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NEW ENERGY SOURCES AND ENERGY SAVING TECHNOLOGIES

In the age of globalization the problem of energy and energy sources grows into the problem of survival of our civilization.

During the second half of the XX century two facts were realized – that the world reserves of traditional fuels (coal, oil, natural gas, uranium ore) on the Earth are limited and that industrial development and "classical" production of electric power strongly threaten the environment and human health. The stimulus for development of alternative energy sources was given by the danger of ecological disaster – greenhouse effect leading to global warming and climate change, as well as by permanent rise of fuel prices and the outlining global energy crisis.

Renewable ecologically clean energy sources, rational production and use of energy are already elements of energy policy in many countries. At this stage of development of the human civilization the efforts are directed to the use of renewable energy sources based not on exhaustible reserves, but on the use of natural energy flows. They do not pollute the environment and do not endanger human health.

What can alternative renewable ecologically clean energy sources be? It can be the use of energy from the Sun, power engineering based on atmospheric processes and their control, regulation and management – wind energy, whirlwind processes in the atmosphere (cyclones, hurricanes, tornados, electric storms, etc.); the use of energy of geogenesis (geothermal energy, energy of the sea and ocean waves, tsunamis, etc.); the use of waterfall energy. Water, respectively water sources – seas and oceans, are a tremendous source of energy. It can be the use of some chemical productions – e.g., connected with production or emanation of hydrogen, ammonia, carbon oxide, etc. Hydrogen emanated from water electrolysis can be used as a source of energy. It can be some biochemical processes going with emanation of hydrogen and other sources of energy, such as duckweed, some plants, etc.

The European Union faces two great challenges: growing electric power deficit and the problem with the increased emanation of greenhouse gases in spite of the global concern and the Kyoto Protocol undertakings.

In the preface to the Bulgarian national program for energy efficiency it is written: "Following crime and corruption, energy consumption is the third factor pulling our economy backward. If the state does not conduct a purposeful policy on decreasing of energy consumption, the latter will continue "eating up" the share of salaries and other expenditures. Both competitiveness and quality of Bulgarian goods and services will lag behind those of the common market. Revival of economy and successful European integration will remain an unrealizable dream. Social tension will grow up in view of impossibility to cover energy expenditures in private and budgetary spheres. National independence and security will be insufficient.

Saving energy and renewable energy sources are the first priorities in the energy policy of the country. The program is worked out on the basis of experience of 55 countries. It comprises 6 main spheres: macroeconomic and branch dynamics, industry, service sector, transport, effective lighting, energy sector. The state and development for each sphere is analyzed till the year 2020.

Development of the domestic competitive energy market, integration of the Bulgarian energy system and energy control with the European ones, providing of social justice are defined as basic priorities of the Bulgarian energy policy. Bulgaria is in the process of liberalization of its energy market and introduction of competitive rules in its functioning. It is necessary to note that interaction between science, policy, government, society, respectively production and consumption is of great importance for prosperity of a country. It is very important for our power industry as a strategic branch, especially on the background of the existing realities connected with fossil fuels and permanent increase of prices for electric power.

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NACID is a governmental institution affiliated to the Ministry of Education and Science. NACID collects, processes, maintains and disseminates reference and analytical information to support the national policy in the field of education, science and innovation as well as to support Bulgarian research bodies, individual researchers and SMEs.

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- Providing information about national, European and trans-European research programs.
- Performing the functions of a National Centre for Academic Recognition and Mobility within the ENIC-NARIC network.
- Performing the role of institutional contact point of the Seventh Framework Program in Bulgaria.

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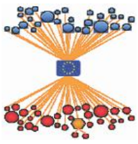

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NATIONAL SCIENTIFIC PROGRAMMES WITH EUROPEAN DIMENSIONS

SOLAR CELLS TECHNOLOGY ON THE BASE OF III–V HETEROSTRUCTURES

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Abstract
This paper describes the objectives and scope of the work carried out under National Science Programs (New Energy Technology) of the National Science Fund at the Ministry of Education and Science in Bulgaria. A group of three partnering institutes takes part in the present project. They are: Central Laboratory of Solar Energy and New Energy Sources (CLSENES) at the Bulgarian Academy of Sciences, Central Laboratory of Applied Physics (CLAP) in Plovdiv and Semiconductor Physics Chair (SPC) at the Physics Department (PD) of Sofia University St. Kliment Ohridski (SU) . The present contract aims at addressing the challenges associated with the development of low-cost high-efficiency III-V solar cells in Bulgaria. The duration of the contract is three years. At the first stage of the work high efficiency single-junction solar cells on the base of multilayer AlGaAs/GaAs heterostructures were fabricated.

INTRODUCTION

The photovoltaic conversion of a high concentrated solar radiation is one of the most promising ecological methods for electricity production. In a concentrator system ultra-high efficiency solar cells enable greater electric power generation capacity and thus reduce the cost per watt. These systems will typically work at very high concentration levels of 500-1000 suns. In this case, the cost of the photovoltaic receiver is not price limiting, and expensive high-efficiency solar cells can be used. Especially multijunction III-V heterophotocells making use of the full spectrum of solar radiation are well suited.

Among III-V materials GaAs as a basic material is the best one to provide the most effective conversion of sun light in single-junction solar cells. The high efficiency single-junction solar cells have been developed on the basis of a multilayer AlGaAs/GaAs heterostructures. The highest one-sun AM 1.5 efficiency for single junction GaAs solar cells of 24.8% and a concentrator AM 1.5 efficiency of 28.7% at 200 suns have been demonstrated by Spire Corporation, USA [1]. Single-junction GaAs solar cells for very high concentration ratio have been developed at Ioffe Physico-Technical Institute, Russia and Institute of Solar Energy in Spain. The efficiencies of 26.2% (AM 1.5) at 1000 suns [2] and of 23% (AM 1.5) at 5800 suns have been achieved in the developed cells [3].

The efforts to improve solar cells efficiency have involved development of various types of multijunction cells. The multijunction cell divides the solar spectrum into two or more portions: the photons in each partition are absorbed by separate subcell. The subcell materials are chosen for a combination of band-gaps that together yield a more efficient match to the solar spectrum than can be attained with only one material. The conversion efficiency more than

35% has been reported by many authors [4-10] for 3- and 4-junctions cells. The highest conversion efficiency of 40.7% up to date was received for Spectrolab 3-junction solar cells [10].

This project seeks to develop technologies that can provide cost-effective electricity generation. One strategy to reduce cost is to use concentrating optics to focus the sunlight on small high-efficiency solar cells. Multijunction solar cells have achieved the highest efficiency and have theoretical potential to achieve efficiencies equivalent to or exceeding all other approaches.

OBJECTIVES

The present contract aims at addressing the challenges associated with the development of high-efficiency III-V solar cells in Bulgaria. The duration of the contract is three years. As the contract has just started, this paper will focus more on the objectives and scope of the work to be performed, and less on specific results.

The goal of this contract is to develop low-cost, high-efficiency III-V solar cells, working at high concentration levels of light.

Specific objectives are:

1. To develop multilayer AlGaAs/GaAs heterostructures for single- and two-junction solar cells;
2. To design and fabricate high-efficiency, high-reliability concentrator cells;
3. To demonstrate ultra-high-efficiency (capability of 35-40% efficiency) with concentrator cell approaches.

KEY TECHNOLOGY FOR SOLAR CELL PERFORMANCE

Various techniques have been investigated principally for high efficiency multijunction solar cell performance:

• Mechanically stacked solar cells. The subcells in these cells are fabricated on separate substrates and assembled one over the other by means of an adhesive layer. This device is also a four terminal system. The primary advantage is that the subcells are the best achieved cells actually available today. The second advantage is in versatility of the four-terminal system, which allows many series or parallel configurations. The disadvantages are the necessity of a very good precision in grid alignment and an increase in optical losses by absorption in the base of the higher bandgap cell and reflection at the two cells interface.

• Monolithically grown cells. They constitute the second promising in the high efficiency challenge match. The multijunctions are realized in materials with different bandgaps, grown on the same substrate. It is the most interesting configuration but in practice it involves some difficulties. The main problems are due to mismatches in the lattice constants and the thermal expansion coefficients of the materials.

1. AlGaAs/GaAs tandem solar cells

Monolithic two-junction solar cells based on the material system AlGaAs/GaAs offer the promise of high-efficiency conversion for concentrator-based terrestrial photovoltaic power systems. The lattice matched AlGaAs/GaAs materials with a mature growth technology remains attractive for high performance. Through a study on lattice matching with GaAs and applicability to tandem solar cells, AlGaAs with 35% AlAs content was selected as a material for wide-bandgap solar cells. Compared with a GaAs single junction solar cell the theoretical solar cell efficiency improved from 28 to 35% due to a remarkable increase in output power at wavelength between 300 to 650 nm.

A schematic cross section of an AlGaAs/GaAs two-junction solar cell is shown on Fig. 1. Obtaining high efficiency requires work on several technical points: improving solar cells performance of both AlGaAs and GaAs single-junction solar cells; reducing both electrical and optical power loss at the GaAs tunnel junction cells, and reducing surface reflectivity of the cell.

In two-junction solar cell fabrication, about fifteen crystal layers are successively grown on a GaAs substrate in a wide range of carrier concentrations and thicknesses between 10 nm and 3.5 μm. In order to grow each layer with precise carrier concentration and thickness, we selected the low-temperature Liquid-Phase Epitaxy (LPE) method. This is the most simple and safe method for producing high quality AlGaAs/GaAs heterostuctures for high efficiency solar cells. The high quality in terms of lifetime, mobility and freedom from defects of the LPE layers derive from growth under near equilibrium conditions and the cleansing action of the Ga, by which impurities are retained in the liquid rather than being incorporated in the growing crystal. The crystallization process in the temperature range 550-400°C makes it possible to grow layers as thin as 2-20 nm, as well as layers, which are several

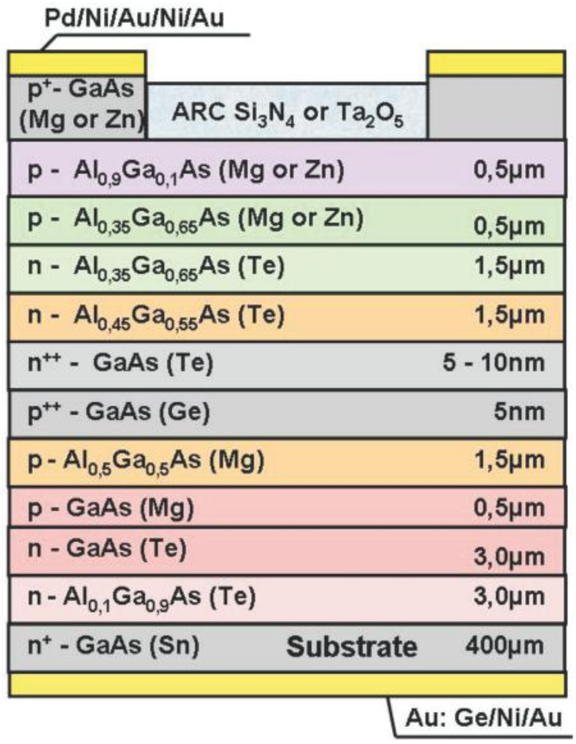

Fig. 1. Schematic cross section of an AlGaAs/GaAs two-junction solar cell

microns thick, with a smooth surface and flat interfaces.

1.1. GaAs single junction solar cell

At the first stage of the project we introduced improvements in single-junction GaAs solar cells for increasing their efficiency under high concentration levels. The GaAs solar cell is suited for a bottom subcell in monolithic two-junction AlGaAs/GaAs tandem.

Thin film multiheterostructures for solar cell application were grown by low temperature LPE. The aim of the work is to optimize the layer thickness, doping and composition, in order to ensure high efficiency solar cell fabrication.

The developed structures consist of several layers grown on a highly conducting GaAs substrate: n-GaAs base, p-GaAs emitter embedded between two AlGaAs layers, and heavily doped p^+GaAs surface contact layer. The second 0.03 µm thick "window" AlGaAs layer has band gap energy of 2.1 eV and ensures penetration of the higher-energy photons in the active region of the p-n junction. The optimized heterostructure has a back-surface-field (BSF) AlGaAs layer of several microns and an ultrathin (20-40 nm) window layer providing the best conversion efficiency and maximum spectral response in the range 300-900 nm.

The electrical and optical parameters of the multilayer heterostructure as well as the layer's thickness are designed by numerical simulation using a computer modeling. This is an important premeditated step for optimization of technological parameters of different layers in the multilayer structure of the device and decreases the number of experiments needed. For that purpose PC1D device simulator was used. We calculated solar cells output parameters (short circuit current Jsc, open circuit voltage Uoc at solar spectrum AM 1.5), taking into account many material and structure parameters. Using calculated and experimental data we have optimized the layer structure, which was further confirmed by SEM and EDX and Raman Spectroscopy measurements. The scheme of the optimized structure is shown in Fig. 2.

The measured layer thicknesses of the grown structures are near to those of the model solar cells structure.

High efficiency solar cells on the base of $pAl_xGa_{1-x}As$/ pGaAs/nGaAs heterostructures grown by LPE were fabricated. The high conversion efficiencies are due to the optimal thicknesses and doping of the photoactive region and the high AlAs molar fraction (x = 0.8-0.9) of the thin (about 30 - 40 nm) window layer, used also for surface passivation. The high conversion efficiencies are also due to the heavily doped p^+GaAs capping layer, grown on the surface of the structure, providing low-resistance contacts.

The external quantum efficiency (EQE) of solar cells with and without antireflection coating (ARC) was measured. The measurements were carried out in the spectral range of λ = 340 - 920 nm. The evaluation of the photoresponse is in absolute units due to comparison of the test structure photocurrent magnitude with that of a calibrated reference cell (NASA Lewis Research Center) at monochromatic illumination. A two-

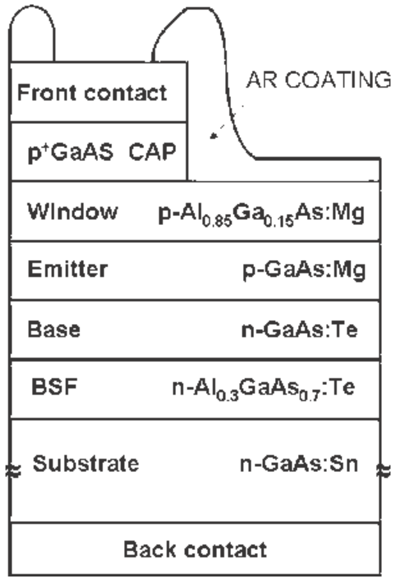

Fig. 2. Cross section of single-junction GaAs solar cell structure

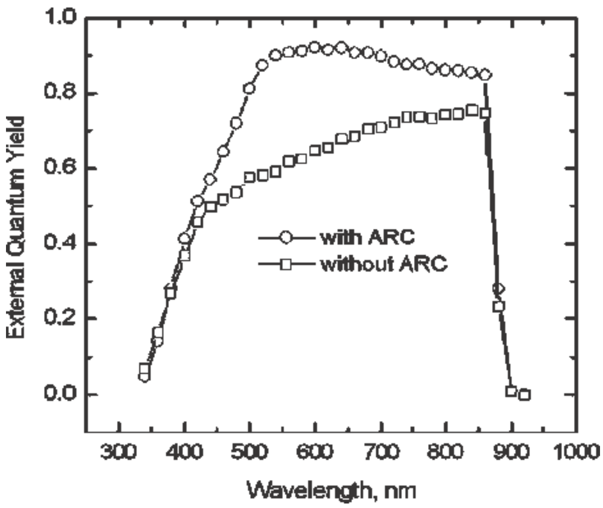

Fig. 3. External Quantum Yield of the single-junction GaAs solar cell

layer ZnS/MgF_2 antireflection coating was deposited on the cell surface. Fig. 5 shows the EQE of multilayer structures with and without ARC. The EQE is increased by the deposition of the ARC and reaches values as high as 90-92 % for 540-700 nm wavelength range. The ARC slightly lower values of efficiency for the long wavelength region of the spectrum are due to the non-optimized thicknesses of the ARC layers. The thin $Al_{0.8}Ga_{0.2}As$ window layer is transparent to most sunlight, and eliminates the surface states and other imperfections on the GaAs p-n junction surface that would ordinarily result in a high recombination velocity and ensure high EQE values down to 400 nm wavelength.

1.2. AlGaAs single-junction solar cell

Development of a single-junction AlGaAs cell is of interest for application as a top cell in the two-junction solar cell.

The use of AlGaAs for the top cell on GaAs largely avoids lattice mismatch, but introduces the problem of obtaining adequate minority carrier lifetime in material with high aluminum content. The best quality $Al_xGa_{1-x}As$ layers (x=0.3-0.5)

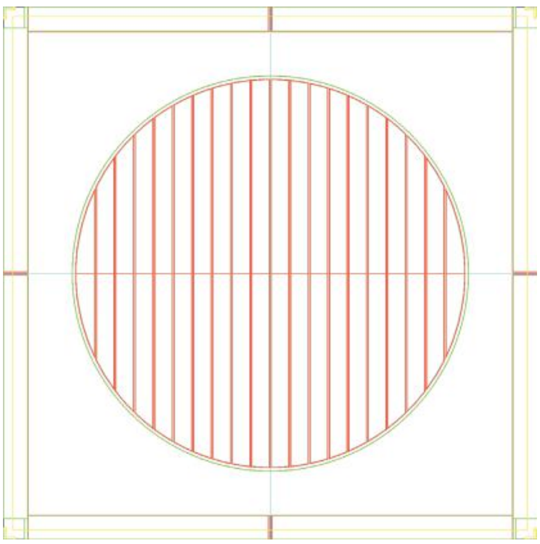

Fig. 4a. Design of photomasks: Mask 1-black, Mask 2 - red, Mask 3 - green, Mask 4 - yellow

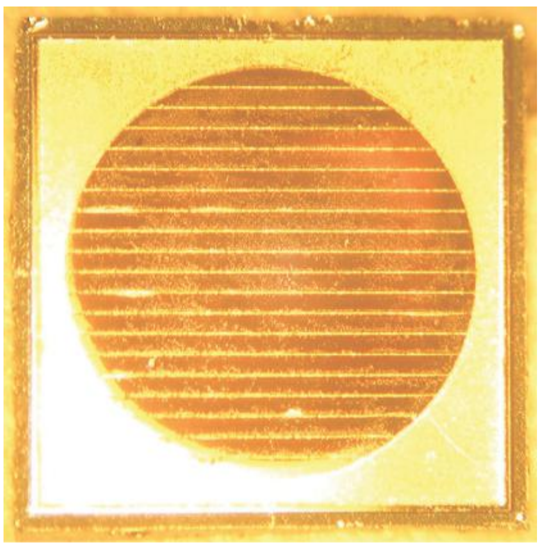

Fig. 4b. Photograph of a GaAs solar cell

can be obtained by LPE growth. High-quality multilayer $Al_{0.35}Ga_{0.65}As$/GaAs heterostructure for single-junction solar cells were fabricated by low-temperature LPE. By using highly sensitive time resolved photoluminescence, minority carrier lifetime higher than 10 ns for our best solar cell structures was measured. Solar cells made on the base of these structures are sensitive in the spectral range 300-650 nm and the EQE peak is higher than 90%.

SOLAR CELL DESIGN

A set of 4 masks for a chip with a multiplication step of 2.75 mm is developed,the chip size being (2.75x2.75) mm^2. The design of the mask and a photo of a GaAs solar cell are shown in Fig. 4a, b.

The active area of the chip is 3.14 mm^2- a circle with a diameter of 2mm. With mask 1 (Window) the contact p^+- GaAs layer is etched off selectively until the window is open in the regions outside the contact grid. Mask 2 (Contact) forms the face metal grid, using a "lift-off" photolithography. The width of the metal lines is 8 μm, while the space (illuminated window) between the lines is 92 μm.

