NORDIC CENTRE OF EXCELLENCE IN PHOTOVOLTAICS (NCOE IN PV)

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ABSTRACT: A NCoE in PV has been formed by seven research institutions in the Nordic region. The centre is funded by Nordic Energy Research, Renewable Energy Corporation ASA, Elkem Solar AS, Solibro Research AB, Topsil A/S, Energinet.dk, and Luvata as well as the participating research organisations. The main objective is to strengthen the already formed Nordic R&D network and to serve the fast-growing and demanding Nordic PV industry. This will be achieved by educating PhD students with compulsory mobility of the students, arranging general workshops within solar cell research, organizing in-depth workshops on selected topics, giving hands-on workshops on processing of solar cells, and actively disseminate results both in public and scientific media channels.

Keywords: Nordic co-operation, mobility of students, workshops, solar cell materials

1 OBJECTIVE

The main objective of the centre is to strengthen the existing Nordic R&D network and develop it into a centre of excellence effectively serving the fast-growing and demanding Nordic PV industry. This will be achieved by:

• Defining a PhD program with compulsory mobility of the students
• Arranging general workshops within solar cell research
• Organizing in-depth workshops on selected topics
• Giving hands-on workshops on processing of solar cells
• Actively disseminate results both in public and scientific media channels

2 BACKGROUND AND APPROACH

The overall challenge for the solar cell industry is to bring down the cost/kWh in order to become competitive with other energy resources in the future. Currently the annual increase of the shipment of solar cells is higher than 40 % and has been between 25 and 50 % during the last decade. This large increase has mainly been achieved by:

One of the most important factors to further expansion of the PV industry in the Nordic region is the presence of well educated personnel, since several of these new solar cell players are in a research-intensive development phase.

Modern solar cells are complicated devices and are results of extensive studies and engineering work. Therefore, working in collaboration helps to share special knowledge between partners, follows to keep scientific relations, that finally allows one to speed up achievement of the significant for industry scientific results.

Furthermore, a coordinated marketing of the scientific personnel and their research lines, characterisation equipment and process equipment within the Centre will give the industry a better overview of the R&D possibilities available in the Nordic region. This opens opportunities for companies to find research partners, within the Nordic/Baltic region and facilitates use of advanced equipment available within the Nordic PV collaboration. This will contribute to a more efficient use of advanced equipment, and possibly lead to a higher quality of the research, and subsequently in high-quality scientific output.

The NCoE in PV will also aim to further expand the activity internationally by promoting the centre as a unit toward research groups in Europe, USA and in Asia.

3 RESEARCH PARTNERS

The research partners involved in the centre are University of Uppsala located near Stockholm in Sweden, Helsinki University of Technology in Finland, Danish Technological Institute located in Copenhagen in Denmark, Norwegian University of Science and Technology located in Trondheim in Norway, Tallinn University of Technology in Estonia, Ioffe Physico-Technical Institute in St. Petersburg in Russia and at Institute for Energy Technology located near Oslo in
Norway. In the figure below it is shown where in Scandinavia the partners are located.

Figure 1 Map over Scandinavia and the Baltic region

Below is listed a short description of solar activity of each partner within the centre.

3.1 Institute for Energy Technology

The PV activities at IFE are focusing mainly on silicon based solar cells and the institute has both a solar cell laboratory with a dedicated R&D line for producing silicon-based solar cells as well as a fully-equipped characterization laboratory for doing electrical, optical and structural characterisations.

Among the solar cell research topics at IFE are the production of high purity silicon from gas phase compounds, modelling of crystallisation processes, defect engineering[1], improvement of existing solar cell technology[2], development of new silicon based solar cell technology, solar cell characterization as well as system integration.

The research projects are performed in close cooperation both Norwegian and international solar cell industry.

