# SOLAR ENERGY CONVERSION IN NANOSTRUCTURED INTERFACES

**Igor Tyukhov**
*Moscow State University of Mechanical Engineering, All-Russian Scientific Institute of Rural Electrification, Russia*

**Keywords:** solar energy, nanostructures, solar cells (SC), photovoltaic effect, semiconductor interface, organic SCs, nanostructured materials.

## Contents



## Summary

Application of nanotechnologies creates ample opportunities for perfection of solar energy conversion processes. Nanostructured materials are already used both for direct conversion of solar energy into heat, electric energy and fuel, and for indirect use of solar energy, for example, in special devices for hydrogen production and storage or for manufacturing of self-cleaning glass and coatings. Scientists are interested in special physical effects, connected with nanoscale dimensions of created materials, since these effects lead to amazing macroscopic properties of nanoproducts, very useful in solar power engineering.

Use of nanotechnologies allows to master new efficient and inexpensive methods of application of solar energy in all spheres of human life.



## 1. Introduction

As it is well known, the Sun is a primary and basic power source for our planet. The solar energy, coming from the Sun to the Earth in the form of sunlight, is an ecological and renewable power source. The Sun is the source of heat and light, without which the origin and existence of diverse life on our planet would be practically impossible. Already our deep ancestors understood that their existence significantly depends on the Sun**.** Solar energy is practically inexhaustible, complex and accessible at any country, at any point of the globe. The amount of sunlight, received by the Earth for 40 min, is quite enough for provision of the world population with electric energy during the whole year! Only 1% of conditional solar "fuel" per year (i.e. 1 bln. ton) can solve all power problems of humankind during the next hundreds of thousands of years.

Currently about 80% of the energy, consumed in the world, is received from fossil fuel. However, fossil fuel resources are limited, and their distribution on the Earth is nonuniform. During conversion of fossil fuel energy into useful energy through combustion inevitable pollution of the environment takes place that leads to global climate change and threatens the nature of the Earth. On the contrary, solar energy is widely accessible and weakly influences the environment and the Earth’s climate, so it is an attractive alternative power source.

In spite of high world rates of growth of solar energy based on photovoltaic conversion (30 - 40% per year during the last ten years), there is a huge gap between potential and real use of solar energy because of relatively high cost of solar cells (SCs) and not so high efficiency of conversion of solar energy.

Traditional fossil fuel satisfies our current demands for energy, as a much cheaper power source in comparison with solar energy, partially because fossil fuel represents itself a concentrated power source. For this reason important task for wider use of solar energy is increase of efficiency of solar energy conversion, the lifetime of SCs, and a decrease of their cost. Therefore, solar energy conversion in nanostructured interfaces is a very important topic both in scientific research activity and in applied work in the area of solar power engineering.

Solar radiation is not only the most plentiful power resource on Earth; it is also one of the most universal (multifaceted) resources of energy, allowing receiving heat, electric energy and fuel (Figure 1).

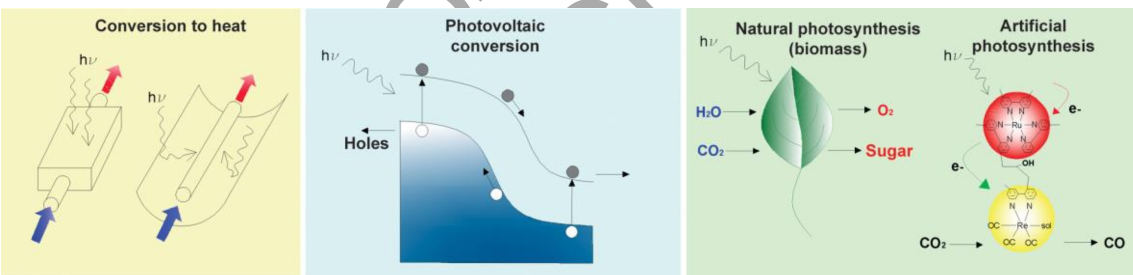


Figure 1. Conversion of quanta of sunlight into three forms of energy: heat, electric energy and fuel.