After the deposition of a two-layer ARC on the solar cell face, the unnecessary layer of the contact pads is removed with mask 3 (ARC). The coating remains only on the solar cell active area - the central circle with a diameter of 2 mm.

At the end, using mask 4 (Mesa), individual solar cells are divided by mesa etching.

An option of depositing the p+ contact layer directly over the emitter layer under the window is envisaged. If this technological version with the contact layer under the window is realized, the total number of masks will be reduced to 3.

CONCLUSION

High-efficiency single-junction GaAs and AlGaAs solar cells have been fabricated on the base of multilayer AlGaAs/GaAs heterostructures grown by low-temperature LPE. At the second stage of the work two-junction monolithic AlGaAs/GaAs solar cells will be prepared. Another field of interest is a development of infrared-sensitive solar cells based on GaSb that can be mechanically stacked under AlGaAs/GaAs solar cells. The efforts aim at establishment of a technology for high-efficiency solar cells on the base of III-V heterostructures.

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THIN FILM OPTICAL COATINGS FOR EFFECTIVE PHOTOTHERMAL SOLAR ENERGY UTILIZATION

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Abstract

Thin film optical coatings for effective solar energy utilization cover basically two areas; the first one is electrochromic materials and devices and the other - spectrally selective absorbing coatings. The first group of materials is related to "smart windows" applications, the second group comprises solar absorbers for collectors and solar installations. Smart windows can dynamically control the energy of the flux entering a building or automobile, while the solar absorber is supposed to strongly absorb the solar light, converting it into heat and transferring the generated heat through a metal substrate to a working fluid. The solar absorber should posses a spectral profile which assures low thermal emittance, which means high infrared reflectance. We will first start with the electrochromic optical coatings which are our recent interest.

In this paper we will present our research related to the electrochromic materials and devices developed in the Central Laboratory of Solar Energy and New Energy Sources, Bulgarian Academy of Sciences.

ELECTROCHROMIC MATERIALS, BASIS AND APPLICATIONS

Transition-metal oxides exhibit a wide variety of structures, properties, and phenomena. Their unusual properties are related to the unique nature of the outer d electrons and therefore the d-band defines interesting electrophysical and optical properties of transition metal oxides [C. N. R. Rao and B. Raveau, 1998, C. G. Granqvist, 1993]. The chromogenic behaviour presents a specific characteristic of the transition metal oxide films, which show a reversible modulation of optical characteristics under influence of external factors. The induced change in the optical absorption retains even when the excitation source is removed. Electrochromism has been discovered in several different metal oxides and all the pertinent metals are localized in a well-defined area of Periodic table [Granqvist, "Handbook of Inorganic Electrochromic Materials", Elsevier Science, 1995]. All these metals belong to the transition series. This experimental fact suggests a closed relation between the electrochromic properties and the electronic structure. Electrochromic materials are exclusively interesting due to a variety of potential applications, including elements for information displays, antiglare rearview mirrors, sunroofs and smart windows. The corresponding optical states: coloring (high absorptive state) and bleaching (transparent state), as mentioned above, can be induced by various types of external factors [C.G. P.M.S. Monk, R.J. Mortimer, P.R. Rosseinsky, 1995, S.K. Deb, 1969, S.K. Deb, 1992].

The insertion and extraction of ions (causing the color change in the materials) are often called intercalation and deintercalation, respectively. Due to well established research done on electrochromic effect and materials for optical applications, the terms "colored" and "bleached" are commonly used in literature.

Electrochromism

Electrochromism is a phenomenon connected with a color modulation caused in the material by an external applied electric field or voltage [M.S. Monk, R.J. Mortimer, P.R. Rosseinsky, 1995, Granqvist, 1995].

Nowadays investigations and studies reveal the principal essentiality of electrochromism: on the one hand, basic definitions and electrochromic characteristics have been determined as well as groups of materials, which exhibit EC properties, and on the other hand the place of electrochromism as a subject of solid state ionics has been established.

The main characteristics describing EC effect are the following: *Color efficiency (CE)* - this quality can be regarded as the electrode area

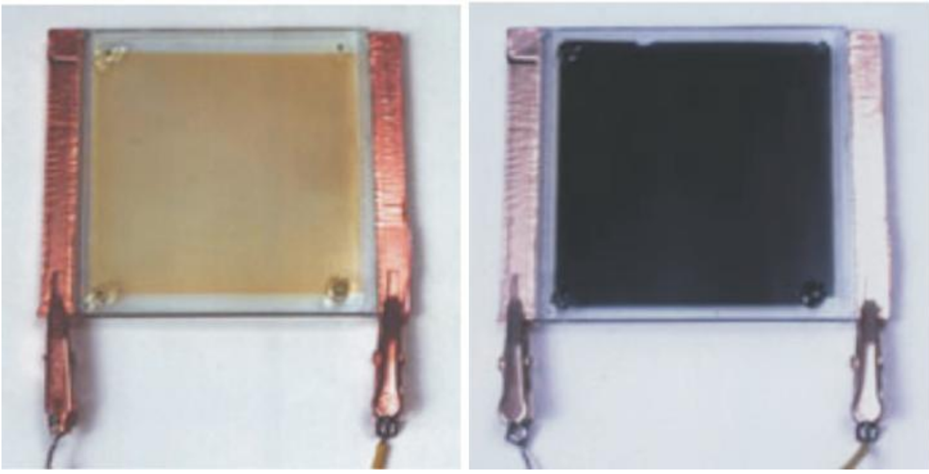


Fig. 1. Electrochromic cell in transparent and colored state

which may be colored to unit absorbance by unit charge [P.M.S. Monk, R.J. Mortimer, P.R. Rosseinsky, 1995]. CE value has a positive sign for cathodic induced coloration and a negative one for anodic electrochroms. Experimentally, color efficiency qualifies modulation of optical properties. This quantity is strongly dependent on the wavelength and changes in the optical density (ΔOD). It can be determined by the equation:

CE = ΔOD/Q,

where ΔOD represents the change in single-pass, transmitted optical density at the wavelength of interest λ, because of transfer of charge Q.

Cycle Life – this is a measure for the stability of an electrochromic film or device, being the number of cycles possible before failure or malfunction.

The Insertion Coefficient - Electrochromic effect occurs when the charge as electrons and positive ions (M^+) is inserted into the solid film (MeO_3). The reaction product is M_xMeO_3, where x is the number of ions entering the film structure and is called *insertion coefficient*. The value of x depends on the charge passed and hence on the extent of electrode reaction.

Electrochromism can be described as a characteristic of a multilayer system – a device, although the device optical function is dominated by one functional active layer [P.M.S. Monk, R.J. Mortimer, P.R. Rosseinsky, 1995]. Many different EC device constructions are possible, but all they can be described only as variants of one basic design, presented in Fig. 2 [N. R. Rao and B. Raveau, 1998]. The most general description is that electrochromic cell consists of two glass substrates covered with transparent and electrically conducting film. Between them an active working electrode (EC film) is situated, followed by ion conductor (or electrolyte) and a counter electrode.

Transparent electrodes can be any high transparent IR reflectors, such as doped oxide semiconductors: In_2O_3:Sn; SnO_2:F; SnO_2:Sb, ZnO:Al or Cd_2SnO_4. There are several standard techniques for producing these coatings, which are commer-

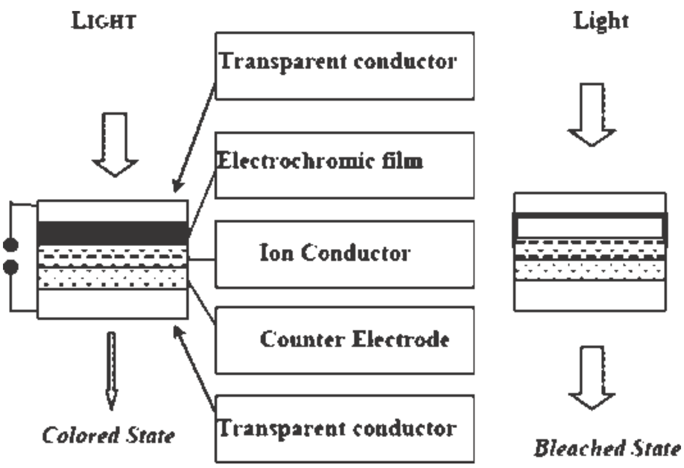


Fig. 2. Basic design of an electrochromic device

cially available [J.S.E.M. Svensson, C.G. Granqvist, 1985].

Electrochromic (EC) films are deposited on the transparent conductor and must possess a mixed conductivity for ions and electrons. When the intercalation of small ions from the neighboring ion conductor begins, an opposite balancing electron flux will be created, which is assured from these transparent conductors [N. R. Rao and B. Raveau, 1998, P.M.S. Monk, R.J. Mortimer, P.R. Rosseinsky, 1995]. Electrochromic film acts as a working electrode, after applying the voltage between the two transparent conductors a spontaneous intercalation of small ions begins from the ion conductor and electrons from the conductors. The electron injection invokes modulation of the optical properties of the EC film; meanwhile the alkali ions balance the charge difference. *Ion conductors* may be liquid, solid or polymeric types. The solid electrolytes are also divided in two groups: a bulk-like and in a form of a thin film. The bulk-like electrolytes use proton type conductors such as phosphorous-tungsten acid, zirconium phosphate [P.M.S. Monk, R.J. Mortimer, P.R. Rosseinsky, 1995, K. Kuwabara, K. Sugiyama, M. Ohno, 1991]. Antimonium oxides are also incorporated in EC cell prototypes, many investigations were carried out for $HSbO_3.2H_2O$ or $Sb_2O_5.pH_2O$ [K. Kuwabara, Y. Noda, 1993]. *Counter electrode* is a very important part of the EC device. During the past years, most scientific studies are focused on the discovery and investigations of electrochromic properties in different materials in the form of thin films. But successful work of the EC device requires finding of suitable counter electrodes [P.M.S. Monk, R.J. Mortimer, P.R. Rosseinsky, 1995, Ceccato, R., Carturan, G., Decker, F., Artuso, F., 2003, A. Pawlicka, C.O. Avellaneda, 2000].

Electrochromic Materials

Transition Metal Oxides

Significant feature of the electrochromic metal oxides is their crystallographic structure [C.G. Granqvist, 1994], consisting of a general building item, which is MeO_6 octahedron with a metal atom Me located in the center, surrounded by six oxygen atoms. These structural items can be bonded together by shared edges and corners, so they can generate a variety of crystal configurations. There are three main groups of crystal structures, characteristic for the EC transition metal oxides: defect perovskite - like, rutile – types, layered and block structures.

Smart Windows

Future needs of energy efficient buildings put apart requirements and higher standards for the used windows: they must reduce the heat loss, prevent overheating and assure comfortable daytime lighting. Glazing is increasingly required to meet multiple,and often conflicting,performance objectives, as: (i) to minimize solar gains to reduce cooling energy consumption and peak electric demand, (ii) to transmit daylight by decreasing lighting energy consumption and electric demand, (iii) to improve occupant visual comfort by minimizing the glare and providing access to clear views of the exterior, (iv) to maintain thermal comfort by minimizing heat losses, and (v) to reduce heating energy consumption by utilizing solar gains for passive solar heating. The ideal glazing must therefore be able to respond to a wide range of conditions in order to achieve various energy and comfort objectives. Conventional glazing, such as clear, reflective, and tinted offers limited control of the above performance criteria since their properties remain static over the broad range of environmental conditions. Therefore, often one performance criteria is met at the expense of another.

The most suitable device configuration as smart windows is the one described on Fig. 2. The most proper construction of EC device applicable as smart windows is the above described five-layered structure. Static state-of-the-art glazings for architectural window applications are reaching their physical limits when it comes to improving the energy efficiency of the building. Using thin film technology it is possible to achieve close to zero thermal emittance leading to "low-e" windows with low U-values. Furthermore, "solar control" windows having twice as high light transmittance (T_{vis}) as solar transmittance (T_{sol}) leading to solar heat rejection with maintained high visual transmittance are manufactured on a regular basis.

A subsequent possible step towards improved glazing energy efficiency may be through the use of switchable (variable transmittance) windows, or smart windows. These windows are desirable to regulate the solar radiation in the range of 300 – 3000 nm. So, it must be pointed out that additional to the color change, which can be observed with the eye (that is in the visible spectrum 400 – 700 nm), the electrochromic windows may also have regulated transmission properties in the other parts of the electromagnetic spectrum in the UV range (for wavelength below 400 nm) and near infrared radiation NIR (700 – 3000 nm). Large-area electrochromic windows have very recently become available in very limited quantities. Samples of these windows have been installed in two side-by-side private office test rooms, enabling researchers to conduct full-scale monitored tests [Kraft, M. Rottman, K.H. Heckner, 2006, A.W. Czanderna, D.K. Benson, G.J. Jorgensen, J. Zhang, C.E. Tracy, S.K. Deb, 1999].

Basic properties and requirements that need to be fulfilled for large area applications of smart windows [N.A. O'Brien, J. Gordon, H. Mathew, B.P. Hichwa, 1999] are: continuous range in solar and optical transmittance, reflectance, and absorptance in bleached and colored states; a contrast ratio at least 5:1 (maximal transmittance/minimal transmittance); a switching speed (switch from colored to bleached state and vice versa) to be a few minutes; thermal and UV stability. The EC windows must survive temperatures between - 80°C and 120°C; switching with small applied voltages in the range of 1 - 5 V; open circuit memory to be several hours (this means the EC device should keep its transmittance state (colored or bleached) without corrective potential impulses); neutrality of color is particularly desirable for EC architectural windows, where the color of the interior furnishing could be affected by non-neutral transmitted color of the electrochromic windows. Also, the neutrality comforts eyes sighting; large area with excellent optical clarity and uniformity; to possess sustained performance for 20 – 30 years (meaning good cyclic lifetime more than 10^7 cycles); mechanical durability [G. Tulloch, I. Skryabin, G. Evans, 1997], acceptable cost.

To improve overall performance and user satisfaction, from the EC windows is expected to be controllable by both the user and an automated system. An automated system cannot fully accommodate occupant preferences for illuminating a given task type, position, and field of view as well as addressing conditions and concerns including glare, direct sun, privacy, view, brightness, color rendition and a multitude of others. Energy-efficiency algorithms are best implemented with permission of the occupant and may require that the occupant relinquish some autonomy regarding the system during critical peak energy use periods. For public (lobbies, glazed hallways, cafeterias, etc.) or open-plan shared spaces, some lack of autonomy regarding the window system may be acceptable to occupants. Multi-pane windows will allow more flexible control than a single-opening window. Failure analysis has formed a key element in the EC design of the device. Two basic reasons can exist for device failure: i) Overvoltage (thermodynamic limit) - the applied voltage should not be higher than the potential required for the destructive side

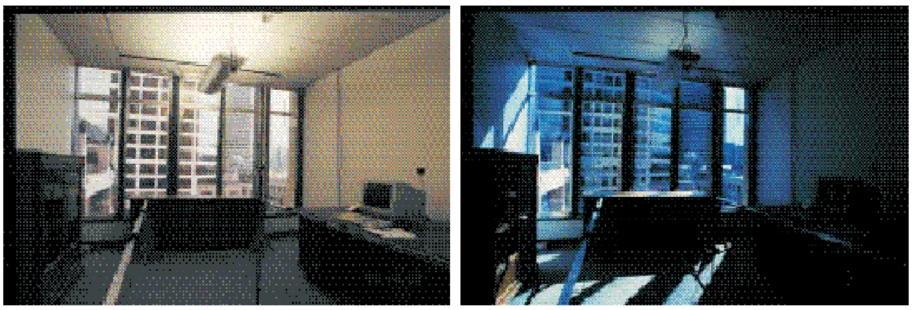


Fig. 3. Interior view of test room on a partly cloudy day, February 23, 2000. The electrochromic windows are in the dear state at 10.30 under diffuse light conditions (left). When sun enters the windows, the electrochromic switches to its colored state by 10.50 (right).

reactions. ii) Excessive charging current (kinetic limit) – high current causes an irreversible Li trapping in the film surface.

Some EC properties of the smart windows as redox potentials, resistance, diffusion coefficients are temperature dependent and required adjustments in switching parameters for changing environment conditions. [www.epsilon-web.net/Ec/manual/ Techniques/CycVolt/cv_analysis.html].

EC windows have some particularities which must be studied by large area tests. These tests are essential for understanding how electrochromic windows will perform in actual buildings. Unlike many energy-efficient glazing technologies, electrochromic glazings have size-dependent characteristics. For example, the switching speed of a 1x2 device will be faster than that of a 2x4 device. The optical range and contrast ratio are expected to remain the same with size; however, this has yet to be verified for the full array of devices developed in laboratories. An electrochromic device will switch significantly more slowly when cold than when hot. An automated, integrated window-lighting control system is needed to realize lighting and cooling energy savings. Few electrochromic prototypes have been produced in the large sizes required by the building industry, so few performance studies of them have been conducted.

The monolithic tandem PV-EC device shown on Fig. 4 requires a transparent PV coating that still outputs enough voltage to drive the EC device and enough current to operate the device in a reasonable speed. For the EC device currently employed, a 25-mC/cm2 charge is necessary to stop the darkening or bleaching effect. To color the window in 5 minutes only about 0.1 mA/cm2 current density from the PV device is required. This gives room to increase the band gap and to decrease the thickness of a standard terrestrial

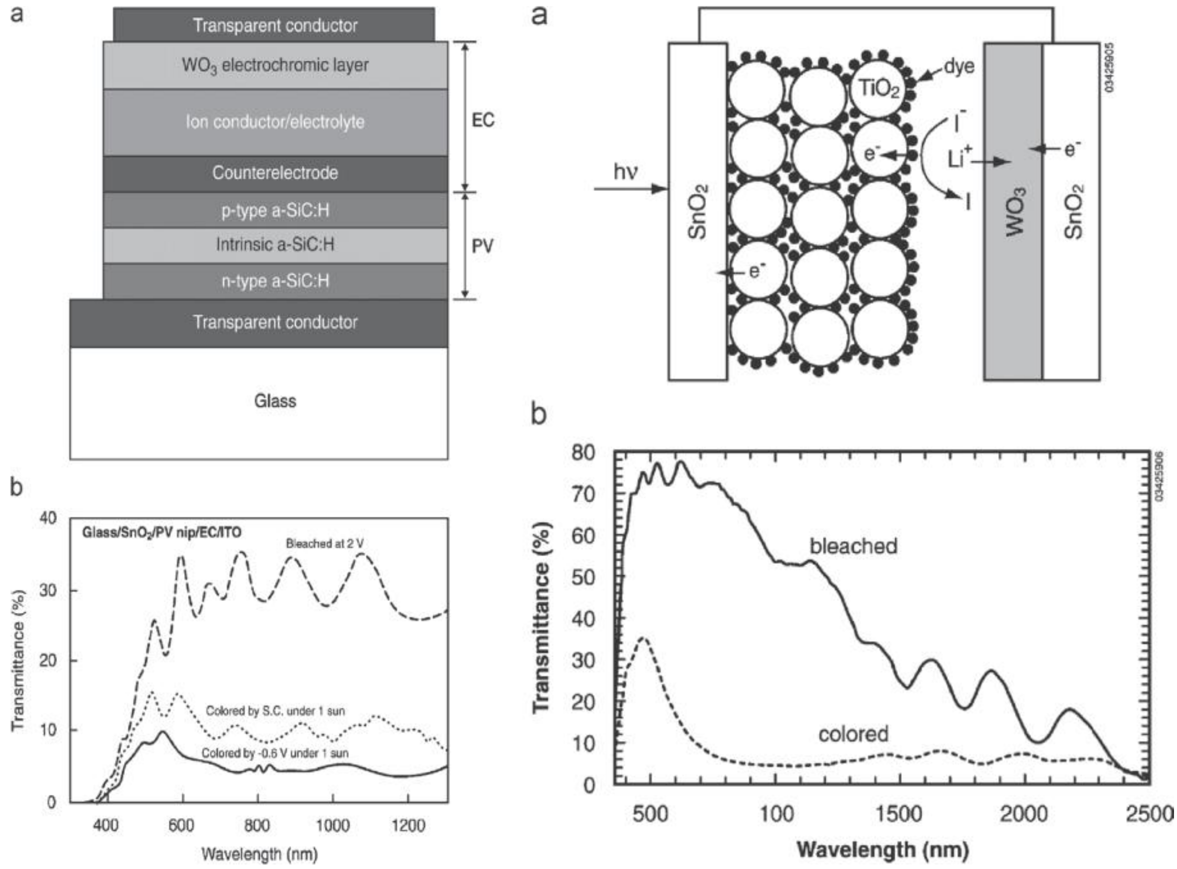


Fig. 4. Monolitic PV-EC smart window: a) schematic structure and b) coloration and bleaching spectra (left side) (after S. Deb, SEM@SC 92 2008) and photoelectrochromic device using dye-sensitized TiO_2 and Electrochromic WO_3: a) schematic diagram and b) spectra of colored and bleached state (C.Bechinger, S.Ferrere, A.Zaban, J.Sprague, B.A.Gregg, Nature, 383 (1996) 608.

