SILICON SOLAR CELL RESEARCH IN NORWAY

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ABSTRACT: Today, solar cells are most commonly made from either mono- or multicrystalline silicon (Si) wafers. In Norway, universities, research institutes and companies in the solar cell industry jointly work towards making the electricity produced by such solar cells ever more cost-effective. Through several research programs, every aspect of Si solar cell technology is covered, from the production of feedstock, through crystallization, wafer sawing, solar cell production technology and characterization to incorporation of solar cells in solar modules and energy systems. In this paper, a brief overview of the main Norwegian companies and research groups within this field, as well as current research activities will be presented.
Keywords: Silicon, R&D and demonstration programmes, c-Si

1 INTRODUCTION

Today, solar cells made from crystalline silicon (Si) substrates have a share in excess of 90% of the global solar cell market, and they are likely to continue to dominate this market in many years to come. In Norway, a large and growing industry and several active research groups currently work within the field of crystalline Si solar cells. Their combined research spans the entire Si solar cell value chain, with projects on topics ranging from the production of feedstock, through crystallization, wafer sawing, solar cell production technology and characterization to incorporation of solar cells in solar modules and energy systems.

One main goal of the current Norwegian research is to make the solar cell industry in general, as well as the domestic solar cell industry increasingly competitive. Another goal is to educate and train the highly qualified personnel the growing solar cell industry requires.

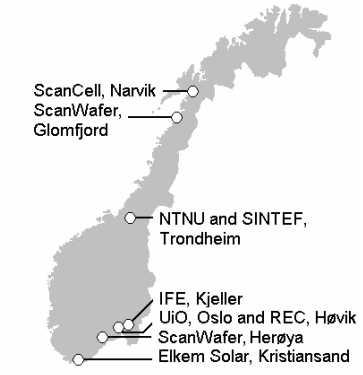

Figure 1: Map showing the location of the various Norwegian solar cell companies and research groups

Research groups and extensive laboratory facilities have been built up at several Norwegian universities and research institutes. Currently, there are Si solar cell activities at two universities, namely the Norwegian University for Science and Technology (NTNU) and the University of Oslo (UiO), as well as at two research institutes, the Institute for Energy Technology (IFE) and the Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology (SINTEF).

A significant fraction of the research at these institutions is being performed in collaboration with domestic industrial partners. Chief among these are Elkem Solar AS, which in August this year will open a pilot plant based on a newly developed metallurgical production process for solar grade Si, and Renewable Energy Corporation (REC) and several of its subsidiaries, ScanWafer and ScanCell in particular. ScanWafer is a world-leading producer of multicrystalline Si wafers, ScanCell a Si solar cell producer. Figure 1 shows the location of the various Norwegian Si solar cell companies and research groups presented in this paper.

This paper aims at giving an up-to-date overview of the current Norwegian Si solar cell research activities. In the following, the various research groups and their facilities will be described, as well as a list of some current projects. A list of recent publications is attached at the very end.

2 NORWEGIAN RESEARCH GROUPS

2.1 The Institute for Energy Technology

At IFE, which is located at Kjeller east of Oslo, there is much activity in the field of Si solar cell research. The main focus at IFE is currently on Si solar cell production technology and characterization, although a range of projects on a wide range of topics including the development of novel production routes for Si feedstock, modelling of Si crystallization processes, solar panel technology and system integration of solar panels in stand-alone and mini-grid systems, are also being pursued.

In the solar cell laboratory at IFE, a complete R&D production line designated to processing Si solar cells has been installed. This production line contains equipment for performing all process steps required for making complete, industrial solar cells from mono- and

multicrystalline Si wafers. The main cell processing line contains a set of wet benches for etching and other wet chemistry processes, an IR diffusion furnace, a plasma etcher for performing edge isolation, a plasma enhanced chemical vapor deposition (PECVD) chambers for depositing Si nitride anti-reflective layers, a conventional screen-printer and an IR firing furnace. Additional equipment includes a second PECVD chamber, which is currently used for depositing thin films of amorphous Si and Si carbide and for hydrogen plasma treatments and a screen-printer for hot melt ink printing. Figure 2 shows the IFE solar cell laboratory.