The basic physical principles, used in numerous devices and technologies of application of solar energy, are represented in Figure 2. It is necessary to distinguish methods of direct and indirect conversion of solar energy.

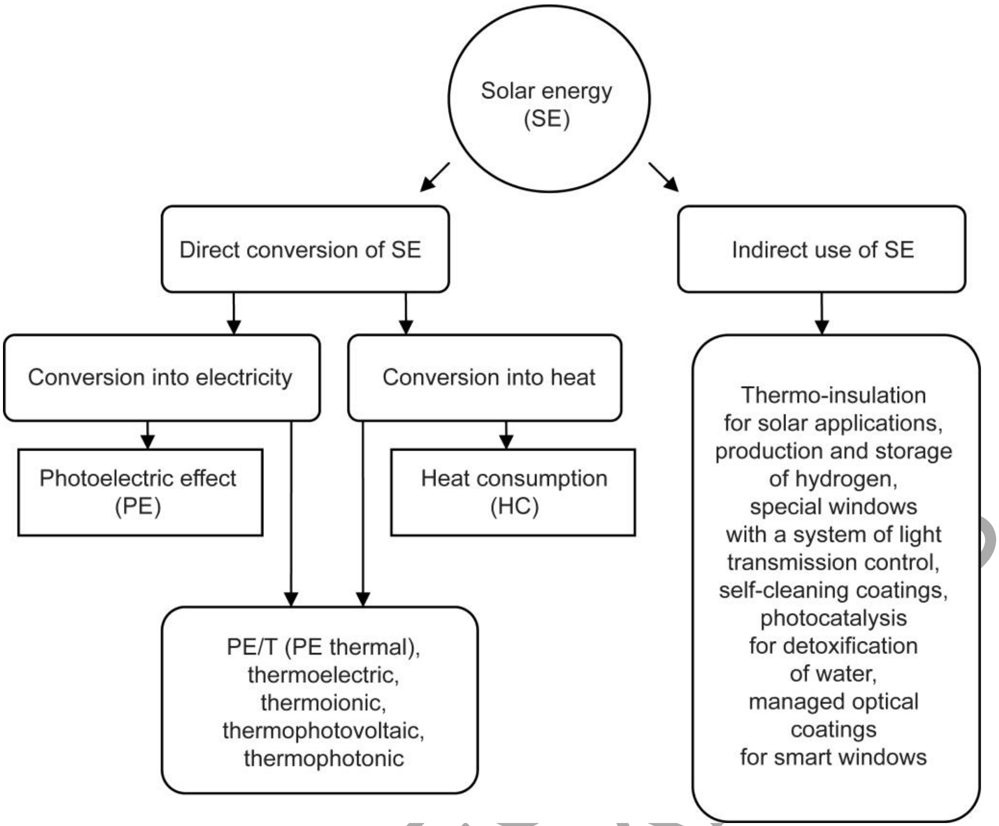


Figure 2. Main methods of solar energy conversion (both of current usage and under development).

## 2. Nanotechnologies for Solar Energy Conversion

There are at least two reasons for use of nanostructured materials in solar power engineering.

First of all, it can be explained by specific, unusual physical and chemical properties of nanostructures. The particle, containing only several atoms, for example $Au_3$, has properties, similar to properties of ordinary molecules. In the case of electronic states - they are discrete, valence electrons cannot form a conduction band, and clusters of this type cannot manifest metal behavior. At increases of size of a cluster up to several hundreds atoms, as, for example, for a cluster of $Au_{309}$ with a diameter of ~2 nm, its properties become closer to properties of a solid of gold, since a certain conduction band appears, and the cluster demonstrates metal properties. In many cases the range of dimensions, interesting for us, is close to dimensions of a transition zone, where properties change from molecular to volume. Exactly in this area properties can be adjusted specifically enough to develop special materials with specifically set properties for concrete applications.