PV device in order to reach enough transparency in the bleached state. The device uses a wide-bandgap aSiC:H n-i-p PV cell as a semitransparent power source and a Lix $WO_3/LiAlF_4/V_2O_5$ EC device as the optical modulator from colored to bleached state. We can see the modulation spectra in the right side down part of Fig. 4.

Several device configurations of TiO_2/WO_3 photoelectrochemical (PEC) solar cells USA patents (of S. Deb, the discoverer of the electrochromic effect in WO_3, the long-term Director of the Research division of the National Renewable Energy Laboratory, Denver, Co) are shown on Fig. 5.

Recently the interest is focused on two types of PEC structures: one for photoelectrochemical

The second type of device uses two redox systems in which one reacts with the holes at the semiconductor surface and the other gets reduced by electrons at the counter electrode. In the example on the figure, the water is used as a redox system, in which case H_2O is oxidized to O in semiconductor electrodes and gets reduced to hydrogen in the other electrode.

In our Laboratory in the thin film optical coatings group we have employed atmospheric pressure CVD technology and developed several thin film materials by carbonyl process using as precursors hexacarbonyls of the corresponding metal. For instance, the first developed is WO_3, by $W(CO)_6$ precursor APCVD process. The

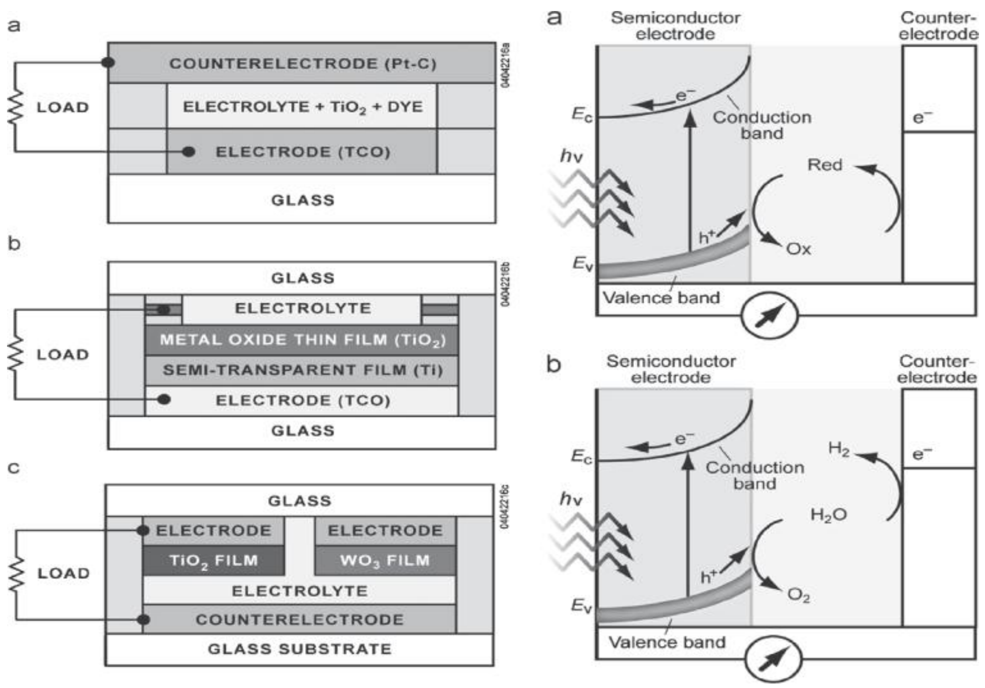


Fig. 5. Some early developments of photoelectrochemical solar cells based on TiO_2 and WO_3 (left); Operational principle of photoelectrochemical solar cells a) photogeneration of electricity and b) photogeneration of hydrogen by water splitting

power generation, see Fig. 5 right, the upper case, and for water splitting - right side, down. In process one the photogenerated electron-hole pair is separated at the interface, and electrons move through the semiconductor electrode to the electrode and external circuit. The hole oxidizes the reduced form of the redox couple, which in turns gets oxidized by electrons reaching the counter electrode. As a result no net chemical changes occur, and this is the mechanism of all regenerative PEC devices, including dye-sensitized Ti.

electrochromic properties of the films (coloration efficiency, optical modulation, switching time, memory) depend on the degree of thin film crystallinity, porosity, stoihiometry, water content, etc. [A. I. Gavrilyuk and N. A. Sekushin,1990 (in Russian), C. G. Granqvist, Handbook of Inorganic Electrochromic Materials, Elsevier, Amsterdam, 1995].

The structure, optical and electrochromic properties of the WO_3 films obtained by two stage processes are thoroughly investigated by

Donnadieu et al. [A. Donadieu, 1990, Davazoglou and A. Donnadieu, 1987; D. Davazoglou, A. Donadieu, R. Fourcade, A. Hugot-Le Goff, P. Delicher and A. Peres, 1988].

We have developed a low-temperature carbonyl technological process permitting in-situ deposition of tungsten oxide films, according to the following reaction:

$W(CO)_6+9/2O_2 <=> WO_3+6CO_2\uparrow$

Thin films of WO_3 were deposited at 200, 300 and 400°C by pyrolysis of tungsten hexacarbonyl vapours in an oxygen stream in a CVD horizontal reactor with cold walls. The sublimator, containing the $W(CO)_6$ powder was immersed in a silicon oil bath, the temperature (T_{subl}) of which was maintained at 90-110°C and controlled with an accuracy of ±1 K. This temperature diapason provides sufficient $W(CO)_6$ vapour pressure.

ELECTROCHROMIC BEHAVIOR OF CVD GROWN TUNGSTEN OXIDE FILMS

The electrochromic (EC) material is the most important layer in an electrochromic device and therefore its properties are the subject of a number of investigations [A. I. Gavrilyuk and N. A. Sekushin, 1990 (in Russian), C. G. Granqvist, 1995; P. M. S. Monk, R. J. Mortimer, D. R. Rosseinsky, 1995, M. Gillet, K. Aguir, C. Lemire, E. Gillet and K. Schierbaum, 2004].

For a passive electrode in an electrochromic device with a CVD-WO_3 basic layer we used sol-gel produced TiO_2 films. The electrochromic properties of the EC active single layer ⁻ WO_3 or TiO_2 were examined by a standard three electrode system in 1 M $LiClO_3$ - PC electrolyte solution. The transmittance decreases monotonically as the injected charge density increases. Figure 6 represents the change in the optical density at λ=550 nm (the middle of the visible spectrum) as a function of the injected charge density. The value of the coloration efficiency can be determined from the slope at the linear part of the curve in Fig. 6. The coloration efficiency of a 170-nm-thick amorphous APCVD-WO_3 film was estimated 205 $cm^{-1}C^{-1}$, which approximates the value of 230 $cm^{-1}C^{-1}$, reported by Maruyama and S. Arai, 1994 and it is larger than not only the one reported for CVD polycrystalline WO_3 films (41 $cm^{-1}.C^{-1}$), but also for amorphous ones prepared by the PVD methods. The WO_3 films have intensive broad-band absorption throughout the visible spectral region which yields a deep blue coloration and a high coloration efficiency.

Several mechanisms have been suggested to explain the coloration of the electrochromic films: formation of color centers at the oxygen vacancies, electronic transitions between W^{6+} and W^{5+} ions, small polaron absorption, intraband transitions,etc. [A. I. Gavrilyuk and N. A. Sekushin, 1990 (in Russian), C. G. Granqvist, 1995, P. M. S. Yu. S. Krasnov and G. Ya. Kolbasov, 2004].

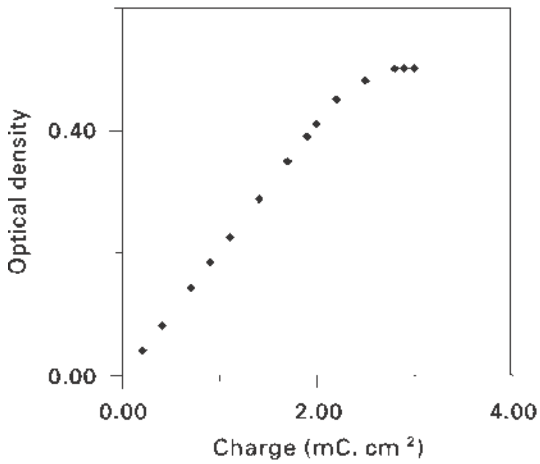


Fig. 6. Change in the optical density at λ = 550 nm as a function of charge density.

Fig. 7 views an entirely solid state electrochromic device - glass/ITO/WO_3/PVA+$LiClO_3$/TiO_2/ITO/glass - in bleached and colored state. The optimal modulation achieved is about 60% at 800 nm and the time response from transparent to blue state is 15 s. The above described device, when working in the absence of a counter electrode (TiO_2) has a 30 s switching time (transparent→ blue state) and 12 min for transition to bleached state. APCVD-WO_3 thin films are capable to satisfy the requirements of "smart window" and may find possible applications in architecture and automobile industry for controlling the incident solar energy and thus allowing saving of energy for cooling or heating.

For CVD polycrystalline WO_3 films the deeply coloured state reflectivity of 56% has been achieved at 2.5 μm (not shown here) and it approximates the value reported by Goldner in [R. B. Goldner et al, 1985]. It is greater than the value of 35% reported for thermally evaporated and crystallized by annealing WO_3 films [H.

Demiryont and K.E. Nietering, 1989, M. Stolze, D. Gogova and L.-K. Thomas, 2005].

Durability tests demonstrated that the carbonyl APCVD-WO_3 samples can stand more than 6

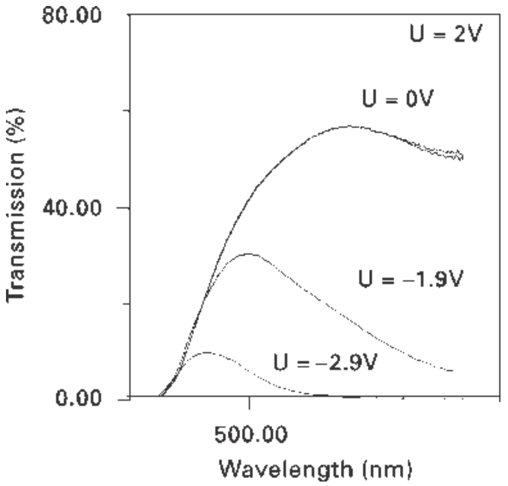


Fig. 7. Modulation of spectral transmission of electrochromic device: glass/ ITO/WO_3/ PVA+$LiClO_4$ /TiO_2/ITO/glass – in dependence of the voltage applied.

000 EC cycles without considerable changes in their performance.

As a lower temperature material than the tungsten oxide, we were expecting for MoO_3 to satisfy the requirements for high growth rate at lower temperatures. The electrochromic devices technology involves glass as an important part of it, which defines a necessity toi keep the temperatures below the diffusion processes limit, and glass softening.

CVD Molybdenum Oxide Thin Films as Electrochromic Material

Molybdenum oxide compounds focus the scientific interest due to their important technological applications [M. Figlarz, 1989, B.C.Satishkumar, A. Govindaraj, E.M. Vogl, L. Basumallick, C.N.R. Rao, 2000] and reactive ion beam deposition [Gouma, P., Comini, E., Sberveglieri, G., 2004]. MoO_3 has been also an intriguing intercalated material for ambient temperature solid state Li batteries. MoO_3 films become interesting in a respect to their chromogenic properties as they possess electrochromic, thermochromic and photochromic effects [J. N. Yao, K. Nashimoto, A. Fujishima, 1992, J. Scarminio, A. Lourenco, A. Gorenstein, 1997]. Most of the research attention related to electrochromic materials has been paid to tungsten trioxide (WO_3), which is found to be excellent candidate exhibiting an efficient reflectance and absorption modulation depending on the

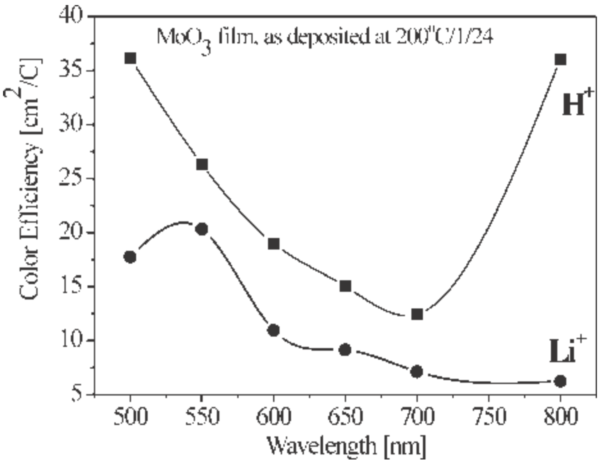


Fig. 8. Spectral dependence of the coloration efficiency values, determined for the as-deposited MoO_3 films under Li^+ and H^+ ions intercalation.

film structure and phase. MoO_3 thin films, on the other hand, have received a comparatively insignificant amount of research attention, despite their EC performance paralleling that of WO_3 films. Molybdenum oxide films exhibiting a cathodic coloration under lithium ion/electron double injection have fairly high mixed ion-electron conductivity.

It is proposed that the electrochromic response in MoO_3 might be superior to many other electrochromic materials because it shows a stronger and more uniform absorption of light in its colored state. Molybdenum bronzes exhibit an improved open circuit memory compared to the more popular tungsten bronzes [Leftheriotis, S. Papaefthimiou, P. Yianoulis, 2004]. Furthermore, since the wavelength maximum of the intervalence band of the molybdenum bronze is more akin to the sensitivity of the human eye than the tungsten ones, so such materials show greater apparent color efficiency. It must also be noted that the MoO_3 films in proper deposition represent more neutral color than the blue color of tungsten oxides. The color efficiency can be determined from the cyclic voltammometric data and the CE-equation, and it is found to be 39 cm^2/C for as-deposited MoO_3 films at the substrate temperature of 200°C and highest oxygen content - 1/40.

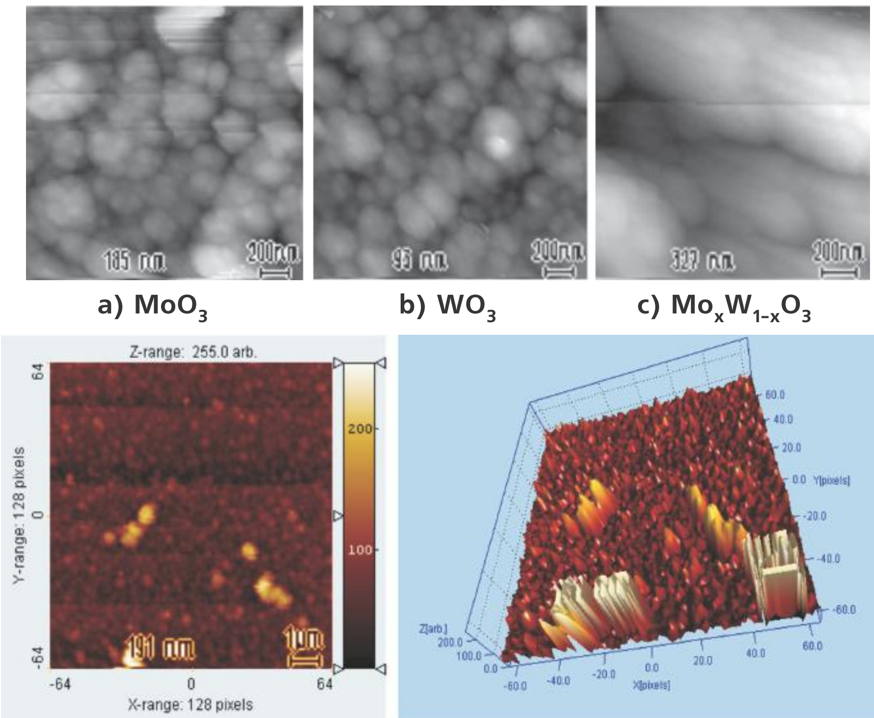
Fig. 8 presents the coloration efficiency of molybdenum oxide films in lithium and hydrogen containing electrolytes. The values of CE for hydrogen electrolytes are larger. Glycerin is added to the electrolyte in order to reduce the damage to the oxide film. However, the MoO_3 film was damaged after 50 cycles.

As a result we have some advantages and disadvantages in WO_3 and MoO_3 technology and optical properties. We were expecting the excellent optical properties of WO_3 and the high growth rate of MoO_3 to be combined in mixed oxide coatings based on these single components. In this research we were really successful.

Investigation of CVD Mixed Oxide Films Based on Molybdenum and Tungsten

Mixed oxide systems have been proposed in order to modify the physico-chemical properties. The mixed oxide films based on tungsten and molybdenum are also prepared by CVD method using our previous experiences on the depositions of WO_3 and MoO_3 films. The precursors are the molybdenum and tungsten hexacarbonyls. The two chemicals are both powders slightly yellowish crystal compounds inert to the air at room temperatures. Metal oxide films have been deposited by the pyrolytical decomposition of the corresponding hexacarbonyls ($W(CO)_6$, $Mo(CO)_6$ or their physical mixture in a ratio of $Mo(CO)_6$:$W(CO)_6$=1:4) in argon-oxygen at the atmospheric pressure (APCVD process) in the horizontal cold walls CVD reactor [T. Ivanova, K. A. Gesheva, A. Szekeres, A. Maksimov and S. Zaitzev, 2001, A. Szekeres, T. Ivanova, K. Gesheva, 2002, K. Gesheva, A. Szekeres, T. Ivanova, 2003, K. A.Gesheva, T. Ivanova, A. Kovalchuk, V. Gurtowoi, O. Trofimov, 2003-08]. The precursor powder placed in the sublimator immersed in the silicon oil bath has been heated at the temperature of 90°C .Through a separate line oxygen (99.95%) enters the reactor. In the present study the ratio of flow rates of argon to oxygen is 1:32.

For the comparative study the deposition temperature was kept at 200°C because only at that temperature it was possible for the three kinds of the metal oxide films to be obtained. WO_3 can be prepared at higher temperatures



AFM images of WO_3 films, annealed at 300°C in the smallest magnification in 2D and 3D views

Fig. 9. 2D and 3D AFM images of annealed at 300°C CVD MoO_3 and WO_3 and also as-deposited mixed Mo-W oxide films (the precursor is a mixture of Mo and W carbonyl powders).

