investigation of the optical properties of Si-por. and to the creation of new **Si nanooptoelectronic (SNOE)** devices and systems. The scientific and practical results of the priority level have been obtained in this aria [6]:

– the nature and mechanisms of the light emission in Si-por. were established, it was strictly conformed that nanoscaled particles of Si-por. have the direct gap semiconductor properties as to compare to the bulk Si which is an indirect gap semiconductor;

– an integral type Si-por. light emitting diodes (LEDs) in a visible range have been developed with the life time more than 10000 hours (Fig. 4);

– optoelectronic pair consisting this Si-por. LED and bulk Si photodiode connected by the embedded Al_2O_3 optical waveguide with the response time less than 2 ns and – "near to the eye displays" on the basis of Si-por. LEDs were produced;

– oxidized Si-por. waveguide embedded into the bulk Si with the extremely low losses <0.1 Db/cm (Fig. 5) have been elaborated and produced.

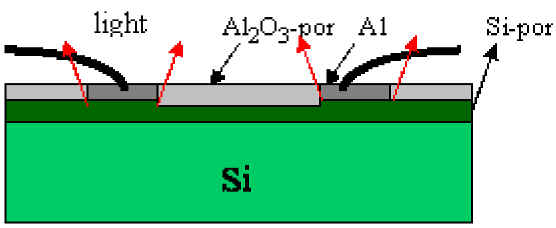


Fig. 4. Si-por. LED

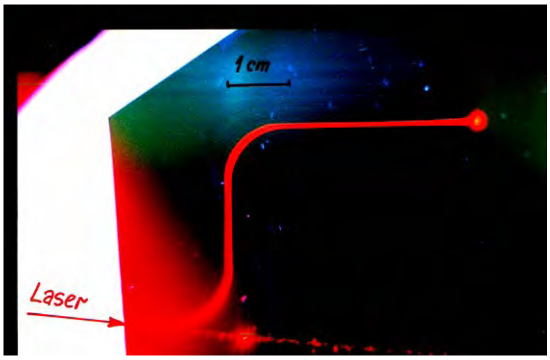
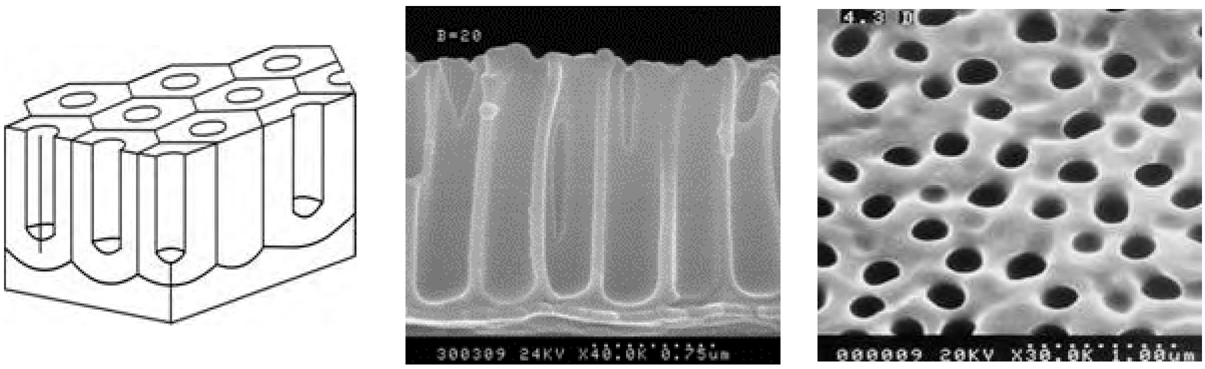


Fig. 5. Oxidized Si-por. waveguide

Porous aluminum oxide (AI_2O_3-por.) consists of the regular self-organized vertical pores produced in the process of the electrochemical oxidation of AI (Fig.6)



a) Drawing b) Cross-Section c) Top view

Fig. 6. Porous Al_2O_3

The pores size (from μm to nm) and location might be regulated by the electrolyte composition and regimes of the anodic treatment. In the conventional ME Belarusian scientists have developed the multilevel interconnections in the semiconductor (Fig.7) and hybrid ICs; integrated resistors, capacitors, different types of sensors on the basis of AI_2O_3-por.