The second reason of wide use of nanostructured materials in solar power engineering is connected with the advantages of serial production of SCs. For example, thin-film technologies are not power-consuming, and easily automated, similar to all continuous processes, unlike with traditional technologies of production of single-crystal silicon

SCs. Also technologies, which use new, for example self-assembling, principles, can be widely engaged.

In general, manufacturing technologies with application of nanostructures can be divided into four groups, represented in Figure 3. Nanotechnologies will create new instruments and applications, and also new possibilities for solar energy conversion. Integration of photo-electric elements into nanoelectronics and biological objects will extend.

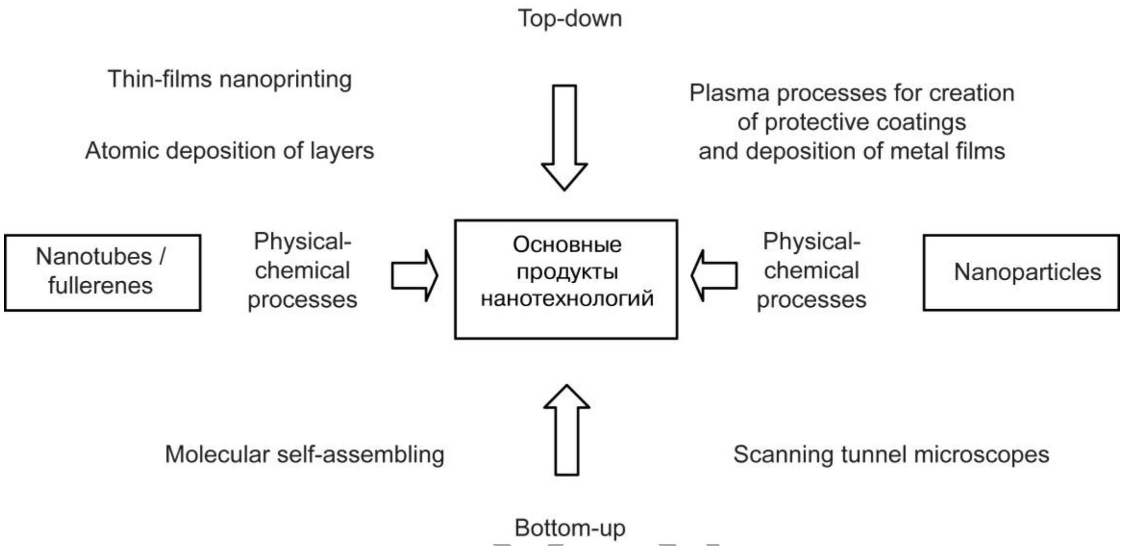


Figure 3. Nanotechnological methods.

*«Top-down» nanotechnologies*

Currently the most developed of the nanotechnologies can used in the semiconductor industry can be characterized by the «top-down» manufacturing principle. This industry rapidly conquers the nanoscale world and requires more and more high accuracy and more expensive equipment for semiconductor lithography nanoprinting can offer applications of a simpler process with use of relatively simple equipment. Traditional usage of transparent masks is replaced by printing. In deposition technologies significant attention is paid to such processes, as atomic deposition of layers and molecular beam epitaxy. These processes allow us to create layers with required parameters, both in reference to thickness and chemical composition. Creating layers one after another, it is possible to create specific structures with set properties.

Methods of plasma-enhanced deposition are based on the phenomenon of physical cathode sputtering (cathode represents itself a target) by accelerated ions of an actuation gas, bombarding a surface of a target under the action of applied negative potential. Clusters (nanoparticles) deposit on a cooled substrate, creating corresponding layers.

*Creation of nanoparticles*

The elementary process of creation of nanoparticles is based on a sol-gel method. At the first stage of a sol-gel process chemical composition of a product (chemical formula of substance and a ratio of components) is set, and then the product is created in the form of finely dispersed colloidal solution - sol. The size of particles of a disperse phase in stable sol is about $10^{-9}$-$10^{-6}$ m. Increase of the concentration of a disperse phase leads to formation of coagulation contact between particles and to the beginning of structuring - gelatinization (the second stage of sol-gel process).

