PROJECT FINAL REPORT

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4.1.1 Executive summary

The aim of this project is to improve the efficiency and the cost-effectiveness of thin-film polysilicon solar modules. Thin-film polysilicon solar cells have recently emerged as a promising thin-film alternative to bulk crystalline Si. With Solid Phase Crystallization (SPC) of amorphous Si, CSG Solar AG achieved in the past mini-modules with an efficiency of around 10%, matching the efficiencies of the best European micromorph mini-modules. The main goals of PolySiMode are to have large-area polysilicon modules with an efficiency of 12% and with a cost of 0.7 Euro per Watt peak at the end of the project. The expected impact of the proposed project is to enhance the efficiency of polysilicon modules, thereby increasing their cost-effectiveness. At the start of the project, the partnership consisted of five research institutes (IMEC, Fraunhofer ISE, CNRS-InESS, Czech Academy of Science – FZU, and HZB) and one company (CSG Solar AG). At M21, the industrial partner CSG Solar AG became insolvent and had to stop all activities and leave the consortium. To be able to continue the project and achieve all technical and valorisation goals, two new industrial partners were included into the consortium from M27 onwards, namely Evonik Industries and Suntech R&D Australia (SRDA).

Within the PolySiMode project we worked on the improvement of the crystallographic and electronic quality of the polysilicon material and on the development of advanced new methods for light confinement. By in-depth characterization of the polysilicon material, a better understanding of the relationship between the processing parameters, the electrical and optical properties of the material and the resulting device properties was obtained. The most promising technique to grow the polysilicon layers was identified as being the e-beam crystallization approach in which a layer of amorphous Silicon is crystallized by scanning an e-beam across. This method enables the largest grain sizes, the best material quality in terms of open circuit voltage, and a significant increase of throughput. Moreover, two fast and effective methods to improve the electrical material quality of Si absorber materials have been established: a lamp-field and a laser based annealing technology. The two methods are advantageous over the standard Rapid Thermal annealing (RTA) as the heating energy is introduced by radiation alone which enables us to keep the thermal load of the substrates at a very low level. The beneficial use of amorphous Si layers as hetero BSF and as hetero-emitter was shown. A new glass texturing process in which the glass is abraded with a bead blaster and glass damage is removed by an etching step has been successfully introduced into the CSG production process, leading to a substantial gain in absolute efficiency on 1.4 m^2 panels. Plasma texturing of the rear Si surface has been developed to create light trapping in devices that need to be grown on flat or slightly textured glass substrates. Moreover, a novel use of Raman spectroscopy was developed to evaluate the light trapping capabilities in Si thin films. Microwave-detected photoconductance decay (MWPCD), Raman mico-spectroscopy and terahertz spectroscopy were identified as candidates for in-line characterization methods that could be used to monitor material quality during production. Overall, a cumulated cost saving potential of about 1 €/Wp was identified for a device process based on steps developed within PolySiMode compared to the original CSG Solar AG process.

4.1.2 Summary description of project context and objectives

Thin-film polysilicon solar cells have recently emerged as a promising thin-film alternative to bulk crystalline Si. With Solid Phase Crystallization (SPC) of amorphous Si, CSG Solar AG achieved devices with efficiencies of around 7% for module areas of 1.4 m^2 and around 8% for module areas of 30x39 cm^2. With this technique, CSG also achieved mini-modules (10x10 cm^2) with an efficiency of more than 10%, matching the efficiencies of the best European micromorph mini-modules. Moreover, simulations point out that with the proper crystallographic quality of the polysilicon material and with advanced device processing, single-junction polysilicon solar cells with efficiencies above 15% are feasible.

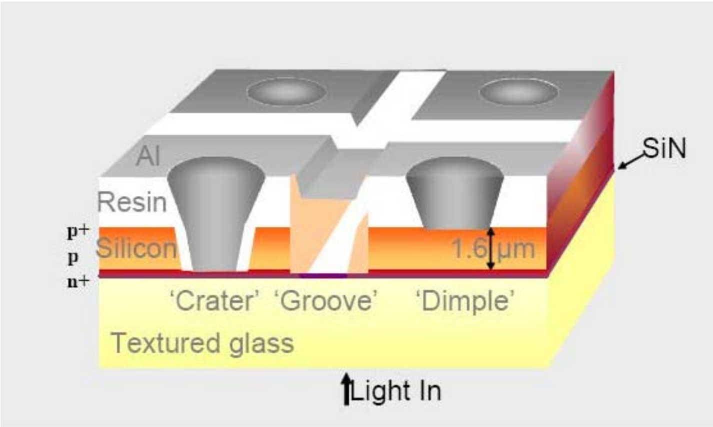

Figure 1: Schematic CSG device structure

The aim of this project is to increase the efficiency of large-area polysilicon modules to more than 12% and thus to improve their cost-effectiveness. This project aims to reduce the Module Cost of Goods Sold per Watt Peak (COGS/Wp) of these modules to 0.7 €/Wp by the end of the project. This will be achieved by the **improvement of the crystallographic and electronic quality** of the active polysilicon material and by the **implementation of new, advanced methods for light confinement**. The device structure and material of the CSG modules at the beginning of this project are taken as the starting point (see Figure 1). By **advanced characterization** of the polysilicon material and related interfaces, a better understanding of the relationship between the growth parameters, the electrical and optical properties of the material and the resulting device properties will be obtained. This information will be used to enhance the material quality by the development of more effective post-deposition treatments (defect annealing and hydrogen passivation) for polysilicon and by the development of improved material growth processes leading to a much lower number of defects in the material. Besides by an improved material quality, the efficiency of polysilicon modules will also be increased by the development of advanced methods for light confinement. We note that there is no need for transparent conductive oxide (TCO) layers in the thin-film polysilicon solar cell technology (see Figure 1), which is, in addition to the long-term stability in performance, a clear advantage of polysilicon modules compared to other thin-film solar cell technologies like the micromorph and CIGS technologies.