In the middle of 90^{th} the intensive work started on the AI_2O_3-por. application to nanotechnology: the nanoporous membranes transparent for gas (Fig.8); the separators for Li batteries;

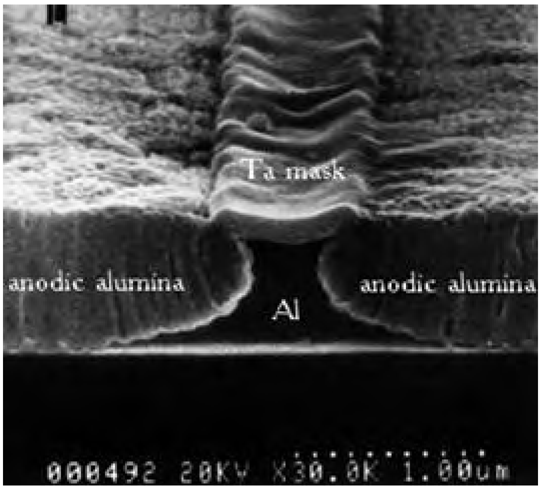


Fig. 7. Multilevel interconnections

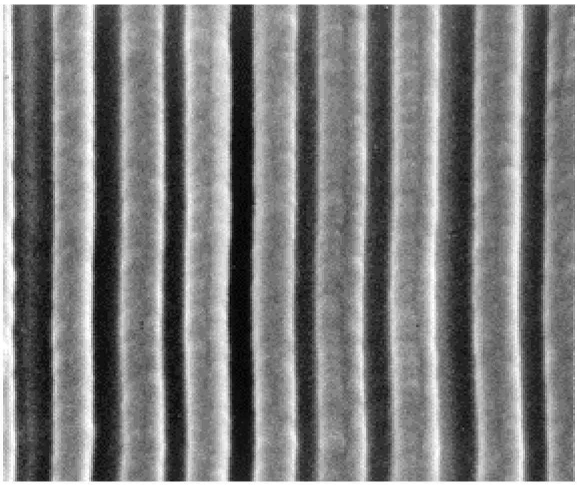


Fig. 8. Nanoporous membrane

high efficiency photo- and electroluminescent structures for the visible range, obtained by the incorporation of organic and inorganic luminophors containing rare-earth elements into AI_2O_3 pores (Fig.9); auto-emission cathodes with the high density (10^8-10^9 cm^{-2}) of the cathodes obtained by the deposition of metals into the pores (Fig.10) have been elaborated and produced [7].

Fig. 9. Photoluminiscent structure AI_2O_3 - luminophor

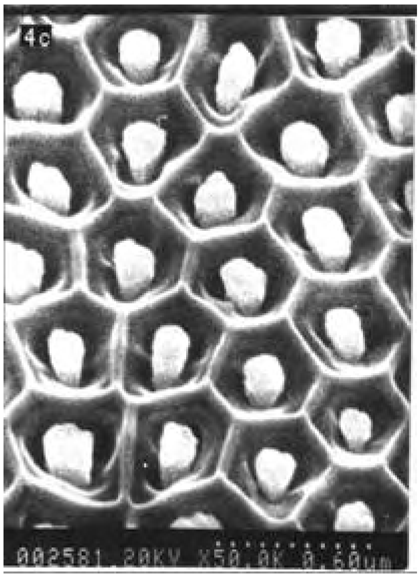


Fig. 10. Auto-emission cathode

Thus, **nano self organized structures** obtained under the electrochemical treatment of the surfaces of Si (Si-por.) and Al (AI_2O_3-por.) expose the unique properties which open an opportunity to create a number of the principally new **nanooptoelectronic** (NOE) devices and systems. But the main results of these materials utilization would be achieved in the combination with **molecules** (fullerenes, carbon nanotubes), **nanoscaled organic molecular crystals** (whiskers) of different materials, **biological objects** (DNA, proteins, antibodies and etc.), when NSOS will be used as the **matrix** of any reasonable size into the pores of which the mentioned above entities would be incorporated. In such a way **nanosystems** can be produced combining the properties of the matrix itself and the molecules.

Besides the Si-por. and AL_2O_3-por., other self organized structures might be used as a matrix, at the surface of which different molecular species might be placed, for example Fe, Ni e.g. nanostructured films which serve as a good catalysts for the growth of the oriented CNTs.