Pyrogenic processes, known from ancient times, nowadays allow creating oxides on surfaces of metals, metalloids and their derivatives in a gas phase during oxidation of substance in a flame.

The technology of refining is a traditional process, which allows producing metal powders with micron dimensions and nanoscale grain structure. Chemical reactions, mechanically activated in the course of refinement, create nanoparticles in the form of nanoscale powder.

*Creation of Nanotubes /Fullerenes*

The main problems in the process of nanotubes manufacturing are their cost and purity. As a rule, mixture of several types of nanotubes is created. Depending on a particular process, their ratio can be changed. Specialists distinguish two kinds of processes according to corresponding temperature ranges: middle-temperature and high-temperature processes. The middle-temperature category includes the majority of catalytic processes, such as usual chemical vapor deposition (CVD), plasma enhanced chemical vapor deposition (PECVD), the CVD-method with use of a hot filament and the CVD-method with use of carbon monoxide at high pressure (HiPCo). Middle-temperature processes are especially useful for synthesis of multi walled carbon nanotubes (MWNT).

High-temperature processes include laser ablation and electric arc methods. By the addition of catalysts (Co, Ni, Fe and powder Y) it is possible to synthesize single walled nanotubes.

It is necessary to mark out that specialists also have developed methods of creation of carbon nanotubes and fullerenes by means of solar concentrators.

*«Bottom-Up» Nanotechnologies*

The last groups of nanotechnologies - «bottom-up» principle technologies imply individual manipulations of atoms and molecules. The most known instrument for this purpose is a scanning tunnel microscope. Advanced microscopes can cope with single atoms. Of course, such processes go slowly; therefore scientists actively search for optimum methods of self-assembling technologies.

## 3. Nanostructured Materials for Solar Energy Conversion

Fundamental properties of nanostructured materials currently are actively studied, since they have huge potential of application in such areas, as electronic devices, optoelectronics, optics, tribology, biotechnologies, medicine, etc. Material science, especially its branches concerning nanostructured materials (materials with nanoscale dimensions of structure), becomes more and more important for best conversion of solar energy from all points of view. Nanostructured materials, such as polycrystalline materials with nanoscale dimensions of crystallites (for example, nanocrystalline silicon), materials with nanoscale gaps between surface ledges (for example, on surface of titanium-aluminum nitride films), granulated or porous materials with nanoscale dimensions of grains (for example, titanium oxides), or nanoscale metal clusters, built into a dielectric matrix (for example, clusters of chromium carbide in diamond-like carbon), can be mentioned as examples. In Tab. 1 concrete examples of application of nanotechnologies in solar energy conversion are represented.

| **Material** | **Physical effect, created by nanostructures** | **Sphere of application** | **Degree of manufacturing application** |
|---|---|---|---|
| Nanostructured and nanoporous metal oxides, nanotubes from titanium oxide | Large area of active surface, high rate of diffusion | Sensitized by dyes solar cells | Pre-production models, pilot series |
| | Photochromic effect | Switched optical coatings (photochromic devices) for «smart» windows and semitransparent facades | Pre-production models, pilot series |
| | Photocatalysis | Water detoxication | Pilot samples |
| | Photocatalytic and hydrolytic effects | Self-cleaning windows | Serial manufacturing |
| | Production of hydrides | Hydrogen storage | Laboratory experiments, pre-production models |
| | Proton-exchange membranes | Hydrogen production | Experimental-industrial samples |
| Nanostructured semiconductors | Optical-electric properties of multiquantum wells | Quantum well solar cells | Laboratory experiments |
| | Luminescence in quantum-dimensional structures | Quantum dot luminescent solar concentrators | Laboratory experiments |
| Nanostructured and nanoporous insulators | Dependence of thermal conductivity on dimensions of elements | Heat insulators | Experimental-industrial samples, serial manufacturing (aerogels) |
| | Optical properties | Low-reflective surfaces | Pilot samples |
| Carbon nanotubes, containing polymers | Dissociation of excitons, carrier transfer | Polymeric solar elements | Laboratory experiments |

| | | | |
|---|---|---|---|
| Embedded metal nanoclusters | Optical and electronic properties of nanoclusters | Selective coatings for solar absorbers | Large-scale industrial production |
| Polymers, doped by nanoparticles | Selective optical absorption (plasmon) | Management of light transmission through windows | Laboratory experiments |
| Nanostructured surfaces | Nonwettability («effect of lotus») | Self-cleaning surfaces | Laboratory experiments |