The research in the IFE solar cell laboratory ranges from fundamental research to process development and optimization. Current research projects include fundamental investigations and modeling of diffusion and gettering processes [1][2], development of novel Si solar cell structures incorporating various functional thin films, process optimizing of plasma-enhanced chemical vapor deposition of anti-reflective coatings [3], development of a novel hot melt ink-based screen-printing process [4] and acidic texturing [5].

Figure 2: The solar cell laboratory at IFE.

A well-equipped characterization laboratory has also been built up at IFE. Here, wafers as well as partially and fully processed solar cells can be characterized. Among the equipment present are a field emission scanning electron microscope (SEM) with an energy dispersive X-ray analyzer, optical microscopes, an atomic force microscope (AFM) and a profilometer for structural analysis, a solar simulator, a spectral response measurement set-up, a lifetime measurement setup and various setups for electrical characterization of contacts, materials and emitters.

Additionally, non-destructive neutron activation analysis (NAA) is being used at IFE to measure impurity levels in Si.

2.2 NTNU and SINTEF

The Si solar cell research groups at NTNU and SINTEF, both located in Trondheim, work in very close collaboration. The main focus of their research is Si as a solar cell material.

Research projects address issues related to the development of new processes for producing solar grade Si feedstock, directional solidification of Si ingots, wafer saw technology and material characterization. The choice of research topics is to a large extent motivated by the current feedstock situation, as well as by a need to increase the fundamental understanding of how Si functions as a solar cell material.

The laboratories at NTNU and SINTEF are well equipped. The core of the activity is Heliosi, a laboratory furnace for directional solidification of Si ingots, which was developed there. This furnace offers unique possibilities for investigating the processes that occur during the crystallization of Si. Additionally, testing new Si feedstock produced by a range of processes under development is performed, giving important feedback to the feedstock-related projects. A schematic drawing of Heliosi is shown in Figure 3.

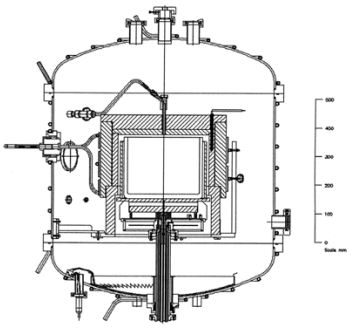

Figure 3: Cross-sectional drawing of the Heliosi laboratory furnace.

In addition to Heliosi, the laboratories at NTNU and SINTEF include facilities for sample preparation and extensive material characterization. Among the characterization equipment is a PVScan6000 for determining grain and dislocation densities, a Fourier-transform infrared (IR) spectrometer (FTIR) for chemical analysis and equipment for performing electron backscatter diffraction for obtaining grain orientation maps. Lifetime testers are also installed. Additionally, a setup for performing carrier density imaging, among others for lifetime mapping is currently being installed.

In neighbouring laboratories, more equipment for advanced material characterization as well as solar cell characterization can be found, including photoluminescence, laser-beam induced current (LBIC) spectroscopy and transmission electron microscopy (TEM).

Recent research projects include the development of a non-thermal surface passivation for lifetime measurements [6] and material characterization of Si [7][8][9].

At SINTEF, much effort has also been devoted to realistic modelling of the processes occurring during the crystallization process itself [10][11]. Additionally, SINTEF is involved in projects investigating thin film-based hetero-structure Si solar cells as well as the incorporation of transparent conductive oxides (TCOs) in Si solar cells.

2.3 The University of Oslo

At the University of Oslo (UiO), the Si solar cell research takes place in new laboratory facilities in the Micro- and Nanotechnology laboratory (MiNa-lab). The MiNa-lab is a joint effort between UiO and SINTEF. The research in this laboratory covers a broad range of topics related to advanced semiconductor process technology and characterization. Figure 4 shows a photograph of the MiNa-lab building.

Currently, the main Si solar cell activities at UiO are related to the incorporation of thin films of functional materials into Si solar cell structures, and the development of hetero-junction solar cells. Additionally, material characterization is performed here.

The MiNa-lab is a state-of-the-art clean room laboratory, which contains a wide selection of Si processing equipment and a range of advanced characterization tools. Among the characterization equipment relevant for Si solar cell research are several deep-level transient spectrometers (DLTS), a range of equipment for electrical characterization, secondary ion mass spectrometry (SIMS), Rutherford backscattering spectrometry (RBS), FTIR, a photoluminescence setup and a lifetime tester. In neighboring laboratories, an AFM, TEM, a scanning spreading resistance microscope and a scanning capacitance microscopy can be found.