(up to 400°C) and the growth rate increases with increasing the temperature. The growth rate of MoO_3 decreases with increasing the temperature due to the gas phase reaction [K. A. Gesheva, T. Ivanova, A. Iosifova, D. Gogova, R. Porat, 1999]. The temperature of 200°C is a crosspoint for the deposition of the mixed oxide films. The deposition time was kept constant (40 min) and because of the different growth rates the film thickness was 300 nm for MoO_3, 400 nm for WO_3 and 120 nm for mixed oxide films.

The morphology was studied by AFM technique for CVD MoO_3-WO_3 films deposited by applying the two approaches.

The 3D images show that the mixed oxide film structure in as-deposited state consists of much larger grains, size 327 nm, compared to the smaller grains of MoO_3 even after annealing - average grain size of MoO_3 is 185 nm and for WO_3 (93 nm). In general, thin films surface roughness increases with increasing in their thickness. With respect to the pure component films (MoO_3 and WO_3 films), the AFM images of the film morphology confirm our previous conclusions that CVD MoO_3 films have higher degree of crystallization even at 300°C (Raman, TEM studies), while WO_3 and the mixed oxide films stay predominantly amorphous. The enclosed observation of the film surface reveals that the grains are not homogeneous; they looked as agglomerates with different contrast through the whole grain.

Raman studies and Infrared spectroscopy studies showed (here not shown, please see the monograph of Gesheva K.A. Thin Film Optical Coatings for Effective Solar Energy Utilization: Spectrally Selective Surfaces and Energy Control Coatings, NovaSciencePublishers, N.Y., 2007) that the mixed oxides are actually WO_3 matrix in which Mo forms a small volume fraction of Mo crystalline phase or Mo is a substitute in the tungsten oxide matrix.

These films grow with growth-rate of one of MoO_3, at the same time they show excellent optical and electrochromic behavior. This was a real technological advance, one of the best electrochromic materials possible to grow-up with APCVD process. Being a process at atmospheric pressure, the high growth rate would assure flow-through production line.

Here we present some of the most important characteristics of the mixed oxides based on W and Mo oxides.

The transmittance in the visible wavelength

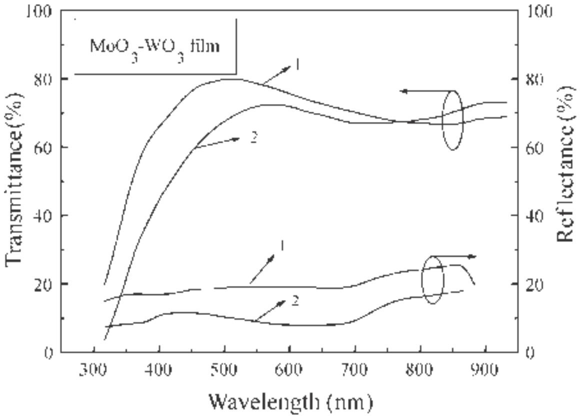


Fig. 10. UV-VIS spectra of CVD WO_3 - MoO_3 films, recorded for the as-deposited (1) and the annealed at 400°C (2) states.

range for all the films (MoO_3, WO_3 and MoO_3-WO_3) varies within 60-80 %, but a direct comparison of the film transparencies cannot be made due to the different film thicknesses. Correspondingly, the values of the reflectance range around 20%. After the additional annealings, MoO_3 and WO_3 films become more transparent; while the transmittance of the mixed oxide films decreases in the spectral range of 400-750 nm, showing a slight increase towards the longer wavelengths (see the monograph). The thermal treatments do not affect considerebly the reflectance spectra of the pure oxides films, at the same time the annealings (especially at 400°C) result in a noticeable decrease in the reflectance, pertaining to the mixed MoO_3-WO_3 oxide films [K. Gesheva, A. Szekeres, T. Ivanova, 2003].

From technological point of view it means that for CVD WO_3 - MoO_3 films no necessity of after-deposition temperature procedures is needed.

CVD $Mo_xW_{1-x}O_3$ films were electrochemically characterized and compared to MoO_3 and WO_3. All the films show coloration as a result of Li intercalation. The CV curves show the most interesting feature: a rapid increasing of the current for MoO_3-WO_3 films, at the same time their transmittance decreases significantly as a result of the intercalation of Li ions. The mixed oxide films color in deep blue and the transmittance drops under 10% both for the as-deposited and the annealed films [Y. Wang, N. Herron,1991, O. Zelaya - *Angel,* 2001, C. Julien, A. Khelfa, O. Hussain, G. Nazri, 1995]. The most intensive color modulation and change has been found for the "in-situ" made APCVD mixed $Mo_xW_{1-x}O_3$ films.

The cyclovoltametric curves for the as-deposited films (Fig. 11) possess no distinct anodic and cathodic peaks, suggesting amorphous film structure. The cathodic wave for the MoO_3 film has no intense peak and a weak one can be found at - 0.42 V. For WO_3 film, there exist two separate peaks at - 0.46 and - 0.82 V. For the mixed oxide system, the cathodic maximum is situated at - 0.73 V, which corresponds to the Li^+ ions insertion into the film structure. MoO_3 does not exhibit an anodic maximum. As it can be observed, for the as-deposited as well as for the annealed MoO_3-WO_3 films, the current density is considerably larger than for pure metal oxide (MoO_3, WO_3) films.

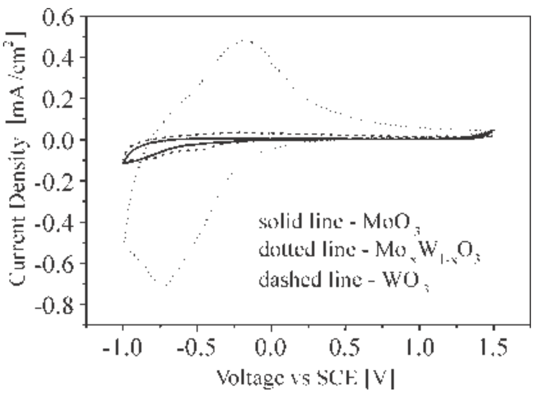


Fig. 11. The cyclovoltametric curves of CVD MoO_3, WO_3 and MoO_3-WO_3 films annealed at the temperature of 400°C in air for 1 hour.

Prior to the electrochemical measurements the as-deposited and annealed films had high transmittance (around 80-60%). The optical modulation is found to be 60-70%. The coloration efficiency (CE) strongly depends on the wavelength and the changes of the optical density ΔOD. The CE values in the visible range for MoO_3-WO_3 films are better than those for WO_3 films (Fig. 12). The optical modulation (transmission difference between colored state after Li insertion and bleached state) is above 50%.

The working electrode usually used is tungsten oxide film and as counter electrode nanocrystalline TiO_2, Cr_2O_3 and V_2O_5 is used as well as mixed Ti-Ce/Zr oxide films [C.G. Granqvist, 1995, P.M.S. Monk, R.J. Mortimer, P.R. Rosseinsky, 1995].

The electrochemical investigation has been performed for that cell: MoO_3-WO_3 (working EC electrode)/liquid electrolyte ($LiClO_4$+PC)/TiO_2 (counter electrode) and a SCE as reference electrode. The stability testing of that EC cell has been performed by applying multiple cycling. The measurements required a long time and these experiments prolonged within two weeks. The results show that up to 1500 cycles the EC cell prototype does not change its color/bleached cycles and the cyclic voltammograms have very good reversibility with similar shapes. MoO_3-WO_3 films color immediately when negative voltage is applied (-1 V). When positive voltage is set up, the transparent state has been restored for about 3-4 minutes. Such switching times are in the range of those required in architectural smart windows.

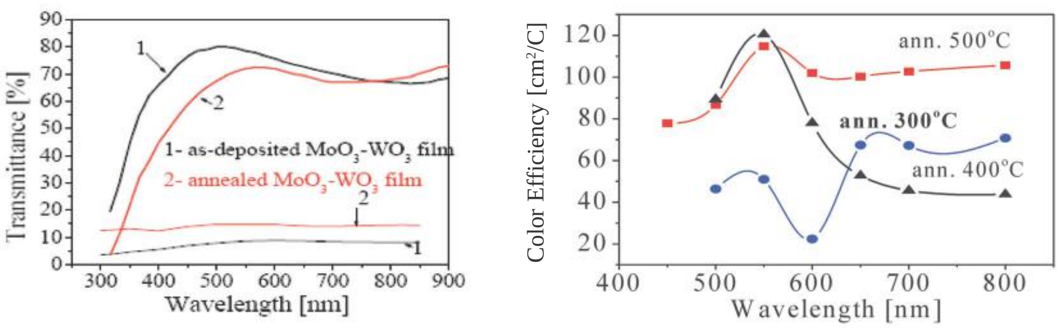


Fig. 12. Change in the optical transmittance before and after Li ions inserting in CVD MoO_3-WO_3 films (left), color efficiency values of MoO_3 -WO_3 films annealed at 300, 400 and 500°C (right side of the figure).

The mixed oxide films were found to combine the desirable properties of the molybdenum and tungsten oxides. These films show the absorption peak at 2.5 eV (550 nm), where is the human eye sensitivity maximum as with MoO_3. The porous structure of Mo/W oxide films favors the electrochromic effect, resulting in high color efficiency and optical modulation values approaching the electrochromic properties of the best WO_3. The tested electrochromic cells and their working characteristics prove for the applicability of the APCVD films as functional electrodes in electrochromic smart windows.

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MODELING ENVIRONMENT FOR RESEARCH OF RENEWABLE ENERGY SOURCES OPERATION IN POWER LIMITED ENERGY SYSTEMS

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Abstract

In the recent years large employment and development of renewable energy sources has become noticeable. Energy converters and power limited energy networks mutual operation modeling and investigation are questions of present scientific interest. Renewable energies have stochastic nature and the produced power is variable. Thus, the power flow control in regard with the UCTE network quality requirements is indispensable. This paper presents the infrastructure project "Modeling environment for research of renewable energy sources operation in power limited energy systems" financed by the Bulgarian Ministry of Education and Science (MES). Within the frame of this project a scientific network of existing laboratories joined by wide research program is created. The stipulated project investigations have both theoretical and experimental aspect. The main object is to study different energy conversion chains based on renewable energy sources. Reliability of some theoretical models will be experimentally tested. For this purpose all laboratories from the scientific network will be provided with supplementary equipment from the project grant.

INTRODUCTION

The priority development of Renewable Energy Sources (RES), part of which are wind power plants (WPP), hydro power stations (HPS) and photovoltaic plants (PvP), reveal the actual research and modeling problems of their mutual operation in concentrated power limited energy system (CPLES). The stochastic behavior of the wind and the solar radiation, sometimes even the water flow, causes a variation in the energy supplied to the power system. On the other hand, the load variations have a casual character, too. This imposes the need of some regulations in regard to guarantee the quality of the produced power, in accordance with UCTE demands.

The power infrastructure project "Modeling environment for research of renewable energy sources operation in power limited energy system", financed by the Bulgarian Ministry of Education and Science (MES), set up a cooperative network of different existing laboratories, engaged with the project realization.

The envisaged research program has both theoretical and experimental aspect. The main goal of the project is to investigate the whole energy conversion chain in some power units, which use renewable sources, starting with the primary energy, passing through power converters and ending with the grid connection. Reliability of certain theoretical models in experimental environment will be proved.

The study is focused on systems producing electric energy by converting the energy of:

- Water – Hydro Power Stations;
- Wind – Wind Generators;
- Sun – Photovoltaic Generators.

Special attention will be paid to the primary energy potential study, especially for the wind and solar energy.

RESEARCH TEAMS

The complex and interdisciplinary character of the investigation requires a team of researchers in different scientific fields. The founded consortium of the following scientific organizations: Technical University of Sofia (TU-Sofia), Technical University of Gabrovo (TU-Gabrovo) and National Institute of Meteorology and Hydrology - Bulgarian Academy of Sciences (NIMH-BAS), affords an opportunity to create a network of different laboratories and research teams, which participate together on the successful project realization.

The TU-Sofia research team comprises researchers from the Renewable Energy Sources Laboratory (RESLab) at the Faculty of Electrical Engineering and the "Systems and Control" department at the Faculty of Automation, and the team is led by Dr. Vladimir Lazarov, who is also a whole project coordinator. The TU-Gabrovo and NIMH-BAS research teams are led respectively by Dr. Pencho Vladimirov and Dr. Peter Ivanov.

PROJECT TASKS

In the present project the renewable energy sources operation in power limited energy systems or in hybrid systems is investigated [1], [2]. The generated power is injected in the grid by different power plants such as: HPS, WPP and Photovoltaic Generators (PG) and is consumed by loads with varying parameters. The transferred power from the WPP and the PG has *a priori* stochastic character because of the variable nature of the primary energy potential – the wind and the sun. The load has also a fortuitous character as consequence of non-controlled users' connections and disconnections. It is assumed that renewable energy sources (WPP and PG) and their control systems are designed to operate at maximum efficiency rate. Thus, for each time interval of plants operation, the maximum available power is extracted from the primary energy sources. Still, every change in generated/consumed active power ratio leads to perturbations of the electrical frequency. In the limited power energy system the function of frequency controller is dedicated to the turbine regulators of HPP. That is why it is important to develop an adequate control system, which regulates the instantaneous power of the Hydro Power Unit (HPU) in order to reestablish the accurate frequency rate.

When the produced power exceeds the consumed one, the turbine regulator needs to decrease the HPU power rate. Thus, a hydro energy potential is stored, just in case of wind and solar energy production failure or increase of load demands. So, the model of HPU-WG mutual operation is an interesting scientific problem and of the prior project tasks.

Many of the scientific papers in this area [3], [4], [5], [6] are dedicated to the turbine regulators quality issues and also focus on the system performance and stability when load disturbances transient phenomena occur. The project task can be extended taking account of the variable WPP and PG power production. In the model the dynamics of the renewable energy sources, the grid and the electrical load [3], [7], [8] should be taken into consideration. Modeling of HPU implementation can be made with or without grid line parameter consideration [9]. The aim presented in the introduction will be fulfilled with the realization of the following research tasks.

1. Study of solar and wind energy potential in some regions of Bulgaria (NIMH–BAS)

1.1. Solar energy

The development of scientific infrastructure will facilitate the study of solar energy potential and more precisely:

- The resources of the solar radiation, as primary source of renewable energy, basically the rate of solar radiation duration and the rate of direct and global solar radiation on the horizontal and differently orientated inclined planes;
- The time and spatial distributions of the solar radiation over some regions of the country with the purpose of their optimal use in the production of heat and electricity;
- The theoretical and technological potential of solar radiation in order to estimate the part of solar radiation which can be used in the energy balance of selected regions of Bulgaria.

The solution of these problems will be made with the device equipment from *Kipp&Zonen.* This equipment will be installed in the areas of Sofia and the Black sea coast and will help to fulfill the existing database of NIMH-BAS for the solar radiation duration, global radiation falling on horizontal surfaces, the overcast and other environmental parameters.

1.2. Wind energy

The wind speed variation is very important for wind generators integration into the distributed grid, as well as for securing reserve power from the system operator, when wind generators do not operate due to the lack of suitable wind speeds. For the estimation of wind energy potential the following tasks will be performed:

- Investigation of the rate of wind direction and speed and the wind time and spatial surface distribution for utilizing the wind as a source of renewable energy;
- Estimation of the theoretical and technical wind energy potential as a source of renewable

energy for different levels above the earth surface;

• Investigation of the wind direction and speed fluctuations for different time intervals (seconds, minutes, hours, days and weeks);

• Determination of different wind power characteristics at different heights like: mathematical expectation, dispersion, distribution density, correlation and spectral indices of wind direction and speed and energy density (power) of the wind flux for different time intervals: seconds, minutes, hours, days and weeks.

2. Wind generators modeling (TU–Sofia)

Systems converting wind energy into electrical energy are various. Nowadays modern wind generators attain power of 1÷5 MW. The trend toward a permanent increase of the generators' power continues, expecting to reach 10÷15 MW in the near future.

They could be mainly categorized according to their mechanical and electrical components. Regarding the electrical part, wind power plants are divided according to the type of electrical generators and converters. The most utilized in the wind industry are: synchronous generators (SG), permanent magnet synchronous generators (PMSG), doubly-fed induction generators (DFIG) and squirrel cage induction generators (SCIG).

The industry approach today is to connect wind generators to the grid via power electronic converters [10], [11], [12]. The point is to enlarge the operation range of wind generators by producing maximum power for each particular wind speed. Within the converters, 2 types of configurations are the most utilized:

• Configuration with non-regulated rectifier (Diode Rectifier), Boost chopper (DC-DC converter) and Voltage Source Inverter (VSI);

• Configuration with two Voltage Source Inverters which are back-to-back connected via DC link bus.

In order to study in detail the wind generators' operation and energy conversion systems in various configurations and to improve their design with the purpose of increasing their power (absorbed from the wind), mathematical modeling and computer simulation of different elements of the system, and of the whole system as well, is necessary. There are several approaches for modeling and simulating synchronous and induction generators and power converters. Those different approaches depend on the parameters' choice of the electrical system and the type of simulations. In other words, they depend on the complexity of the expected results. Their choice is influenced by the fact if the generator is connected directly to the network or not. While connecting the wind generator directly, the turbine should maintain constant rotation speed in order to guarantee the required magnitude and frequency of the voltage supplied to the network. In the case of non-constant wind speed (which means variable rotation speed of the turbine) electrical generator should be connected to the network via converters, by means of the aforementioned configurations.

After analyzing the existing publications in this field, it is concluded that modeling becomes more complicated when the generator stator currents are chosen as state variables. But this approach enables more freedom and flexibility of the whole system simulation. Therefore modern computing equipment and software is required. The modeling of all electrical components is performed in the Matlab® software environment.

Comparison of the analytical simulation results with the experimental results is very important to validate the modeling and the innovations applied in the wind generators' design. That is why physical modeling of the energy conversion system is required for realization of the research project. Experiments implementing real high power machines (1÷5 MW) are extremely difficult and expensive. In the research practice the use of corresponding low power machines is involved for physical modeling and real processes simulations.

One of the main project aims is to create two new experimental benches for examination of wind turbine-electrical generator (SG, DFIG) system operation. The object is to study the system dynamic behavior and maximum power production at variable wind speed. The maximum power production can be achieved using the so-called "Maximum Power Point Tracking" control system or simply MPPT system. This control system was first developed for the PG application, but today it is also used in other renewable energy technologies and especially in the WPP. MPPT can maximize the wind (or solar) energy capture and likewise serves to protect the turbine at above rated wind speeds. The MPPT system is a complex strategy and is closely related to the variable speed turbine concept design. The main idea behind is to control the generator speed (or generator torque, depends on the control loop type) and to keep turbine operate at rated level, predetermined in a specified look-up table. Also serves as a source of some signal references for the converter PWM control system. The MPPT algorithm can be constructed with different logic structures, the most utilized among them are:

• The real-time power comparison techniques, such as Hill Climbing Searching algorithms (HCS);

• Online measurement techniques based on signal available from an anemometer, such as Tip-Speed Ratio Control (TSRC),Optimal Torque Control (OTC) and Power Signal Feedback Control (PSFC);

• Wind prediction control techniques, such as Fuzzy Logic (FL) and Neuron Network (NN) structures.

A typical MPPT strategy look-up characteristic used for control algorithm formation is shown on Fig. 1.