Table 1. Nanostructured materials for solar energy conversion, used directly or indirectly

Interest to special physical effects, pertaining to nanoscale dimensions, constantly grows, since these effects lead to very interesting macroscopic properties with wide areas of application in solar power engineering.

-

-

-



**Bibliography**

Andreev V.M. (2007). Nanoheterostructure photoelectric converters of solar energy. *Alternativnaya energetika i ekologya*, No. 2, p. 93-98. [In Russian]. [The basic directions of research in the area of application of nanotechnologies in photo-energy engineering are considered].

Crabtree G. W., Lewis N. S. (2007). Solar energy conversion. *Physics today* 60(3), p. 37-42. [The brief review of methods of conversion of solar energy into heat, electric energy and fuel].

Green M. A. (2003). *Third Generation Photovoltaics: Ultra-High Efficiency at Low Cost*. 160 pp. Springer-Verlag, Berlin. [New approaches to creation of solar cells of the third generation are considered in details].

Iwamoto M., Kaneto K., Mashiko S. (eds). (2003). *Nanotechnology and Nano-Interface Controlled Electronic Devices*. Elsevier, 511 pp. [Different aspects of nanotechnologies (from one-molecular electronics to methods of control and corresponding technologies) are considered in details].

Kazmerski L. L. (2006). Solar photovoltaics R&D at the tipping point: A 2005 technology overview. *Journal of Electron Spectroscopy and Related Phenomena*, 150, p. 105–135. [Current situation in the area of photoelectric conversion of solar energy is represented and ways of its development with detailed consideration of characteristics of solar cells and modules are discussed].

Parashchuk D. Yu., Kokorin A. N. (2008). Modern photoelectric and photochemical methods of solar energy conversion. *Ros. Khim. Zh*. (Zh. Ros. Khim. ob-va im. D.I. Mendeleeva), LII, No. 6, pp. 107-117. [In Russian]. [A review of photoelectric and photochemical methods of conversion of solar energy].

Soga T. (ed.) (2006). *Nanostructured Materials for Solar Energy Conversion*. Elsevier B.V. [Use of nanostructured materials and nanotechnologies for photoelectric conversion of solar energy is considered].

**Biographical Sketch**

**Igor Ivanovich Tyukhov,** Dr., Associate Prof. of the Moscow State University of Mechanical Engineering (UMech), Institute of Environmental Engineering and Chemical Engineering, UNESCO Chair “Ecologically Clean Engineering” and the Deputy Head of the UNESCO Chair «Renewable energy sources and rural electrification» (part time) at the All-Russian Scientific Institute of Rural Electrification, a member of the International Solar Energy Society (ISES), the Associated Editor of the journal *Solar Energy*. The sphere of his scientific interests includes photoelectric technologies. He has been affiliated with the Moscow Power Engineering Institute for more than 30 years teaching various physics disciplines (from general physics to solid state physics, photoelectricity and semiconductor lasers) and conducting research work on solar energy, solar concentrators, optical metrology, semiconductor physics and technology, solar cells. He worked as an invited professor at the George Mason University (1999-2000), the Oregon State University (2002-2003), and the Oregon Technological Institute (2003). He is the expert of the TEMPUS program. He is the co-author of the monograph «Space educational techniques: investments into the future (theory and practice) » edited by M. A. Shahramanjan, I. I. Tyukhov, N. S. Voshchenkova (Kaluga: Institute of professional development of educators, 2009). He is the author of more than 300 papers, patents, and book chapters.