Current Si solar cell projects at UiO include the development of a low-temperature technology for processing Si-based hetero-junction solar cells and the use of TCOs [12][13].

Figure 4: Picture of the MiNa-lab at UiO.

2.4 ELKEM SOLAR AS

Elkem is one of the largest industrial companies in Norway and one of the world's leading suppliers of metals and materials. Elkem Solar AS, located in Kristiansand in southern Norway, has developed a novel metallurgical process for refining metallurgic grade Si into solar grade Si. A pilot plant unit with a capacity of some tons per week will be started in August 2005.

In addition to the pilot plant unit, the facilities at Elkem Solar AS include a pyro-metallurgical laboratory and a characterization laboratory.

The equipment in the pyro-metallurgical laboratory includes laboratory scale electrical smelting furnaces, induction furnaces, a rotary kiln, casting facilities and raw material handling equipment.

In connection to the pyro-metallurgical laboratory, a laboratory for performing material characterization has been built up. This laboratory contains equipment for performing X-ray fluorescence microscopy, inductively coupled plasma (ICP) mass spectrometry and ICP optical emission spectrometry, SEM, resistivity measurements and particle detection.

In addition to several internal and national research projects, Elkem Solar AS has been participating in several EU-projects including EPIMETSI and TREASURE. Several recent publications describe the metallurgical production route for solar grade Si, as well as solar cells made using this material [14][15][16].

2.5 RENEWABLE ENERGY CORPORATION

The headquarters of REC, a company operating subsidiaries covering the entire value chain for Si solar cells, are located at Høvik, just outside of Oslo. In addition to ScanWafer and ScanCell, both located in Norway, the list of subsidiaries includes ScanModule, a solar panel maker, located in Sweden, and Solar Grade Silicon LLC (SGS), the world's first dedicated producer of polycrystalline Si for solar applications, which is located in the US. ScanWafer and ScanCell will be presented separately in two following sections.

Due to the large variety in the activities performed by REC and its subsidiaries, their research covers a large range of topics. In addition to internal and various national research projects, REC and its subsidiaries have been participating in several European projects including TOPSICLE, CRYSTAL CLEAR, SPURT, RESICLE and MOPHET. Several recent publications have arisen from these collaborations [17][18][19].

2.6 SCANWAFER

The largest of REC's subsidiaries operating in Norway is ScanWafer, a producer of multicrystalline Si wafers. In 2005, ScanWafer is expected to be the worlds largest wafer manufacturer, with a market share exceeding 20% within multicrystalline wafers.

ScanWafer operates wafer-manufacturing plants in two locations in Norway. One is in Glomfjord in northern Norway, the other at Herøya, southwest of Oslo. The combined production from these two plants was 130 MW of multicrystalline Si wafers in 2004. In 2005, the production is expected to exceed 200 MW.

ScanWafer continuously works to increase the material quality and to reduce the production costs.

2.7 SCANCELL

The other large REC subsidiary operating in Norway is ScanCell, a producer of multicrystalline Si solar cells. ScanCell is located in Narvik in northern Norway.

ScanCell has established a world-class facility for cost-effective production of solar cells from multicrystalline Si wafers. Here, 20 MW solar cells are currently produced per year. However, in 2006, ScanCell will more than double its production capacity to 44 MW.

ScanCell continuously works to reduce costs through highly focused technology development.

3 CONCLUDING REMARKS

This paper has aimed at describing the current situation of Norwegian Si solar cell research. The activity in the various Norwegian research groups working with Si solar cells has grown rapidly during the last years. Today, the research covers a wide range of topics. Evidence for the emergence of several strong research groups can be found in an increasing number of publications within this field.

The building up of research groups and well-equipped laboratories, both at universities and research institutes, has been made possible by past and current research programs. These programs have both strengthened the research effort and research facilities of each individual research group and established fruitful collaborations between the different institutions.

Now, with good laboratory facilities and experienced

research groups in place, all looks set for a strong Norwegian presence in the global Si solar cell research community.

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