By the developing and using such NSOS it is planned in the frame of the SP to develop fast enough and in a reasonably cheap way a new generation of nanooptoelectronic devices and systems. Based on the results of previous investigations exposed above, the following subjects would be under the further investigation in the frame of SP "Nanoelectronics".

– Further investigation of such NSOS as Si-por. and AI_2O_3-por. which can be used as the matrixes in the pores of which different molecules can be incorporated and other NSOS which can serve as the catalysts (Fig.11-12) for the growth of the molecules at their surfaces (Fig.13).

– The processes of the production and the properties of the vertically and horizontally oriented CNT, DNA and whiskers of different materials.

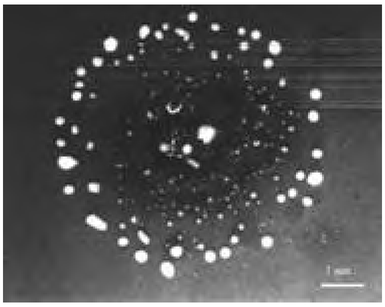


Fig. 11. Self organized structure of Ni nanoparticles (ring shape)

Fig. 12. Self organized structure of Ni nanoparticles (linear shape)

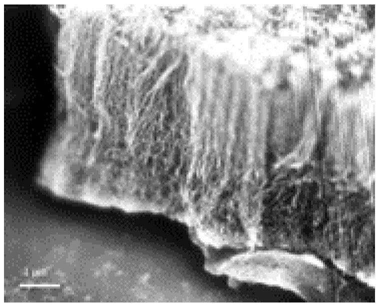


Fig. 13. Oriented CNT grown on the Self organized nano structures of Ni

On the basis of these two types of the matter, by their combination the following nanodevices would be investigated and developed:

– single-electron transistors(Fig.14); transistors with the horizontally (Fig.15) and vertically(Fig.16) oriented CNT and DNA;