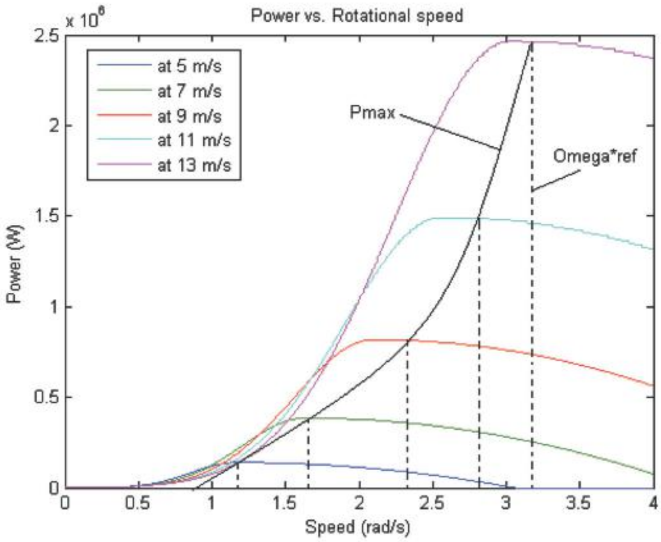

Fig. 1. MPPT characteristics

On Fig. 2 a schematic structure of a wind generator simulator connected to the grid and composed with SG and electronic power converters is depicted:

The upper part of the Fig. 2 represents the real physical wind generator system (in blue) and the bottom part represents the test bench - the wind turbine emulator (in red). The yellow arrows show the correspondence between the two structures. The wind turbine and the gear box are replaced with DC motor driven by electronic converter with microprocessor control. The DC motor simulates the turbine characteristics at different wind speeds. The correct modeling is very important because the wind turbine has a specific characteristic with distinct maximum (Fig.1). The DC motor drive allows for varying the generator speed as well as for setting different speed profiles [13], [14], [15].

The grid-side converter is a pulse width modulation (PWM) VSI with insolated-gate bipolar transistor (IGBT) switches. The diode rectifier is non-controlled and has a capacitive filter.

A converter structure with two back-to-back connected VSI will be also investigated. The generator-side PWM VSI has IGBT switches and serves as rectifier, feeding the synchronous generator with sinusoidal currents.

Other most used wind generator type is the DFIG. Its stator is directly connected to the grid, while the wound rotor is connected with the grid via electronic converters [10]. The second test bench is designed to study and to model the dynamic behavior of the DFIG as wind generator. The basic scheme is presented in Fig. 3. The rotor circuit is connected with the grid by two back-to-back VSI. The power flow can be bi-directional depending on the operation mode. The whole system is controlled by microcontrollers.

The two wind turbine emulators are also equipped with measuring DAQ system. It consists of different measuring sensors for current, voltage, speed and torque, all connected via specialized interface to a personal computer. The PC is provided with appropriate software for data acquisition and processing.

3. Investigation of real systems with photovoltaic and wind generators (TU-Sofia and TU-Gabrovo)

At TU-Gabrovo laboratory with 10 kWp PV

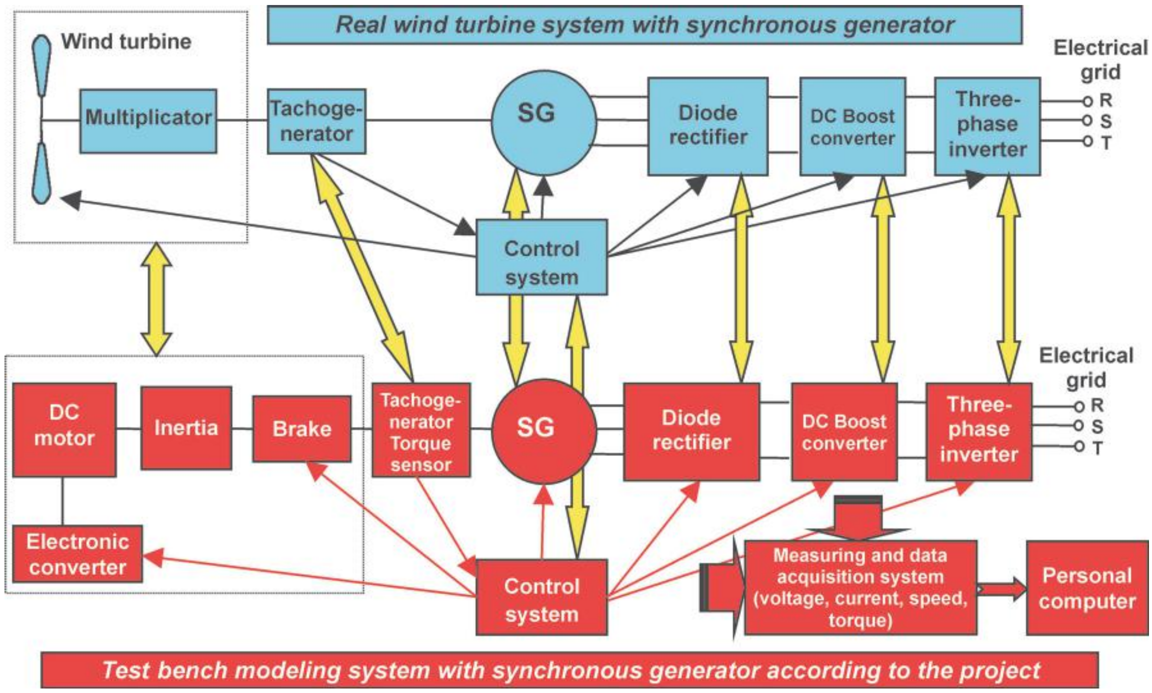

Fig. 2. Test bench modeling system with SG according to the project

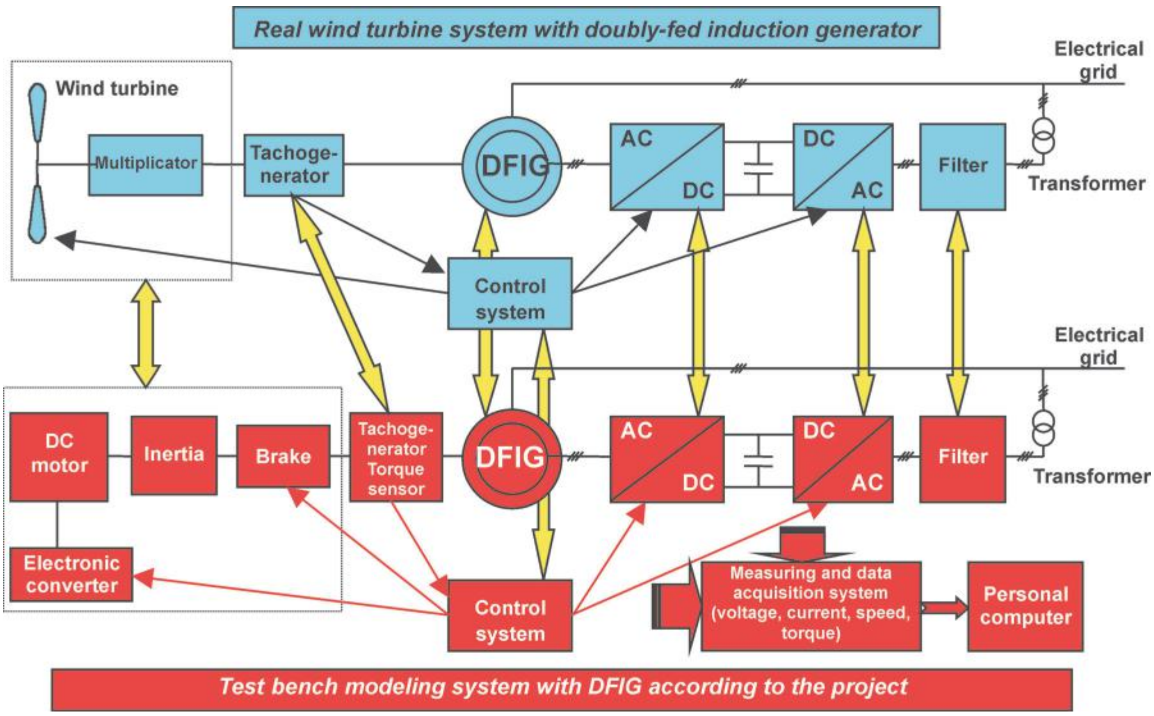

Fig. 3. Test bench modeling system with DFIG according to the project

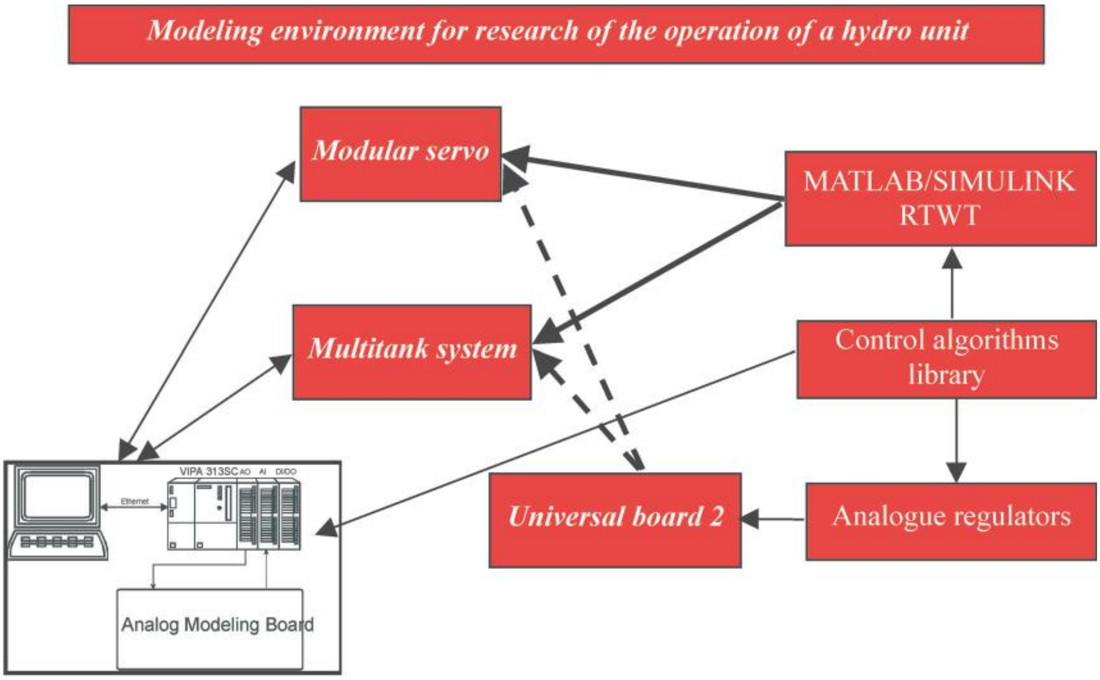

Fig. 4. Basic scheme of the modeling environment

system connected to the network is available. Research work for data acquisition of sun radiation, operational temperature, energy, system's efficiency and other data is carried out.

With the purchase and installation of wind generator, wind measurement equipment and system monitoring it is envisaged to carry out research work on the wind's characteristics, generated electrical energy, energy quality, theoretical and experimental study of the dynamic and steady state modes of the wind generator, system's efficiently, etc. Detailed studies of different photovoltaic systems applications are also envisaged.

The Renewable Energy Sources Laboratory (RESLab) at TU-Sofia disposes with RES hybrid system, which can promote comparative real-time studies. The hybrid system control and design optimization represent a perspective and very interesting research field [16], [17], [18].

4. Modeling and investigation of hydro power unit (HPU) operation

The actual problems studied in the project are related to the design and adoption of contemporary HPP turbine regulators, which realize the primary frequency control. For the project aims, it is foreseen a hybrid laboratory environment for modeling and studying of the processes in a speed and active power control system of HPU to be created. This environment holds different modeling benches, measuring equipment, programmable logic controllers (PLC) and computers. Block scheme description of the modeling environment is shown on Fig. 4.

The research objects are:

1. Mathematical modeling using identification procedure, taking into account different features of the studied plants:

• Different operational modes and related linearization conditions of the models.

• Influence of the water column elasticity and its compensation.

2. Investigations of disturbance rejection algorithms for active loads or variable generated power of power limited energy system, with hydro unit and distributed generations from other RES [1].

3. Development of a methodology for design of controllers with gain scheduling for wind generator, which are based on the usage of linear parametrically varying transformations [19]. These transformations have to be used since the wind generator system represents a time-variant system, i.e. its parameters vary with the time. The advantage of the gain scheduled controllers comes from the possibility to control the system

with a single controller that ensures stability and desired performance of the closed-loop system for the whole range of working conditions.

The resolving methods are various and include: realization of hybrid models of the studied controlled object; investigation of reliable analytical mathematical models; obtaining of models from experimental data and optimal parameter tuning of *a priori* selected structure model; development and realization of disturbance rejection algorithm; design of digital regulators.

For solving those problems, a creation of the following test benches is foreseen:

• ***Multi tank system***, which gives the possibility to model and to study the hydro unit operation. The system is fully integrated with Matlab/SIMULINK® and operates in real time. This test bench and the interface of the computer environment for real time control – Real Time Workshop® of Matlab are suitable for experimentation of different control algorithms such as adaptive and robust control algorithms.

• ***Modular servo system*** supplied with different modules for study of variable inertia, clearances, mechanical elasticity and frictions. The system is completely integrated with Matlab/SIMULINK® and operates in real time. The system is developed as environment for analysis of servo systems digital control algorithms. It is designed especially for research and practical realization of classical and new control methods – from PID to LQ, robust, adaptive and optimal control laws, taking into account the peculiarities of the real systems, mostly connected with non-linearity of the components. The modular servo system is controlled by a digital regulator created in Matlab. The IO power interface between the PC and the system is controlled by RTW of the Matlab. Different researching tasks can be solved, like control of technological processes in HPP, i.e. investigation of speed and power regulation processes of HU as well as in the teaching process tasks, using this model.

• ***Analogue modeling bench (Universal Board 2)***, which proposes flexible options to model standard continuous objects. The benches have standard levels for IO analogue signals to communicate with the PLC. This gives a possibility a hybrid modeling environment for study of the speed and active power control system processes of the HU to be realized. Building this system, the existing programmable controllers of SIMATIC S7 200/300 of SIEMENS type will be used. They are basic elements for the design of hybrid control environment.

A simulation model of RES operation in power limited energy system will be created, according to the goals of the infrastructure and research project mentioned above.

CONCLUSION

The presented project foresees to develop an infrastructure for different research investigations in the field of renewable energy sources and produced power quality.

The expected results have a complex character and will be expressed as follows:

• Methodology and modeling environment for simulation and visualization of the processes related to the variable power supply of the RES will be developed, as well as its influence on the operation frequency of a stand-alone power limited energy system;

• The obtained results will be presented in models (physical devices and computer simulations), software and methodological instructions for complete study of RES operation;

• The partner's laboratories will be modernized for future projects utilization within the frame of created network for scientific cooperation;

• A high density utilization of the equipment for educational and scientific purposes is expected;

• Dissemination of the project results is guaranteed after the project end through the research and teaching activities.

The developed infrastructure will contribute for further research tasks realizations in the field of renewable energy sources modeling, operation studies and control, as well as the energy network connection and interactions.

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BULGARIAN ADDED VALUE TO ERA

CL SENES – BULGARIAN CENTRE OF SOLAR ENERGY

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SIGNIFICANCE OF SOLAR ENERGY UTILIZATION TODAY

Nowadays there is hardly anyone who has not heard about the threats of global warming and has not worried because of the rising cost of fossil fuels and their scarcity. In order to limit green house gas emissions the global community has produced the Kyoto protocol to which most developed and developing countries are signatories. A concern for the environment and sustainability are among the main motivations behind the revised Lisbon strategies of the European Union. As a consequence a goal of 20% share of renewables in energy consumption by 2020 has been set and legally-enforceable targets for each member country will be agreed.

Solar energy is a major renewable energy. It arrives every day on the surface of the earth and it is up to human effort and available technology to use this energy source more efficiently. There are two main ways of utilizing this energy - using it for heating and applying photovoltaic technology to generate electricity. In recent years because of the drive towards wider introduction of renewable energy sources and the financial incentives that have been introduced in the leading world economies solar energy utilization has developed rapidly and is one of the fastest growing economic sectors. This is also a very research intensive sector and new technological solutions are being proposed all the time. A lot of funding, effort and human resources are being invested so that cheaper and more widely applicable solutions for solar energy utilization can be developed.

We like to say that Bulgaria is a "sunny" country and this already signifies that our country has a lot of this renewable energy source. In order to meet the current challenges in its wider use to cover human energy consumption, our country and its researchers have to join the European effort in that direction. The Central Laboratory of Solar Energy and New Energy Sources is the only research institution in the country dedicated fully to these problems. In recent years it successfully demonstrated that it is a functional part of the European Research Area as a research centre of solar energy with an international reputation.

SHORT HISTORY AND PRESENT STATUS OF CL SENES

The Central Laboratory of Solar Energy and New Energy Sources (CL SENES) was founded on January 1, 1978 in response to the importance solar energy acquired after the first petrol crisis. First director of the Laboratory was Professor Stefan Kanev, corresponding member of the Bulg. Acad. Sci. The Laboratory has its own building and testing areas for solar systems. On June 13, 1994 a decision of the General Assembly of the Bulgarian Academy of Science set the Laboratory up as a permanent unit of the Academy.

The staff of the Laboratory consists of 44 persons, 30 of them are scientists and 17 are experts with university or secondary school education. 12 senior researchers work at the Laboratory, one of them is a professor. There are 21 scientists with a PhD degree and one with a DSc degree.

The laboratory has the following scientific structural units:

Solar Cells, Devices, PV Modules and Systems

• Advanced technological processes and materials for highly efficient Si solar cells;

• Investigation and assessment of solar cells and modules;

• Computer modelling of devices and systems;

• Applied scientific development of photovoltaic modules and systems.

Photoelectric Materials

• Deposition and investigation of thin films of amorphous and polycrystalline materials based on Si, C, ZnO, etc., for applications in solar cells, sensors, etc.;

• Deposition and investigation of dielectric thin films containing dispersed nanoparticles for optical and electronic applications.

Multinary Compounds for Thin Film Solar Cells

• Preparation and investigation of thin films of $A^1B^3C^6$ and A^2B^6 compounds with the purpose of application in the production of solar cells.

Photothermal Solar Energy Conversion

• CVD and sol-gel technologies for preparation of optical metal oxide films, which can be applied in solar energy conversion and energy management;

• Development of devices and systems for photothermal solar energy conversion.

EUROPEAN UNION FUNDED PROJECTS

Bulgarian Centre of Solar Energy (BGCSE) – (01.02.2003 – 01.08.2006) – Supported by the European Commission in the 5th Framework Program [1]

The objectives of the project were in three main directions:

1. To raise the scientific and technological level of clean energy technologies and especially technologies of solar energy conversion in Bulgaria.

2. To promote the rapid implementation of solar systems and installations in our country.

3. To improve the educational level and spread awareness and understanding about new solar energy technologies and their environmental impact.

The project was successfully completed and consisted of the following main activities:

Workshop on High Efficiency Solar Cells with Low Cost technologies:

The workshop was held on May 2 - 22, 2004 in Sofia. The basic topics concerned low cost technologies suitable for industrial upscaling. Leading foreign experts in the field were invited to give lectures. Among them were: Prof. R. Hezel, head of the Institute of Solar Energy Research (ISFH) in Emmerthal, Germany; Dr. G. Beaucarne, Head of Si Solar Cell Group, IMEC, Belgium; Dr. Miso Vukadinovich, Faculty of Electrical Engineering, University of Ljubljana, Slovenia. Interested scientists and students from Sofia University and other places took part in the workshop, as well as most of the staff of CL SENES. There were active discussions and the guests were shown around the laboratory and got acquainted with the research under way in CL SENES. Some of the participants from abroad were partners of CL SENES in another project – ADVOCATE.

Workshop on Low Cost Technologies for Thin Film Solar Cells

Two main topics for discussion were planned:

• Low cost processes for CIS solar cells, and

• Deposition of poly- and microcrystalline silicon.

The topics are among the main ones for the research carried out in CL SENES and they are included in the international cooperation of the Laboratory. The aim of the workshop was to strengthen scientific links between scientists from Bulgaria and other European Countries and create favourable conditions for future joint projects.