3.2 Uppsala University

There are two main activities related to research on PV at Uppsala University. The Cu(In,Ga)Se₂ (CIGS) thin film solar cell group led by Marika Edoff and the group for Dye Sensitized solar cells (DSC) led by Anders Hagfeldt. The CIGS research activities are focussed mainly around the absorbing CIGS layer and on the interface between the CIGS layer and the buffer layer. During the last few years the development of alternative buffer layers have led to an efficiency increase up to 18.5 % confirmed total area efficiency for Cd-free CIGS solar cells. In the area of DSC the focus is on development of organic dyes for solid state DSC and on process development of DSC modules based on monolithic geometry

3.3 Helsinki University of Technology

The PV activities at Helsinki University of Technology (TKK) are concentrated around novel solar device concepts, in particular the nano-structured dye-sensitized solar cells [3, 4, 5, 6]. The research strategy is to look on approaches based on easy available and cheap base materials and which lend themselves to mass-production (e.g. spraying, printing, pressing).

The key areas of research on dye solar cells is on device optimization (e.g. charge transfer, advanced characterization, integration on nanotechnology components (e.g. replacement of ITO with nanostructures, use of functional nanobuds, etc.), industrial substrates (e.g. metals, plastics), and scaling up of structures. Main results include world-record dye-cells on flexible non-conventional substrates.

3.4 Danish Technological Institute

The Danish Technological Institute is dedicated to the research and development of dye-sensitized solar cells (DSCs). The research expertise covers all aspect of the cell, from basic design principles over investigations and development of novel dye, electrode and electrolyte systems to the setup and testing of completed cells under various environmental conditions, including outdoor testing facilities.

The move towards semi-automated and standardized larger-scale DSC production is a second focus area of the institute. Finally, the use of dye-sensitized solar cells in architectural applications, such as façade integration, light-filtering systems and as decorative elements, is being investigated.

3.5 Norwegian University of Science and Technology

The PV research activities at the Norwegian University of Science and Technology (NTNU) are mainly concentrated around materials research for first and third generation solar cells. The key areas of research within first generation solar cells are silicon ingot crystallization and characterization and wafer characterization. This activity is led by Otto Lohne. Within third generation solar cells the focus is on the so-called quantum dot intermediate band solar cells. The cells are fabricated using molecular beam epitaxy and pulsed laser deposition. This activity is lead by T.W. Reenaas.

In addition there are activities on the optics of solar cells for increased light harvesting, on (wet chemical) fabrication of TCOs and up-conversion layers, on electrochemical solar cells and on soft PV-materials.

The solar cell research activities at NTNU are carried out in close collaboration with SINTEF, through the Gemini centre – PV Solar cell materials.
3.6 Tallinn University of Technology

Department of Materials Science at Tallinn University of Technology has been nominated as EU Centre of Excellence in PV Materials and Devices, as Estonian Centre of Excellence in Chemistry and Materials Science. Ideology of research activities in Department in the field of PV could be characterized as the use of low cost through cheap materials (replacing rare and highly cost In by Zn and Sn in CIS to yield CZTS), the use of cheap technologies for both materials production and device assembling, such as recrystallization in molten salts to produce powders, electrodeposition and chemical deposition, spray pyrolysis and sol-gel deposition for thin films production and R2R preparation of PV cells.

Laboratories of chemical technologies for powder and thin film production, and of electrical and optical spectroscopies are well-equipped to perform state-of-the-art research and have long-time experience in characterisation of materials by SEM, XRD, Raman, XPS, FTIR, PL and UV-VIS spectroscopies and of solar cell structures by EBIC, AC and DC methods.

3.7 Ioffe Physico-Technical Institute in St. Petersburg

Ioffe Physico-Technical Institute and then its department Photovoltaics Laboratory were pioneers of photoconverters based on AlGaAs/GaAs heterostructures, which were created by Zh.I. Alferov and V.M. Andreev in 1969. The first world large-scale production of heterostructures arrays for space application was started by using technology developed in the Ioffe institute. Increase of radiation resistance has been achieved in the developed AlGaAs/GaAs solar cells with internal Bragg reflector[7].

Today the main solar activity of Photovoltaics Laboratory is connected with development of multi-junction solar cells operating under concentrated solar radiation. High efficient monolithic GaInP/GaAs solar cells [8] and concentrator tandem stacks based on GaInP/GaAs-GaSb cells [9] as well as the high-efficiency space and terrestrial concentrator modules and autonomous photovoltaic installations with these tandems have been developed.

4 INTEGRATED RESEARCH TASKS

The research tasks of this project take place mainly within the partners organisations.