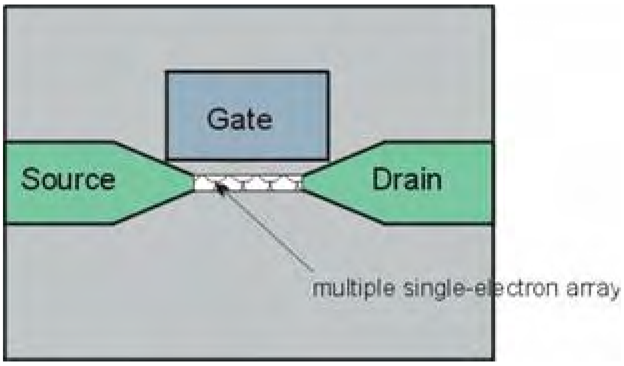


Fig. 14. Single-electron transistor

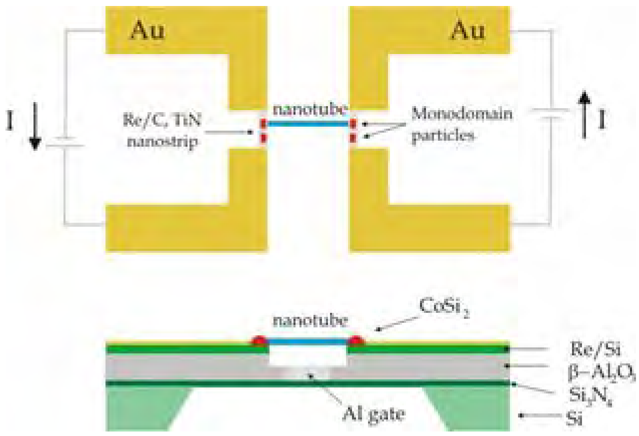


Fig. 15. Transistor with the horizontally oriented CNT

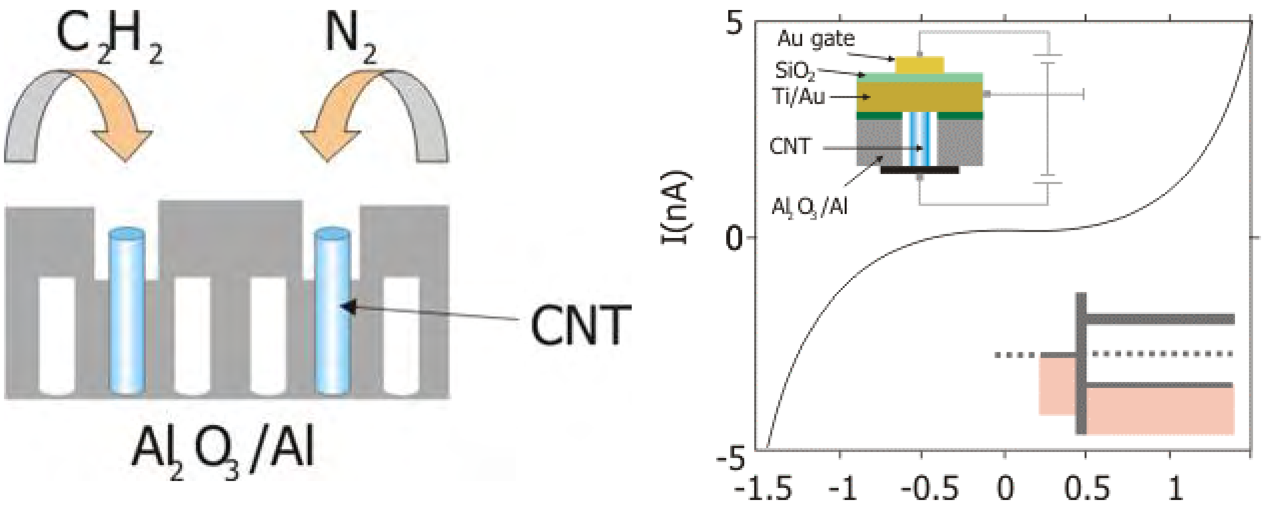


Fig. 16. Transistor with the vertically oriented CNT

– integrated nanooptoelectronic pairs: Si-por. LED - bulk Si photodiode connected by the embedded AL_2O_3 or oxidized Si-por. optical waveguides and new generation of nanooptoelectronic ICs on their basis;

– integrated Si-por. LEDs and "near to the eye displays" on their basis [8,9];

– field emission displays on the basis of AI_2O_3-por., vertically oriented CNT in the pores and organic luminophores (Fig.17);

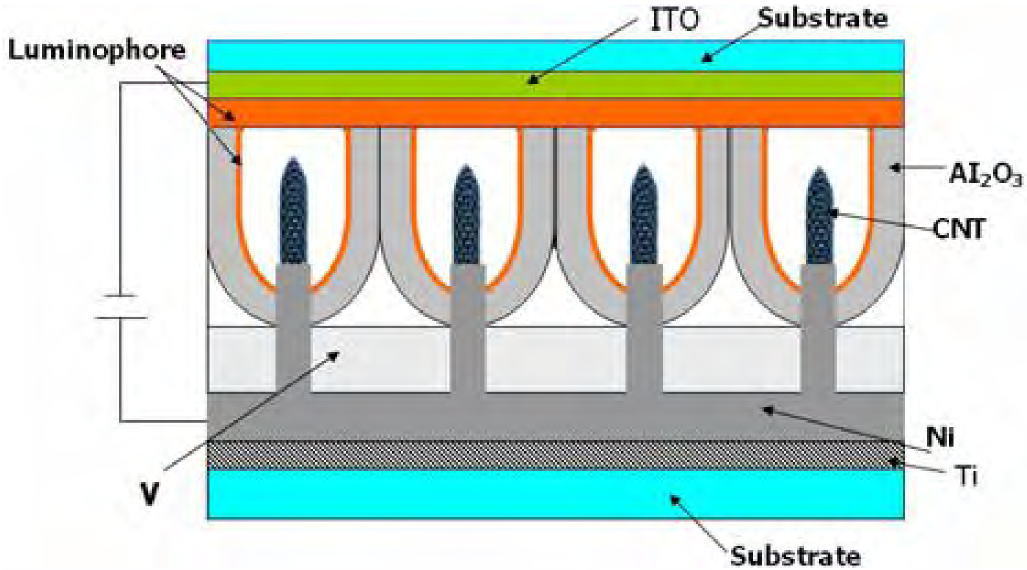


Fig. 17. Field emission display on the basis of AL_2O_3 and CNT

– hybrid solar cells with the interdigitated Volume distributed heterojunctions of the vertically oriented CNT , phthalocyanines (CuPc), perylenes (PTC) (Fig. 18, 19);