The Workshop was held in Sofia on September 30 – October 1, 2005. As a Chairman Dr. A. Tiwari from the Swiss Federal Institute of Technology in Zurich, Switzerland was invited, who was also a member of the International Advisory Board of the Bulgarian Centre of Solar Energy. Lecturers from Switzerland, Germany – Hahn-Meitner Institute, Berlin and France – Ecole Nationale Supйrieure de Chimie de Paris, Institute of Research and Development for Photovoltaic Energy (IRDEP), presented lectures at the workshops, in which 26 Bulgarian scientists participated as well. At the end there was a round table discussion where future trends of thin film deposition for solar cells as well as possibilities for future projects and agreements for cooperation among the participants were under consideration. All lectures delivered at the Workshop were recorded on a CD so that researchers and PhD students involved in similar investigations can profit from them.

Testing Laboratory for Solar Systems

The laboratory consists of two separate testing sites:

1. Testing System for PV Modules, the object of which is PV testing and quality control under natural ambient conditions (Fig. 1)

The accurate measurement of PV array performance is critical to the development and assessment of photovoltaic solar energy systems. There exist EU regulations and standards concerning functionality testing for parameters such as system lifetime, energy rating, degradation mechanisms, etc. The goal of CL SENES was to establish a testing laboratory for PV modules covering these standards. In this way manufacturers and suppliers of such systems in Bulgaria can have them tested according to the international standards.

The outdoor testing field incorporates a large area test platform, $2X2 m^2$, equipped with a solar tracker, a data acquisition system for electrical and temperature measurements up to 250 W_p and a weather station. The tests are divided in different types depending on the derived information:

• Tests of the main electrical parameters and initial characterization;

• Additional characterization tests for obtaining information about the behaviour of the PV module under different operating conditions;

• Environment degradation tests;

• Mechanical tests to investigate the module's ability to withstand wind and snow loads.

2. Solar Water Collector Testing System (Fig. 2)

A facility was built to carry out water collector efficiency tests according to the corresponding European standard. The main support frame is mounted on a non-tracking base with variable tilt. The maximum area of the tested collector is 6 m^2. The whole system operates under natural outdoor conditions. A slightly modified construction from the one described in the standard is used to ensure more stable flow and temperature conditions at the input to the collector under test. The measurement equipment consists of high class sensors and controllers and is computer controlled. An isolated storage tank was built near the test frame allowing long term tests to be carried out in parallel with or after efficiency tests. Up to now several solar water collectors from different manufacturers have been tested.

CL SENES is following the necessary procedures for obtaining authorization to carry out certified tests of solar water collectors. After finishing the procedures a four years valid Authorization Certificate will be issued to the Laboratory. In parallel a manual on testing collector quality was prepared and is available to interested companies and members of the public.

Third National Conference on RES

Traditionally CL SENES is the organizer of a National Conference on Renewable Energy Sources. In this case it was financially supported by the Bulgarian Centre of Solar Energy. It was held on October 23-24, 2003 in the National Palace of Culture under the honorary Chairmanship of the Minister of Energy. There were 144 participants from Universities, institutes of the Bulgarian Academy of Sciences as well as from companies, governmental agencies, NGOs and the media. 46 oral and poster presentations were made to the Conference in the fields of solar, wind and geothermal energy and biomass. All the submitted papers were refereed and published in a Proceedings book. A parallel exhibition of solar thermal technology was organized with the cooperation of the Sofia Energy Centre and the Greek Centre Exergia. At the end of the conference a discussion on Strategy and Policy for RES in Bulgaria took place. Many of the recommendations of this discussion are already implemented, such as introduction of feed-in tariffs for RES, making this field of research a priority for funding agencies and scientific institutions, using demonstration projects as focal points for informing stakeholders about these new technologies.

National School on Renewable Energy Sources: Nature, development and perspectives

The National School on Renewable Energy

Fig. 1. Tracking system for photovoltaic modules

Fig. 2. General view of the solar collector test stand

Sources took place on September 1-6, 2004 in the Summer House of the Bulgarian Academy of Sciences on the Black Sea coast near Varna. The School programme consisted mainly of lectures and a permanent poster exhibition. A full course of lectures was delivered covering basic technologies and methods of RES utilization.

All the lectures were received in advance and the Proceedings recorded on CD were given to each participant. 27 lecturers and 55 PhD students from 5 Institutes of Bulg. Acad. Sci., 10 Universities and 2 companies took part. Alongside the lectures the programme included discussion panels on the same topics as the respective lecturing sessions. All participating students received Certificates for attending a specialized course in RES. Each of them had to make a short oral presentation of his/her poster in front of a specialized audience and answer their questions.

Fig. 3. 10 kWp PV generator in Sofia

As a result of the completion of this project CL SENES became established as a major information and consultancy centre for energy specialists interested in implementation of solar energy conversion. The activities related to the BGCSE gave an excellent opportunity for disseminating knowledge about the advantages of solar energy.

"PV Enlargement" – Supported by the European Commission in the 5th Framework program [2]

A demonstration project has been implemented in CL SENES which has had a marked effect for informing the Bulgarian public about solar electricity generation. The system AcadPV is the result of a joint effort and technology transfer in the framework of a project named "PV Enlargement" coordinated by WIP-Munich with 11 participants. The main object is establishment of a network of PV systems followed by careful performance monitoring.

Thanks to its situation in Southeast Europe Bulgaria has a promising solar potential. Thus solar energy can be used successfully for power generation especially in remote areas where grid fluctuations occur during the summer. It is the first 10kWp PV system installed in Bulgaria connected permanently to the low voltage public grid. The distributed power generators of this kind are expected to support the grid in times of peak consumption and increase the quality of electricity supply for the end user. In view of the long-term system performance special attention has been paid to the application of state-of-the-art-engineering and top quality equipment and materials.

The AcadPV generator is designed as a free-standing shading element over the parking lot in front of the CL SENES building. (Fig. 3) The supporting metallic construction is inclined at 30 degrees and faces south. The PV modules are mounted on the level of the roof in 3 rows (PV subfields). The first two subfields consist each of 20 pieces of framed PV modules based on monocrystalline Si solar cells. Subfield 3 consists of 33 pieces framed PV modules based on multicrystalline Si solar cells. The DC/AC conversion is performed by single-phase SUN Profi string inverters. Every PV subfield is connected to a single inverter and to appropriate data logger. The electricity produced by the generator AcadPV is fed after conversion into 3 separate phases of the low voltage grid. The separation of the PV generator into PV subfields is intended to compare the functionality and differences in performance of monocrystalline and multicrystalline solar cells in real conditions.

A group from CL SENES recently completed its participation in a research and development project supported by the 5th Framework Programme of the European Union - **Advanced Dry Processes for Low Cost Thin Multicrystalline Silicon Solar Cell Technology – (ADVOCATE).** The project included 7 other participants from Belgium, France, Slovenia, the Netherlands, Hungary, Austria and Germany. Its objective was a significant cost reduction of crystalline silicon solar cells by developing fully dry, environmentally friendly multi-Si cell fabrication processes [3].

The Bulgarian team developed and optimized a new technological process for depositing a dielectric layer of $(Al_2O_3)_x(TiO_2)_{1-x}$. The existence of a negative electrical charge at the interface dielectric - semiconductor influences the surface recombination rate of the minority carriers. Covering the semiconductor surface with an $(Al_2O_3)_x(TiO_2)_{1-x}$ layer passivates the surface and reduces the losses from surface recombination. That is why this dielectric layer is very suitable for application in highly efficient silicon solar cells on thin silicon substrates (< 150 microns) [4]. The idea is the subject of a European Patent and the technology is adopted in IMEC, Belgium. As a continuation of the European project the scientific team from CL SENES has been cooperating for the last 3 years with the French company "Photowatt" in the development of an original technology for solar cells on thin Si wafers (125 x 125 mm), based on this patent.

CL SENES participated as a partner of European teams in two R&D projects connected with solar thermal energy storage: **Phase Change Material Slurries and their Commercial Applications (PAMELA)** with 8 participants from 6 countries and **Energy Storage for Direct Steam Solar Power Plants (DISTOR)** with 13 participants from 5 countries. Both projects were supported by the European Framework Programmes.

In addition to research and demonstration activities the Laboratory has contributed to the compiling of information about the development and distribution of solar energy utilization in European projects like **Accompanying Measures for Co-ordination of NAS (New Accession States) and European Union RTD Programmes on Photovoltaic Solar Energy (PV-NAS-NET)** and **Distributed Generation in the Associated States – Research Priorities and Challenges on the Open Electricity Market (DIGENAS)** [3]**.** The project PV-NAS-NET concluded that PV will develop in the New Member States but for this there are still many opportunities to be effectively exploited and some barriers to be overcome. Highly skilled PV researchers, appropriate infrastructure and external funds constitute together a prerequisite for a strong RTD effort in PV in New Member States. In order for PV to become also a powerful technology and industry, awareness should be increased in society and among key decision makers. In particular a legal and market framework should be developed and strengthened in order to make key stakeholders invest in PV in these countries [5].

CL SENES has co-organized two **NATO Advanced Study Institutes** on "Photovoltaic and Photoactive Materials - Properties, Technology and Applications", Sozopol, September 11-22, 2001 and "Nanostructured and Advanced Materials for Applications in Sensors, Optoelectronic and Photovoltaic Technology", Sozopol, September 6-17, 2004. These are high level tutorial courses to convey the latest developments in the subject to an advanced-level audience funded by NATO. They give the opportunity to PhD students and young scientists to keep up to date on current subjects of interest in their chosen field. The two schools mentioned above were highly valuable as a venue where Bulgarian scientist could meet their counterparts from around the world, to hear and discuss lectures given by leading authorities in the given subject area connected to photovoltaic applications. Many collaborations started at these institutes. The lectures and part of the posters presented were published in NATO Science Series [6, 7].

INNOVATIONS, INDUSTRY APPLICATIONS, RESEARCH ACHIEVEMENTS

A group of researchers from CL SENES took part in the contract "Development of chemical and bio-chemical sensors of the type "Electronic nose" for environment monitoring". The contract coordinator is the company "Nano Toolshop OOD"-Botevgrad, which maintains the only technological line in the country for microelectronics technology. A technology and a prototype have been developed based on a matrix of four piesoresistive sensors. The technology is a complex combination of microelectronic technological processes and processes of micromachining of elements in a silicon wafer. In the framework of the research and development process a close cooperation between the two units was forged, which became the basis of joint activities in other projects.

Major contracts with companies

1. Framework contract with "ENEMONA AD" "Utilization of Solar Energy", 2006.

2. Framework contract with "ERATO HOLDING AD" "Utilization of Solar Energy by Photothermal Conversion", 2007.

3. "Monitoring in Real Conditions of Two Photovoltaic Systems Connected to the Power Network", commissioned by the company SunEnergy, Germany, 2007.

4. "Putting in operation, optimization and one year monitoring of a 100 kW Photovoltaic System" - commissioned by the company Venture Equity, Bulgaria, 2008.

In the framework of a detailed additional agreement after an application from ERATO Holding, a new type of vacuum-pipe solar collector is being tested. The task is to assess its parameters and to optimize its design in preparation for mass production. The investigations are carried out on the test stand for solar water collectors developed as part of the project "Bulgarian Centre of Solar Energy", supported by the programme Centres of Excellence. This equipment turned out to be very useful in the development of innovation activities in the field of solar water collectors. Contracts with SMEs are regularly fulfilled. CL SENES is perceived as an authoritative and reliable partner in this kind of technology. A contract was concluded with the company "Electrostil-S OOD" for the development of a prototype of a flat water collector with materials and technologies allowing for low prime cost of the product.

PLANS FOR THE FUTURE

In 2007 a regulation was issued by the State Energy and Water Regulatory Commission for preferential prices for electrical energy produced by photovoltaic conversion of solar energy. This provoked a heightened interest from industry, investment agents and investors. The demonstration of 10 kW photovoltaic system "AcadPV" working at CL SENES was visited almost every day. A great number of consultations and discussions took place with the aim to respond to the public interest. For practical application of the new technology for electricity generation, a new methodology for design of photovoltaic systems connected to the low and medium voltage grid was developed. It consists of three modules: an assessment of the potential, optimization of the solar generator and estimation of the electrical power to be produced, economic analysis for the returns on investment. A real test with experimental results from the demonstration system AcadPV has been made.

In the framework of a bilateral agreement between Bulgaria and India a preliminary study was conducted and a draft design proposed for a 300 kW solar power station. CL SENES participated in the preparations for the negotiations during the official visit of the Prime Minister of Bulgaria to India. For the implementation of the project a new legal entity "SolarEnergy" was created with main participants CL SENEI and Enemona AD. The new company will be responsible for the administrative and technical management of the project, which will be executed with the financial assistance of India. The objective is within the framework of this project to create a research and demonstration centre for promoting the utilization of renewable energy sources.

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ASSOCIATION OF PRODUCERS OF ECOLOGICAL ENERGY

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Association of Producers of Ecological Energy (APEE) was established in 2004, from 16 companies willing to invest and to develop the ecological energy in Bulgaria.

The major aim of APEE and of its members is to help and protect the private initiative of Bulgarian contractors in the area of production and distribution of ecological energy from renewable energy sources, representing their economic and branch interests to the state authorities and other organizations.

The goals of the Association are:

1. To help scientifically the Bulgarian companies specialized in the area of producing ecological energy from renewable energy sources.

2. To carry out research, launching and protection of the economic, social and professional interests of the members of the association in relation to the development of production of ecologic energy from renewable energy sources.

3. To collect information, and give ideas for a change of the operative legislation, as well as to establish contacts with legal and executive authorities in the country and the European Union, with regard to active participation in normative deeds and their alternative projects in the area of renewable energy sources.

4. To cooperate between the members of the association and the state and local authorities and management in respect of development of the production of ecologic energy from renewable energy sources; as well as to cooperate and participate in the development of different projects.

Our aim is to cooperate in the integration of Bulgarian companies in the European economic structures using international contacts with similar associations in the ecological energy area.

At present we have more than 30 members – they are from different regions of the country, mainly from Varna, Sofia and Burgas. Some are Bulgarian representatives of Spanish, German, Austrian companies with interests in the ecological energy. Almost all of our members are interested in using the wind power.

Some of our bigger members are:

o Enel
o AES Electric
o Geo Power
o Global Wind Power (Denmark)
o Cycleenergy (Austria)
o Elana Holding
o Asarel Medet
o Elatsite Med
o ABO Wind (Germany)
o Eolica Bulgaria

The first wind park in Bulgaria is in operation since the beginning of the year 2005. The site is near Gorichane and Tyulenovo villages, in the North-East Bulgaria. The total capacity is 1.6 MW. The turbines – second-hand MICON M750.

Besides using the hydro power, which already has traditions here, the wind energy is being considered as the fastest developing renewable energy source in Bulgaria in the last few years.

The Association also actively **participates in domestic and international industry events.** We are members of EWEA and WWEA since 2006. Our aim is to participate in policy working groups, and cooperate with other members of the European Union.

Cooperation with Bird Life International and their representative in Bulgaria – the Bulgarian Society for Birds Protection:

• A draft agreement for co-operation between APEE and BSBP has been signed, the purpose of which is to minimize the existing conflict between the birds and the energy generating installations;

• Signed contract setting out the implementation of a base research of the migration of the birds.

One of our projects together with Bird Life Bulgaria is for establishing of "green" zones in Bulgaria for wind turbine installations, without posing threats to the birds.

Ministry of Economy and Energy is leading the national policy on energy and energy efficiency, setting up national priorities for deployment of renewable energy among other functions. Today APEE is a part of the working group, patronized by the Ministry of Economy and Energy, comprised of lawyers and experts in various fields of energy, ecology and renewable energy sources. In July 2007 the new Law on Renewable Energy Sources and Biofuels was adopted.

Current projects

Many companies started to explore the options for wind turbine installations in Bulgaria. **The plans at the moment are for installing total 200–300 MW till the end of 2010.** Currently there are numerous wind farm proposals for turbines of varying size and capacity along the Black Sea coast. The biggest projects are planning to use the wind power of the Northern part of the Black sea, where the wind conditions of the sites are the most suitable.

As **the market for new wind turbines in Bulgaria will grow fast in the near future**, we established contacts with Vestas, Enercon, Gamesa and other wind turbine producers in Europe. We believe that this is a very important step of the way we should go for making wind energy utilization attractive and feasible in Bulgaria.

Cooperation with different (non) governmental organizations, institutions, and private companies is one of our main and important issues. We are always open to meetings, discussions and negotiations, which lead to faster development of the wind energy in Bulgaria and our members' activities.

MADE IN BULGARIA WITH EUROPEAN SUPPORT

DISTRIBUTION OF GLOBAL SOLAR IRRADIATION ON HORIZONTAL AND ON INCLINED SURFACES IN BULGARIA

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Abstract

Distribution of solar irradiation in the region of Bulgaria on the base of geographical information system (PVGIS) is presented. Data about daily and yearly values of solar global irradiance for a horizontal surface for every district town in Bulgaria are obtained using this system and regions with the maximal and minimal values of solar irradiation are defined. The comparison between solar irradiation values for a horizontal plane, for south-facing planes at vertical inclination (G(90)) and optimal inclination is presented.

INTRODUCTION

The sun is a condition for existence of life on the Earth and never failing energy source. The Sun radiates energy, which reaches the Earth as heat and light. During one hour the Sun radiates to the Earth surface more energy than that consumed by the earth population during a year.

The use of the sun radiation can be passive and active. The use of passive sun radiation leads to decreasing of energy consumption of a building. This can be obtained through south orientation and suitable glazing of the building. The active use of the sun radiation includes technical components and it is realized by two main systems – solar heating installations and photovoltaic systems. Solar heating installations produce heat energy for heating of buildings, domestic hot water, and water in swimming pools and for cooling systems. Photovoltaic (PV) systems produce electricity and supply it to power network or to individual users. Solar heating installations and PV systems contribute to saving of fossil fuels and petroleum products and to decrease of greenhouse gas emissions.

The geographical location of Bulgaria is suitable for active use of solar energy.

The aim of this paper is to determine the most suitable areas in Bulgaria for installation of solar collectors and photovoltaic panels.

SOLAR RADIATION IN BULGARIA

Accurate prediction of real energy production of solar systems and PV modules in any required location is crucial for decision on investment in these systems. Initial data about solar radiation can be obtained from a web-based geographical information system of meteorological data. Solar radiation and temperature geospatial data are modeled in a geographical information system PVGIS [1, 3], and are based on ten-year average data from a large number of measuring stations.

The computational approach used in PVGIS is based on a solar radiation model *r.sun*, and the spline interpolation techniques *s.surf.rst* and *s.vol.rst* that are implemented within the open-source GIS software GRASS [2]. The *r.sun* model algorithm uses the equations published in the European Solar Radiation Atlas [4]. The model estimates beam, diffuse and reflected components of the clear-sky and real-sky global irradiance/irradiation on horizontal and inclined surfaces. Total daily irradiation (Wh/m^2) is computed by integration of their radiance values (W/m^2) that are calculated at a time step of 15 minutes from sunrise to sunset. On the basis of monthly averages of daily sums of global irradiation available for meteorological stations in the region and monthly averages of the ratio of diffuse to global irradiation at the same number of the ground stations average monthly and yearly irradiation is calculated.

Using the PVGIS system, predictions of solar irradiance have been made at different locations in Bulgaria [5].