NCoE in PV involves research personnel from all the institutions in addition to 7 PhD students on full time. The research tasks within this project are focusing on 7 areas.

4.1 Photonic crystals for photovoltaic applications

The main focus on this topic is to investigate the potential of using photonic crystals for increasing solar cell efficiencies. Photonic crystals are periodic structures made from materials exhibiting differing refractive indexes. Photonic crystals can exhibit several optical properties of interest in photovoltaics. Concretely, this specific project aims at increasing the efficiency in thin solar cells by increasing their ability to trap light with such structures. The work will partly consist of advanced optical modelling and partly of synthesis and characterization of photonic band gap structures. The project is performed in collaboration with the University Graduate Centre at Kjeller.

4.2 Electrical characterization and modelling of CIGS thin film solar cells

The overall goal of his topic is to develop the electric characterization and modelling of CIGS thin-film solar cells. The purpose of this is to gain deeper knowledge of the material parameters that control the performance of the solar cells. Initially the work has started by using established methods of electric characterisation of complete solar cells such as current-voltage measurements (IV), quantum efficiency and temperature dependent IV-measurements (IVT). In a later stage, other electric measurement methods such as Hall measurements, capacitance measurements and electron beam induced current measurements (EBIC) will be tested and evaluated. An important part of the project is the identification of material parameters of the different layers to be used in device simulations. The focus of the device modelling will lie on the CIGS-layer and the area around the pn-junction.

4.3 Ageing and degradation of nanostructured solar cells

The work deals with ageing of nanostructured dye-sensitized solar cells. Degradation mechanisms in electrode structures and materials will be investigated using commercialized test cells. Electrochemical characterization and structure analysis along traditional PV characterization methods will be employed. Basic structures to be studied include different non-traditional substrates and possibly also new nanostructures for the photoactive material. The results of the work will be relevant for improving the performance and durability which are critical factors for the future of nano solar cells.

4.4 Life-Time studies for Dye-sensitized Nanostructured Solar Cells

The aim of this work is to develop understanding of physical mechanisms of the dye sensitized solar cell, and contribute to a detailed model for cell. The dye sensitized solar cell is a PV (Photo Voltaic) element consisting of different functional layers. Initially In this study relevant literature regarding the dye sensitized solar cell as an electric circuit element will be studied, and hence collect information about the present electric model of the cell.

The plan is to further develop a detailed model describing the electric response of the cell based on the material properties and on the working conditions. One possibility is to focus on charge transport and diffusion of particles within the cell. Throughout the project potential solar cell life-time degradation processes will also be considered. The experimental methods should involve investigations of bulk, interface, and surface properties of the cell at the molecular level. We currently consider
optical and X-ray methods for these investigations.

4.5 Developments of GaInP/GaAs/Ge concentrator cells, grown by MOCVD

The progress in the solar energy development is associated with creating the monolithic multi-junction solar cells (SCs) based on the AIIIVB semiconductor compounds. Main materials for manufacturing multi-junction SCs are germanium and AlGaInP and GaInAs solid solutions. Triple-junction AlGa(In)P/Ga(In)As/Ge SCs have high theoretical efficiency, especially in the case of using concentrated solar spectrum. Growth of monolithic multi-junction solar cells is possible in the case of using MOCVD equipment, like AlX 200/4 system, which is used in Photovoltaic Converters Laboratory in IOFFE Physico-Technical Institute.

The main purpose of current work is not only development of high efficient SCs, but also investigation and improvement of there parameters with using different ex-situ methods and in-situ methods, including measuring the normalized reflection and reflection anisotropy spectroscopy (RAS). The in-situ monitoring of semiconductor structure parameters during epitaxial growth are important for obtaining a wide range of data on properties of growing layers and devices. This approach allows better understanding the peculiarities of the growing process of the modern semiconductor devices

4.6 The growth of monograin powders of different chalcopyrite materials in molten salts

The principal technologies used today for manufacturing solar cells are the planar and the thin-film technologies. During the last years there has been a rising interest for so-called spherical technologies of producing solar cells. The biggest advantage of spherical technologies lies in the simplicity of making large-area layers. Peculiarities of isothermal recrystallisation of initial powders in different molten fluxes will be studied with the aim of developing a simple, inexpensive and a convenient method to produce homogeneous single-phase powder materials with an improved crystal structure, that are perquisite for spherical solar cell use. The main activities will be given to In –free materials, such as Cu2ZnSnS4, Cu2ZnSnSe4 and Cu2CdSnSe4 (CZTS). The developed materials will be realized in monograin layer solar cells. The dependencies of technical parameters of monograin layer solar cells on technological parameters of producing powder materials will be studied.