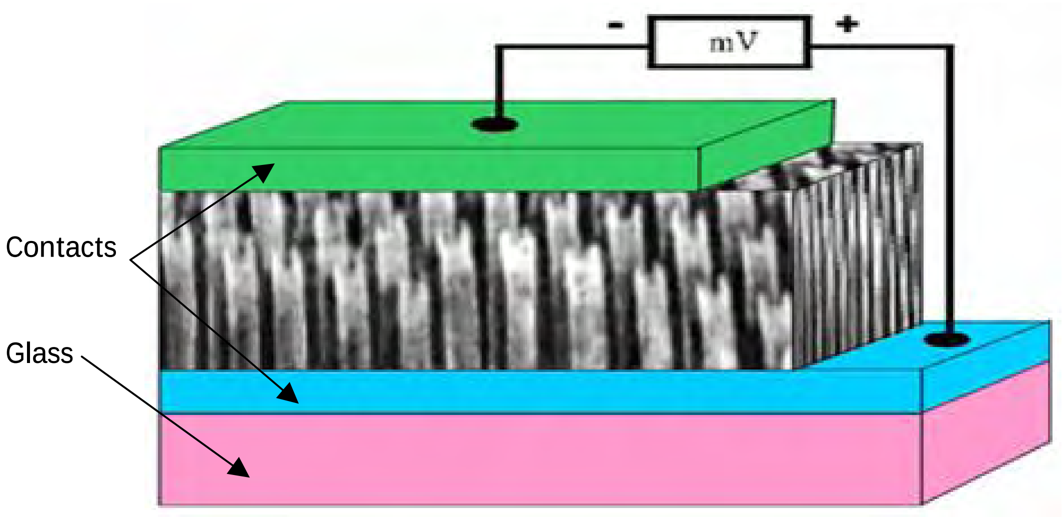


Fig. 18. Interdigitated hybrid solar cell

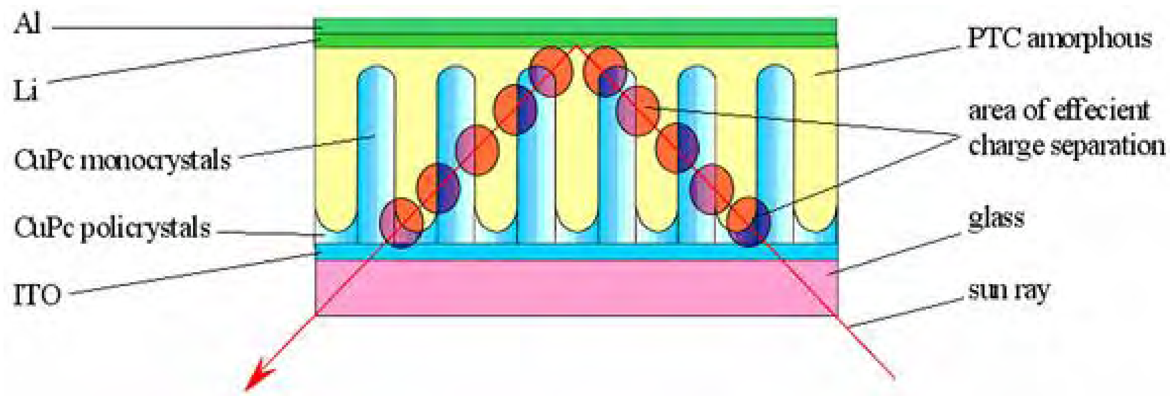


Fig. 19. The mechanism of the charge separation in the interdigitated hybrid solar cell

– micro fuel cells on the basis of Si-por. and AI_2O_3-por. as a proton membranes and CNT as the catalyst;

– highly sensitive sensors on the basis Si-por. and AI_2O_3-por. itself;

– biosensors on the basis of different self organized structures with the different bioobjects (DNA, proteins, antibodies) incorporated into the porous matrix or grown at the surface of catalysts;

– photonic crystals on the basis of Si-por., AI_2O_3-por. and hybrid optical multilevel interconnections.

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Abstract

The main results in the development of nanoelectronics and nanotechnology achieved at BSUIR are presented. Two ways of the NE development are described.

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