In Table 1 data for daily and yearly values of solar global irradiance are presented for a horizontal surface for every district town in Bulgaria and for the towns located in the southwestern part of Bulgaria (Petrich and Sandanski). It is well seen that the maximal value of daily (3748 Wh/m^2/day) and yearly (1565 kWh/m^2/yr) solar irradiation is obtained for the region of the town of Silistra. The towns with yearly solar radiation more than 1500 kWh/m^2/yr are as follows: Dobrich (1541 kWh/m^2/yr); Shumen (1521 kWh/m^2/yr); Sliven (1519 kWh/m^2/yr); Varna (1516 kWh/m^2/yr) and Burgas, Razgrad, Targovishte (1513 kWh/m^2/yr). The specified towns are located in the eastern part of Bulgaria. In the towns with the mildest climate in Bulgaria – southwestern regions – the yearly sun radiation is 1487 kWh/m^2/yr in Petrich and 1481 kWh/m^2/yr in Sandanski.

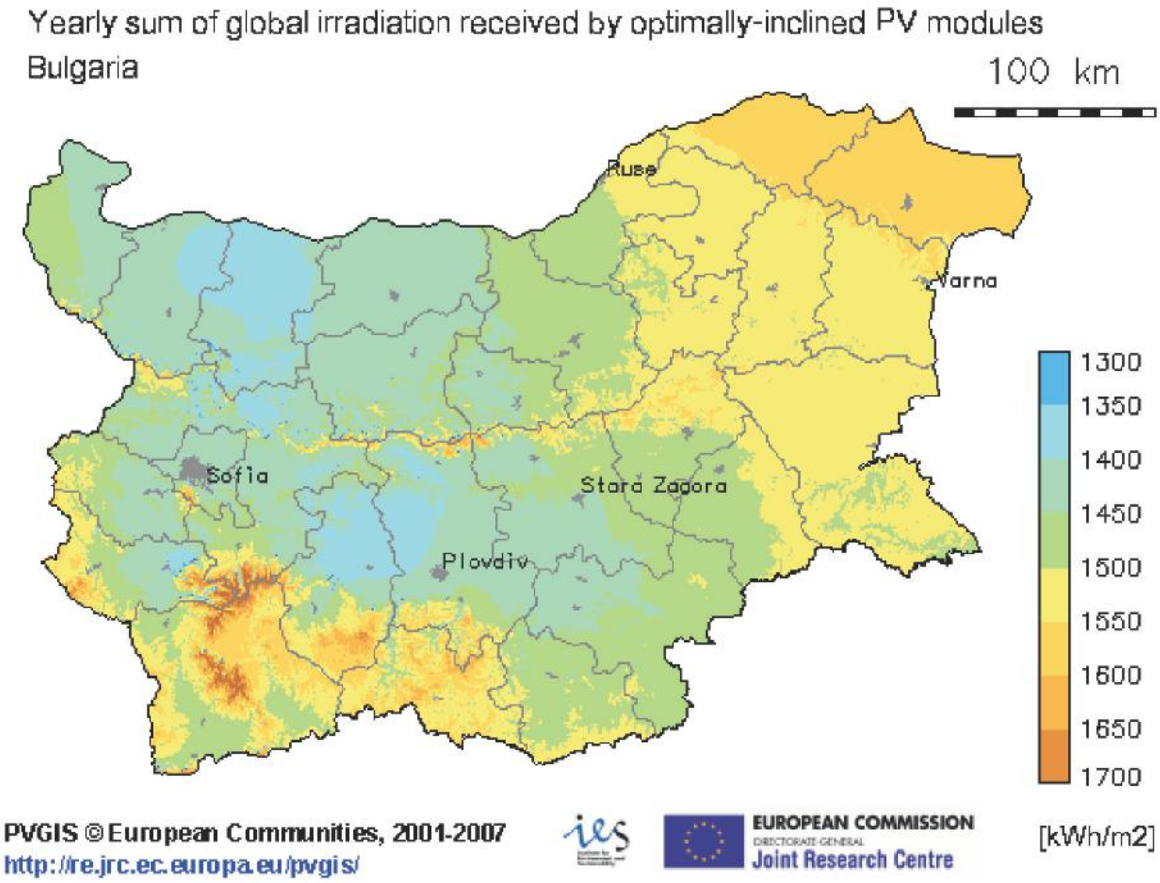

Fig. 1. Solar irradiation map of Bulgaria [5]

Figure 1 shows a solar irradiation map for Bulgaria based on the monthly averages. It is well seen that the yearly sum of global irradiation varies between 1300 and 1700 kWh/m^2 per year. The maximal values of solar irradiation are observed in the mountains Rila and Pirin. Great part of these areas is difficult for access and installation of PV modules, respectively. The areas of eastern Bulgaria, especially the northeastern part, and the southwestern areas are of interest for installation of solar heating systems and PV modules.

The region with minimal value of solar irradiation (1382 kWh/m^2/yr) is the area near the town of Vratsa. Comparison between solar irradiation

Table 1. Data about daily and yearly values of solar global irradiance for a horizontal surface for every district town in Bulgaria

Location	January *Wh/m²/day*	July *Wh/m²/day*	Daily *Wh/m²/day*	Year *kWh/m²/yr*
Blagoevgrad	1470	5973	3580	1457
Burgas	1482	6044	3694	1513
Dobrich	1445	6179	3737	1541
Gabrovo	1442	5891	3482	1440
Haskovo	1535	5738	3568	1451
Kyustendil	1485	6024	3638	1484
Kardzhali	1549	5835	3579	1436
Lovech	1345	5894	3478	1410
Montana	1274	6037	3476	1405
Pazardzhik	1440	5641	3421	1389
Pleven	1309	5880	3471	1409
Plovdiv	1467	5719	3477	1423
Razgrad	1426	6043	3654	1513
Ruse	1363	6022	3615	1496
Shumen	1442	6085	3674	1521
Silistra	1385	6205	3748	1565
Sliven	1511	5999	3668	1519
Sofia	1375	5780	3450	1397
St. Zagora	1514	5793	3571	1460
Targovishte	1464	6041	3660	1513
Varna	1443	6105	3697	1516
Veliko Tyrnovo	1446	6016	3640	1473
Vidin	1254	6113	3525	1432
Vratsa	1270	5944	3433	1382
Yambol	1516	5914	3654	1495
Petrich	1449	6110	3664	1487
Sandanski	1447	6054	3621	1481

in the towns of Silistra and Vratsa shows that the irradiation in Silistra is 1.132 times more than that in Vratsa. In practice this means that a house-owner in Vratsa must install 1.132 times more m^2 of solar collectors or PV panels than in Silistra to achieve the same capacity.

It is interesting to compare the daily irradiation in Silistra and Vratsa for the whole year (see Figure 2). The maximal value of solar irradiation in both towns is obtained in July and the mini-

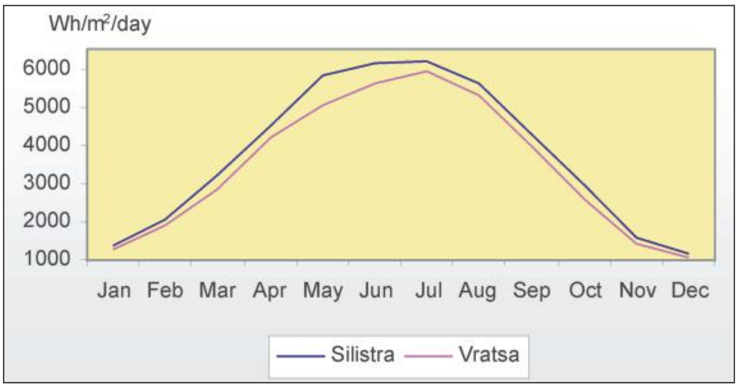

Fig. 2. Daily horizontal irradiation in the towns of Silistra and Vratsa

mal value in December, respectively. In the town of Silistra the irradiation in July is 5.41 times more than that in December, and in Vratsa this value is 5.63 times. Therefore during the winter months the low level of solar irradiation leads to low production of heat or electricity from solar collectors or PV panels.

GLOBAL IRRADIATION AT FIXED OPTIMAL ANGLE

The values for a horizontal plane (Ghor) and for south-facing planes at vertical inclination (G(90)) and optimal inclination (the angle of inclination that will receive the maximum amount of sunlight during the whole year) (Gopt) are presented in PVGIS data base.

Data for horizontal, vertical and optimal inclination irradiation for the towns of Silistra and Vratsa are presented in Figures 3 and 4, respectively. The analyses of results of daily irradiation on a horizontal plane and on an optimal inclination for the town of Silistra shows that inclining of solar collectors or PV panels leads to increase of produced energy by 14.4%. For the town of Vratsa this increase is 10.2%.

The optimal inclination angles of the solar collectors and PV modules to maximize energy

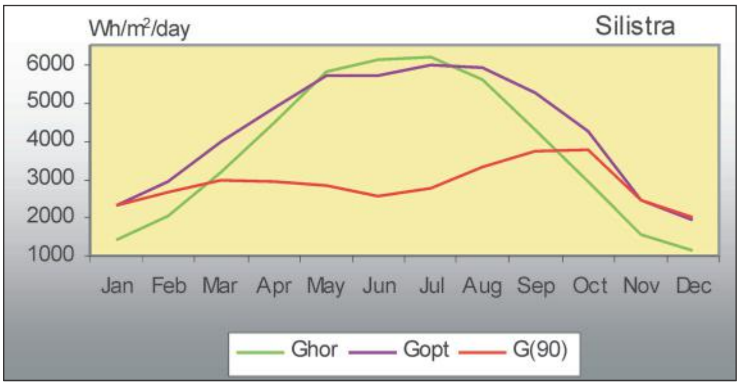

Fig. 3. Data on horizontal, vertical and optimal inclination irradiation for the town of Silistra

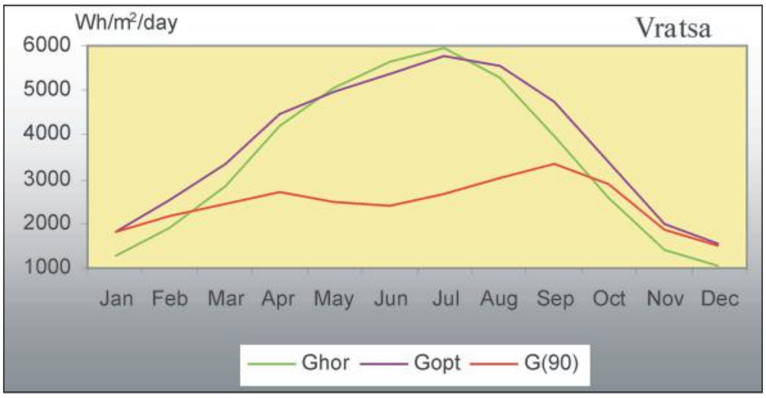

Fig. 4. Data on horizontal, vertical and optimal inclination irradiation for the town of Vratsa

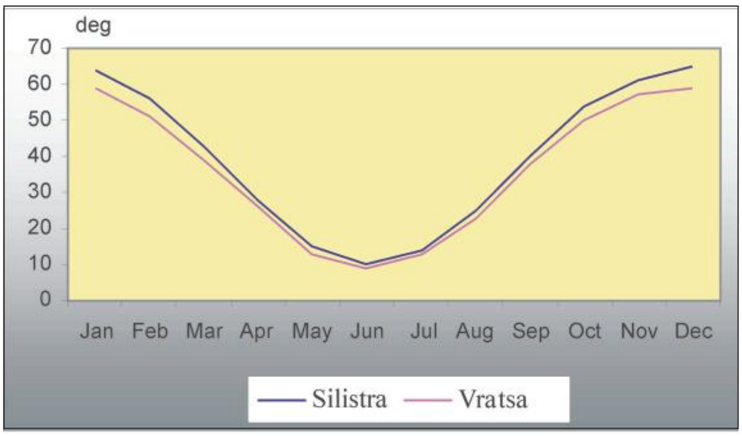

Fig. 5. Optimal inclination angles for the towns of Silistra and Vratsa

yield over a year (degrees] for the towns of Silistra and Vratsa are given in Figure 5. It is well seen that this angle for the town of Silistra is varied in the interval from 64° for December to 6° for July. For the town of Vratsa this angle varies from 59° for December to 9° for July. For the area of Bulgaria this average optimal angle varies in the interval of 31° for the regions of the towns Lovech, Montana, Petrich and Yambol to 35° for the region of Silistra. Solar collectors and PV panels must be installed on tracking elements and it will lead to increase of their cost. The other possibility is installation of panels or modules on an optimal inclination calculated for the examined region.

CONCLUSION

The solar radiation potential on the territory of Bulgaria is considerable, but there is significant difference in sunlight intensity in different regions. Data analysis shows that the maximal value of solar irradiation on the territory of Bulgaria is obtained in the region of Silistra and the minimal value – in the region of Vratsa. Comparison between solar irradiation in both regions shows that the irradiation in Silistra is 1.132 times more than that in Vratsa. The dependence between solar irradiation and time of the year shows that during winter months solar irradiation is more that 5 times less than in July.

The obtained results of solar irradiation on the territory of Bulgaria show that installation of solar collectors for heating and domestic hot water and of PV modules for production of electricity is perspective and economically profitable.

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DESIGN AND CONSTRUCTION OF HEAT PUMP SYSTEMS USING THE GROUND (GEO–ENERGY) AS LOW TEMPERATURE SOURCE AND STORAGE FOR HEATING AS WELL AS COOLING OF BUILDINGS

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A Bulgarian company offers know-how in construction of innovative climatic systems characterized with horizontal ground exchangers situated on different levels. The technology (Borehole Thermal Energy Storage (BTES)) is applied as long-term seasonal thermal energy storage, and is used to store large amounts of thermal energy for heating or for cooling in the ground. BTES has (because of its smaller size and lower hydro-geological restrictions) a big potential for application. The heat exchangers (mostly double U-tube plastic pipes in grouted boreholes) work efficiently in nearly all kinds of geologic media. The system is called Borehole Heat Exchanger (BHE) system. The most popular BHE heating system offered by the company is with one or more boreholes typically 50 - 200 m deep under the ground surface. It is a closed-circuit heat pump coupled system ideally suited to supply heat to smaller, decentralized objects like single family or multi-family houses. A common feature of these ground-coupled systems is a heat pump, attached to a low-temperature heating system like floor panels/slab heating. Experimental and theoretical investigations (field measurement campaigns and numerical model simulations) have been conducted over several years to elaborate a solid base for design and performance evaluation of BHE systems. The ground temperature results are highly informative with respect to the long-term performance. Atmospheric influences are clearly visible in the depth range 0 - 15 m; below 15 m the geothermal heat flux dominates. The results show that in the near field around the BHE the ground cools down in the first 2-3 years of operation. However, the temperature deficit decreases from year to year until a new stable thermal equilibrium is established between BHE and ground, at temperatures that are some 1-2 K lower than originally. The long-term reliability of BHE-equipped heat pump systems, along with economic and ecological incentives (see below), led to rapid market penetration. This was accompanied by the development of design standards. The main reason for using ground source heat pumps for heating and cooling of buildings is the use of the ground as a sustainable and renewable source of (thermal) energy with better temperature conditions for the heat pump when compared to other sources such as air or surface water.

Innovative Aspects:

• Relatively free choice of position next to buildings (or even underneath);

• No need, at least for smaller units, for thermal recharge of the ground;

• BHE systems are installed in a decentralized manner, to fit individual needs;

• In contrast with high temperature geo-energy obtained from greater depth, low-temperature geothermal energy systems are widely applicable under almost any circumstances for heating as well as cooling of buildings;

• The systems operate emission-free.

Advantages:

• Very long life span (more than 50 years);

• Virtually maintenance-free;

• Very dependable;

• There is no need of cooling towers and equipment on facade or roof;

• Smaller technical room;

• No noise production;

• Low areal demand of a few m^2 only (in a country where ground property prices are high);

• Less space demand (several m^3) than for conventional systems;

• No transportation risks and costs as with oil/gas solutions;

• No need for groundwater protection (as with oil boilers/tanks);

• Low operating costs (no oil or gas purchases, burner controls etc. like with fossil fuelled heating systems);

• Local utility subsidies/rebates for environmentally favourable options like electric heat pumps;

• Savings on primary energy (± 1,5 - 3 GJ/MWht/year) and CO_2 emission (± 150 - 200 kg/MWht/year).

CERAMIC MEMBRANES FOR ENERGY AND ENVIRONMENT APPLICATION

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The wide range of advanced products proposed by a Bulgarian research group can be applied in such current branches as energy and environment. For example, the ceramic membranes from the fluorite class of materials are the main part of Solid Oxide Fuel Cells (SOFC). In this context, ion-conducting membranes are an effective transport media for oxygen flux. It is well known that the oxygen ion transport by mix-conducting membranes makes possible partial or completed oxidation of light hydrocarbons to value-added chemical products, and singes on the anode side of the SOFC. Parallel co- generation of electricity can be accomplished. Dense mixed conducting membranes are applicable in the field of gas separation technology as well.

They can act in both innovative directions as oxygen pumps, as well as oxygen generators. An innovative application of zeolite membranes is for engine fuels octane number enhancement. After appropriate catalytic modification of zeolite membranes they are in position to transform normal hydrocarbons contained in the fuels into iso-hydrocarbons. The concentration of these products is responsible for a high octane number and efficiency of engines in parallel with the waste reduction. Regarding environmental protection the ceramic membranes are attractive for application. In the case of zeolite membranes, water detoxification and extraction of heavy metals appear to be easier due to their unique ion exchange properties. The energy produced via SOFC is environmentally friendly, without noise and with a low level of harmful gas emissions. The methods proposed are well developed and the research institute is in a position to apply them in a practical way. In short, low cost and highly productive methods starting from liquid phase – hydrothermal crystallization of gels, wet chemical synthesis, ultrasonic spray pyrolysis, microwave treatment, are within the possibilities of the research institute team. It is also possible to perform solid-state synthesis of ceramic membranes with different compositions. The synthesis of defect-free zeolite membranes is not easy. The research institute is able to apply a modification of hydrothermal synthesis in order to obtain zeolite membranes free of cracks and pin holes. The laboratory is looking for industrial partners interested in further development (both of products and methods for membrane synthesis) and in research institute and companies for testing and methods parameters optimization.

Innovative Aspects:

• Regarding the application, the pore size of the zeolite membranes can be easily controlled by introducing of appropriate template agents with various molecular sizes;

• High catalytic activity and selectivity can be obtained by simple and low-cost ion exchange process with ions of 3d elements incorporation into the channel system of the zeolite membranes;

• A modification of hydrothermal synthesis allows the synthesis of defect-free zeolite membranes;

• In the case of ion-conducting membranes the operating temperature of the SOFC could be lowered via the appropriate choice of compositions and methods for synthesis.

Main Advantages: The basic advantages of the products proposed are: wide range of compositions variation, modification of the surface and/or channel morphology, and wide area of application at a low price. The methods developed and applied are flexible, of low cost, with easy process parameters control possibilities and output for fabrication of thin, thick, dense and porous (with controlled pore size and shape) ceramic membranes.

EQUAL IN EUROPEAN RESEARCH AREA

BULGARIAN VIPs

Assoc. Prof. PETKO VITANOV, PhD

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Director of the Central Laboratory of Solar Energy and New Energy Sources at the Bulgarian Academy of Sciences. Author and co-author of 145 papers that have been published in scientific journals and conference proceedings.

Mr. Petko Vitanov has graduated from Sofia University St. Kliment Ohridsky, Faculty of Physics. He defends his MSc degree in 1968 and his PhD thesis "Properties of Ultra Thin Layers of Silicic Oxide and Their Application in Microelectronics" in 1984 at the Institute of Microelectronics, Sofia. He was an Alexander von Humboldt fellow in 1982-1983 at the Technical University Munich and in 1990 at the Federal Armed Forces University in Munich.

Petko Vitanov is an Associate Professor since 1986 at the Institute of Microelectronics. Since 1993 he is the Director of the Central Laboratory of Solar Energy and New Energy Sources at the Bulgarian Academy of Sciences.