4.7 Polariton enhanced absorption in solar cells

The goal of this subproject is to increase the absorption of solar radiation in the solar cell through field enhancement via surface plasmon excitation in metallic nanoparticles and similar metallic nanostructures on the cell surface or near the pn-junction. Plasmonics is the field of science and technology related to optics of metallic nanostructures which involves surface plasmon (SP) excitations. Plasmonics include the optics of nanostructured surfaces, SP enhanced transmission through sub-wavelength structures and in general field enhancement near surfaces, such as applied in surface enhanced Raman spectroscopy. Surface plasmons and surface polaritons are waves that propagate along the surface of a metal. Light does not interact with surface plasmons on a smooth metal surface. Structuring the surface allows for coupling and opens up the possibility for the development of new photonic devices with length scales that are much smaller than the wavelength of light. Such structures have a potential for improved performance in solar cells. The project will be organized in an experimental part and a theoretical/modelling part. The modelling part will precede the experimental part and will focus on a study of how the field enhancement is related to the metal nanostructure. On the experimental side the main question is how to make the nanoparticles and integrate them in the solar cell. Spherical nanoparticles can be made by gas evaporation while other structures can be made by masking or lithographic methods

5. NETWORK STRENGTHING ACTIVITIES

During the Nordic PV project [10] from 2003-2006 several different networking activities were introduced with success. In this centre this activity will be followed up with Nordic PV seminars, hands on workshops, in depth seminars on selected topics as well as PhD workshops.

5.1 Nordic PV seminars

It is planned 1-2 Nordic seminars covering the general PV activity in the Nordic. At the seminars participants from all major research institutions and industries working on solar electricity will be invited.

The social activities during these seminars will be important in order to built strong relationship between the different Nordic Countries. The seminars will therefore be located on the countryside to “force” the participants to join the social program during the evenings.

5.2 Hands on workshops

These workshops will involve introduction and hand-on on three different solar cell technologies; crystalline silicon solar cells, CIGS, and photo electrochemical III/V solar cells.

Later this year a hands seminar on crystalline silicon solar cells will be given at IFE in Norway.

5.3 In depth workshops with invited speakers

The aim of these workshops is to present the state of the art technology within selected topics.

The first workshop with invited speakers was arranged in Narvik in Norway. The topics presented were on light trapping, on advanced characterization for solar cells, alternative solar cell structures and on contacting technologies. On each topic world-leading speakers from Europe presented the state of art technology, followed by sections of discussions.

The second hands-on workshop is planned to be on selected topic of CIGS based solar cells. The workshop is planned to be arranged in Uppsala this autumn.
5.4 Forced mobility of scientific personnel between the Nordic Countries

In the integrated research tasks between the Nordic institutions students financed by this project are forced to stay at least 18% of the time in another Nordic institution. By doing this the research tasks are truly integrated and strong bonds between the research institutions are formed.

5.5 PhD workshops

In order to strengthen the collaboration between the PhD students in the Nordic region, workshops on the country side will be arranged bringing the all the PhD students together for 2-3 days. During the workshop the students will present and discuss topics of interest.

6 IMPACT ON PV R&D IN THE NORDIC REGION

This project has been successful in forming a very strong collaboration between the Nordic research institutions. This has been achieved through integrated research tasks with high mobility of scientific personnel between the institutions and mutual access to characterization facilities and processing equipment.

Due the fact that more high-qualified personnel are involved in each project and more process and characterisation equipment are available. The quality of the project is higher compared with research projects carried out by the individual partners.

In addition, due to cooperation through the integrated research tasks, new research projects independent of NCoE in PV have been formed between universities, research institutes, and industry. On the long turn this will lead to enlarged industry development in the Nordic region.

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8 REFERENCES