Research Activity

Dr. Vitanov's scientific career from 1970 to 1993 was connected with development of microelectronics in Bulgaria. He worked in the field of physics and MOS integrated circuits technology. He took part in the development and implementation of 4 basic technologies in of integrated circuits production. His research achievements are in the field of physical problems in microelectronics, device modeling, submicron semiconductor devices and nanoelectonics. Since 1994 he has been working in the field of transformation of solar energy, in particular solar photovoltaics, modules and systems. He has research interests in the field of nanotechnologies.

Participation in International Projects

During the period of 1996-2003 he was the leader of two projects financed by UNESCO and four joint projects with European companies and universities. He has worked on 5 European projects (5 FP and 6 FP) in the field on photovoltaics, one of which is establishment of Bulgarian Center on Solar Energy from the program of the Centers of High Competence.

Publications

Dr. Vitanov is the author and co-author of 145 papers that have been published in scientific journals and conference proceedings in the field of physics of semiconductor devices, MOS technologies, physics of submicron devices and solar photovoltaics and systems.

Other Activities

• Member of the Organizational Committee of the International School on Physical Problems in Microelectronics – 1985, 1987, 1989.

• Chairman of the Organizational Committee of the I, II and III national conferences of renewable energy sources - 1994, 1999 and 2003.

• Coordinator of the Paneuropean Conference on Solar Energy 1999 in Sofia.

• Member of the National Expert Council on Renewable Energies.

Assoc. Prof. KOSTADINKA GESHEVA, PhD

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Head of the Photothermal Solar Energy Conversion department, member of the International Advisory Board of the European conference on chemical vapor deposition (EUROCVD).

Kostadinka Gesheva graduated from Sofia University, Bulgaria in 1968. In 1983 she obtained her PhD degree in CVD Technology of Black Molybdenum Coatings - Solar Absorbers and Investigation of Their Properties from the Central Laboratory of Solar Energy and New Energy Sources at the Bulgarian Academy of Sciences.

Kostadinka Gesheva is an Associate Professor at the Central Laboratory of Solar Energy. She is the head of the photothermal solar energy conversion and leads the researches in the area of thin film optical coatings for effective solar energy utilization. More specifically she has been working on spectrally selective surfaces technology and investigation, the start of which she had at Optical Sciences Center at the University of Arizona, where she specialized on new technologies and materials for the photothermal solar energy conversion under the academic advising of prof. Bernhard Seraphin.

After coming back she continues working at the newly formed Central Laboratory of Solar Energy Materials and New Energy Sources, where she has developed similar technological system and continues with thin film optical coatings technology and research. Recently her group works on electrochromic thin films for "smart windows".

Participation and coordination in Research Projects:

• 1992-1994: "CVD and Sol-gel coatings for cutting tools";

Financial support: ISCAR Co. Israel;

Institutions taking part: Central Laboratory of Solar Energy and New Energy Sources, Bulgarian Academy of Sciences.

• 1993-1996: "Technology for deposition of thin film optical coatings of WO_3 and investigation of electrochromic effect";

Financial support: National Research Studies fund at the Ministry of Science and Education;

Institutions taking part: Central Laboratory of Solar Energy and New Energy Sources, Bulgarian Academy of Sciences.

• 1998-2001: "Investigation of electrochromic effect in optical structures based on CVD-MoO_3 and $W_xMo_{1-x}O_3$ and sol-gel TiO_2";

Financial support: National Science Research fund at the Ministry of Science and Education.

• 1992-1994: "Schottky Barriers W/amorphous Si and alloys" – research team participant;

Financial support: Ministry of Science and Education;

Participants: different research groups from Central Laboratory of Solar Energy and New Energy Sources, Bulgarian Academy of Sciences.

• 1996-1998: "Solar cells based on CdS – CdTe – deposition of W ohmic contacts", coordinator Dr. Bohne, Germany, responsible person from the Laboratory, R. Rashenov;

Personal responsibility: CVD W contacts for the solar cells, optimization of the ohmic behaviour of the electrical contacts;

Financial support: European Commission for Science.

• 2004-2007: "Ion-induced crystallization in amorphous media-effects of high-dose implantation with heavy ions";

Financing by the Ministry of Education and Science, National funds for Science;

Basic responsibility: Institute of Solid State Physics, Assoc. Prof. Dr. Maria Kalitzova;

Personal responsibility: High-frequency electromagnetic field treatment and the research of the newly developed nanomaterial – formation of Te nanoclusters, changes in the electrophysical behaviour of the system (Silicon with NCs).

• 2006-2009: National Research Program "Optical Coatings for Effective Photothermal Energy Conversion";

Financial support: National Science Research Fund, Ministry of Education and Science;

Institutions taking part: Central Laboratory of Solar Energy and New Energy Sources, Institute of Electronics, Central Laboratory for Optical Imaging of Information, Bulgarian Academy of Sciences, Technical University in Sofia.

Prof. Gesheva has over 120 publications, about 300 citations, over 20 presentations at international conferences, including several invited papers and seminars. She is a member of the International Advisory Board of the European conference on chemical vapor deposition, EUROCVD, where she represents Bulgaria. This is a huge conference, every two years held in different European countries, in some cases going together with the International conference on CVD. She was active in arranging for Bulgaria to become a member of the European CVD society. She has applied 2011 EUROCVD conference to be held in Bulgaria.

AWARDS

AWARDS FOR SPECIAL CONTRIBUTION TO SCIENCE

On February 20, 2008 the Minister of Education and Science Daniel Valchev bestowed awards for special contribution to science for the year 2007.

Acad. Alexander Petrov, the Director of the Solid State Physics Institute at the Bulgarian Academy of Sciences, won the prize "For Special Contribution to Science". He was distinguished for his research work in the field of liquid crystal physics.

Acad. Petrov is a founder of a scientific school on the liquid-crystal approach in physics of live matter. He is a member of the Board of Directors of the International Crystal Society, member-founder of the International Society of Molecular Electronics and Biocomputers. He is a leader of and participant in many international research projects, as well as a winner of the Freedericksz Medal of the Russian Liquid Crystal Society (2004) for his remarkable works in the field of liquid crystals.

Assoc. Prof. Valentin Popov, lecturer at the Physical faculty of Sofia University St. Kliment Ohridski, won the award "For Special Contribution to Science" for young scientist. He was distinguished for his achievements in theoretical investigation and computer modeling of physical properties of carbon nanotubes.

In 2007 Ministry of Education and Science established a "Young Professor" award, which is adjudged to Bulgarian researchers and lecturers up to the age of 55. Its first winner is **Prof. DSc. Petar Kralchevski**, a lecturer at the Chemical faculty of Sofia University St. Kliment Ohridski.

Prof. Kralchevski is the creator of the theory of interaction between colloid particles on a liquid surface and has a patent registered in Germany. He has two national awards: the BAS and SU St. Kl. Ohridski's Prof. Asen Zlatarov award for chemistry for 1990 and honorary badge of SU Kl. Ohridski with blue ribbon for scientific achievements for the year 2006.

ANNUAL AWARDS FOR CONTRIBUTION TO THE DEVELOPMENT OF BULGARIAN ECONOMY "IN–5"

Bulgarian Industrial Association (BIA) for the fourth time bestowed its annual awards "**IN–5**" for contribution to the development of Bulgarian economy for the year 2007.

The name of the award "**IN–5**" reflects the five major poles of economic prosperity – **industry, investments, innovations, intellect** and **initiative.** The awards are also five: for industrial development, investment activity, applied innovation in production, research project with economic potential and for initiative activity.

The statuette of Ikarus, certificate and entry in the Book of Honour of BIA were awarded to:

• Category INDUSTRY: **Fikosota Sintez OOD – Shumen**, with managers **Krasen Kyurkchiev** and **Zhechko Kyurkchiev** – for expansion of production, certification of all products and gaining new market niches;

• Category INVESTMENT: **Overgas Inc. AD – Sofia**, with executive manager **Sasho Donchev** – for coherent investment policy, mastering new technology for compressed natural gas and systematic work in the field of human resources;

• Category INNOVATION: **Bolyarka VT AD – V. Tarnovo**, with executive manager **Anton Nenov** – for implementation of new technologies, high-productivity machinery and broadening of the export list;

• Category INITIATIVE: **Mebel stil OOD – Targovishte,** with manager **Ilko Iliev** – for realization of a number of initiatives which allowed running of new production capacity, introduction of new technology and creation of more jobs;

• Category INTELLECT: **Optics AD – Sofia**, with executive manager **Ivan Cholakov** – for adoption of quintuply integrated management system from ISO series, protection of industrial design for 16 products and implementation of micro optics and stab lens production.

BIA's badge of honour and a diploma were delivered to:

• Category INDUSTRY: **Bulned EOOD – Vratza**, with manager **Stoyan Stoyanov** – for implementation of new production lines and broadening of production list that have led to increase of export;

• Category INVESTMENT: **Pnevmatika serta AD – Kardzhali**, with executive manager **Valcho Petkov** – for putting to use the investment, which allowed implementation of new technologies and creation of more jobs;

• Category INNOVATION:

– Vaniko OOD – Blagoevgrad, with manager **Sasho Vazharov** – for implementation of innovative solutions for thermal processing and vacuum technologies and mastering of high-performance erosion machine;

– Uniform AD – Sofia, with executive manager **Ognyan Palaveev –** for implementation of a new product and putting in operation of a new production line.

• Category INITIATIVE:

– Agrotehchast OOD – Oryahovo, with executive manager **Sashko Marinov** – for realization of initiatives which have led to increase of export, creation of more jobs and increase in the company's production list;

– Promet steel AD – Sofia, with executive manager **Miroslav Borisov** – for initiatives which have led to certification of production resulting in broadening of the export list and winning new markets in five EU member states.

• Category INTELLECT:

– Centromet AD – Vratza, with executive manager **Borislav Novkirishki** – for steady strategy and policy aiming at implementation of research products and new technologies as well as realized export;

– Research team of **Technical University – Sofia**, headed by Assoc. Prof. DSc. Nikolay Angelov – for developed series of research products with industrial application.

Honorary badge and diploma for manager were bestowed to:

• Category INDUSTRY: **Vasil Velev** – executive manager of **Stara Planina Hold AD** – Sofia, for entire successful development of the holding;

• Category INVESTMENT: **Mariana Pecheyan** – prosecutor of **VSK Kentavar EOOD – Sofia**, for investment activity and market realization of the production;

• Category INNOVATION: **Ventsislav Slavkov** – manager of **Spesima Engineering OOD – Sofia**, for steady innovative policy and standing the market grounds outside Bulgaria;

• Category INITIATIVE: **Kiril Vatev** – manager of **Tandem-B OOD – Sofia**, for a number of initiatives that have led to recognition of the firm as a demanded partner in the country and abroad;

• Category INTELLECT: Eng. **Petar Sabev** – vice-president and executive manager of **Rodina Holding AD – the town of Popovo**, for steady policy in introduction of innovative technologies and intellectual products in production process.

Additional award – honorary badge of BIA and a diploma was delivered to Mrs. **Maria Murgina** – executive manager of the National Revenue Agency for her activities in improvement of communications between business and tax administration through introduction of a series of electronic services.

Journalists from electronic and printed media were awarded for impartial and adequate reflection of problems in economy and business.

ARTICLES

RECENT PUBLICATIONS OF BULGARIAN SCIENTISTS

Title:	**Integrating hydrogen generation and storage in a novel compact electrochemical system based on metal hydrides.**
Authors:	Rangel, C.M.[1], Fernandes, V.R.[1], Slavkov, Y.[2], Bozukov, L.[2]
Source:	Journal of Power Sources, 2008
Author Affiliations:	[1]INETI, Electrochemistry of Materials Unit/DMTP, Paco do Lumiar 22, 1649-038 Lisboa, Portugal; [2]Labtech Ltd., Mladost 1, Building 25/A, Sofia 1784, Bulgaria.
ISSN:	0378-7753

Title:	**Solar energy utilization opportunities in Bulgaria.**
Authors:	Gramatikov, P.[1,2]
Source:	NATO Security through Science Series C: Environmental Security, 2007, 139-151
Author Affiliations:	[1]South-Western University Neofit Rilsky, Ivan Mihailov 66, 2700 Blagoevgrad, Bulgaria; [2]Physics Dept., South-Western University Neofit Rilsky, Ivan Mihailov 66, 2700 Blagoevgrad, Bulgaria.
ISSN:	1871-4668

Title:	**A simple technique for determination of the diffusion length in a solar cell.**
Authors:	Ivanov, P.[1], Vitanov, P.[1], Popkirov, G.[1], Singh, P.K.[2]
Source:	Journal of Optoelectronics and Advanced Materials, Vol. 9, 2, (Feb. 2007), 367-370
Author Affiliations:	[1]Central Laboratory for Solar Energy and New Energy Sources, Bulgarian Academy of Sciences, 72 Tzarigradsko Chaussee Blvd., 1784 Sofia, Bulgaria; [2]Electronic Materials Division, National Physical Laboratory, Hillside Road, New Delhi-110012, India.
ISSN:	1454-4164

Title:	**Study of the rate limiting step of the cathodic process in anode supported solid oxide fuel cell.**
Authors:	Carpanese, M.P.[1], Cerisola, G.[1], Viviani, M.[2], Piccardo, P.[3], Vladikova, D.[4], Stoynov, Z.[4], Barbucci, A.[1]
Source:	Journal of Fuel Cell Science and Technology, Vol. 5, 1, (Feb. 2008), Article number 011010
Author Affiliations:	[1]University of Genova, Piazzale Kennedy 1, 16129 Genova, Italy; [2]Institute for Energetics and Interphases, CNR, Via De Marini 6, 16149 Genova, Italy; [3]DCCI, University of Genova, Via Dodecaneso 31, 16146 Genova, Italy; [4]IEES, BAS, 10 Acad. G. Bonchev, 1113 Sofia, Bulgaria.
ISSN:	1550-624X

Title: **Testing *solar* collectors as an energy source for a heat pump.**
Authors: Georgiev, A.[1] AGeorgiev@gmx.de
Source: Renewable Energy: An International Journal, Vol. 33, 4, (Apr. 2008), 832-838
Author Affiliations: [1]Department of Mechanics, Technical University of Sofia, branch Plovdiv, P.O. Box 7, 4023 Plovdiv, Bulgaria
ISSN: 0960-1481

Title: **A study of the Al content impact on the properties of MmNi_{4.4–x}Co_{0.6}Al_x alloys as precursors for negative electrodes in NiMH batteries.**
Authors: Bliznakov, S.[1,2] sbliznak@binghamton.edu, Lefterova, E.[1], Dimitrov, N.[2], Petrov, K.[1], Popov, A.[1]
Source: Journal of Power Sources, Vol. 176, 1, (Jan. 2008), 381-386
Author Affiliations: [1]Institute of Electrochemistry and Energy Systems, Bulgarian Academy of Sciences, Acad. G. Bonchev Street, Block 10, 1113 Sofia, Bulgaria;
[2]Department of Chemistry, State University of New York at Binghamton, P.O. Box 6000, Binghamton, NY 13902-6000, United States.
ISSN: 0378-7753

Title: **Performance of a DI diesel engine fuelled by blends of diesel and kiln-produced pyroligneous tar.**
Authors: Honnery, Damon Damon.honnery@eng.monash.edu.au, Ghojel, Jamil[1], Stamatov, Venelin[1]
Source: Biomass & Bioenergy, Vol. 32, 4, (Apr. 2008), 358-365
Author Affiliations: [1]Laboratory for Turbulence Research in Aerospace and Combustion, Department of Mechanical Engineering, Monash University, Victoria 3800, Australia
ISSN: 0961-9534

Title: **Investigation of lifetimes in quadrupole bands of ¹⁴²Gd.**
Authors: Lieder, E. O.[1,2,3] lieder@tlabs.ac.za, Pasternak, A. A.[1,3], Lieder, R. M.[1,2], Efimov, A. D.[3], Mikhajlov, V. M.[4], Carlsson, B. G.[5], Ragnarsson, I.[5], Gast, W.[1], Venkova, Ts.[1,6], Morek, T.[1,7], Chmel, S.[8], de Angelis, G.[9], Napoli, D. R.[9], Gadea, A.[9], Bazzacco, D.[7], Menegazzo, R.[10], Lunardi, S.[10], Urban, W.[7], Droste, Ch.[8], Rzaca-Urban, T.[7]
Source: European Physical Journal A - Hadrons & Nuclei, Vol. 35, 2, (Jun. 2008), 135-158
Author Affiliations: [1]Institut für Kernphysik, Forschungszentrum Jülich, D-52425 Jülich, Germany;
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Legnaro, Italy;
[10]Dipartimento di Fisica dell'Universita and Istituto Nazionale di Fisica Nucleare, Sezione di Padova, I-35131 Padova, Italy.

ISSN: 1434-6001

Title: **Influence of H₂SO₄ concentration on the performance of lead-acid battery negative plates.**

Authors: Pavlov, D. dpavlov@labatscience.com, Petkova, G.[1], Rogachev, T.[1]

Source: Journal of Power Sources, Vol. 175, 1, (Jan. 2008), 586-594

Author Affiliations: [1]Institute of Electrochemistry and Energy Systems, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria

ISSN: 0378-7753

Title: **Expanding Plasma Region of an Inductively Driven Hydrogen Discharge.**

Authors: Kissjovski, Zhivko[1], Kolev, Stanimir[1], Shivarova, Antonia[1] ashiva@phys.uni-sofia.bg, Tsankov, Tsanko[1]

Source: IEEE Transactions on Plasma Science, Part 3 of 3 Parts, Vol. 35, 4, (Aug. 2007), 1149-1155, 9 graphs

Author Affiliations: [1]Faculty of Physics, Sofia University, 1164 Sofia, Bulgaria

ISSN: 0093-3813

Title: **Preparation and properties of RF sputtered indium-tin oxide thin films for applications as heat mirrors in photothermal solar energy conversion.**

Authors: Boiadjiev, Stefan I.[1], Dobrikov, Georgi H.[1], Rassovska, Milka M. M.[1]

Source: Thin Solid Films, Vol. 515, 24, 2007, 8465-8468

Author Affiliations: [1]Technical University of Sofia, 8, Kl. Ohridski Blvd., 1756 Sofia, Bulgaria

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10–14 September 2008	XVIII National Scientific Symposium with International Participation **"METROLOGY AND METROLOGY ASSURANCE 2008"** Sozopol, Bulgaria Address: Technical University of Sofia 8, Kl. Ohridski Blvd., 1000 Sofia, Bulgaria Phone: (+359 2) 965 2366 Fax: (+359 2) 9652896; (+359 2) 9653215 Web site: http://www.metrology-bg.org
11–14 September 2008	2nd International Research Conference **LANGUAGE, INDIVIDUAL AND SOCIETY IN THE MODERN WORLD** Sunny Beach resort, Bulgaria Address: Info Invest Ltd. - Bulgaria P.O. Box 309, 8000 Bourgas, Bulgaria Phone: (+359 56) 950077 E-mail: symposium@sciencebg.net; office@sciencebg.net
18 September 2008	International Conference **IDC Business Intelligence Roadshow 2008** Sofia, Bulgaria Address: IDC Bulgaria WTC Interpred, Office 333 36, Dragan Tzankov Blvd., 1040 Sofia, Bulgaria Phone: (+359 2) 969 30 56, Fax: (+359 2) 969 30 56 Web site: www.idc-cema.com
9–12 October 2008	11th International Annual Conference **"Policies of Economic and Social Development in Europe"** Sofia, Bulgaria Address: St. Kliment Ohridski University Faculty of Economics and Business 125, Tzarigradsko chaussee Blvd., bl.3, 1113 Sofia, Bulgaria Tel: (+359 2) 8738310, Fax: (+359 2) 8739941 E-mail: conference@feb.uni-sofia.bg