The main concrete scientific and technological objectives of the project are:

- Development of alternative Si deposition methods, having increased growth rates and/or leading to higher material quality

- Optimized in-line post-deposition treatments (defect annealing and hydrogen passivation) leading to improved polysilicon material quality

- Improved light trapping schemes that enhance the efficiency of polysilicon modules

- Improved understanding of the relationship between silicon growth parameters, post-deposition treatments and material quality

- Thin-film polysilicon modules (39 x 30 cm^2) produced in-line with efficiencies above 12%

- A Cost of Goods Sold per Watt Peak value for polysilicon modules below 0.7 €/Wp at the end of the project

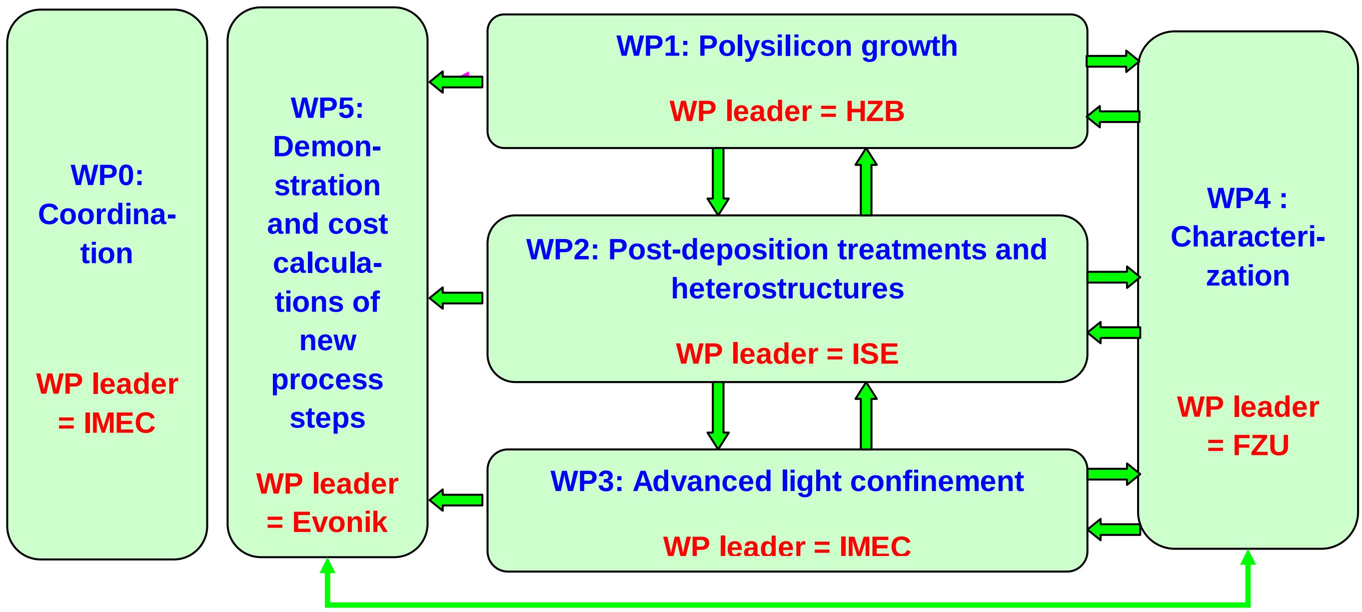

Figure 2: PolySiMode work plan structure

Figure 2 gives an overview of the work package structure of the PolySiMode project and also shows the interrelation of activities within the project. There are five technical work packages and a coordination work package.

It should be stressed that PolySiMode fits very well in the Strategic Research Agenda (SRA) defined by Europe's PV Technology Platform. Thin-film polycrystalline silicon solar modules are listed as one of the priorities in the section 'Emerging and novel PV-technologies'. The targets for this topic are listed in Table 1. The topics for the period 2007-2013, namely improving the material quality of the polysilicon layers, and upscaling of the deposition are covered in PolySiMode. The PolySiMode efficiency target of 12% for a rather large monolithic module of 30 x 39 cm^2 by 2012 (end of the project) is in line with the SRA document (14 %) that does not specify a size. Finally the industrial implementation in the period 2014-2020 (12-14 % efficiency at a cost of 0.5 – 0.8 Euro/Wp) corresponds well to the cost target and the time horizon of PolySiMode. In fact the aim of our project is to have the technology ready to produce polysilicon modules with a cost of 0.7 Euro/Wp by the end of the project. This means that by 2014 industrial production of polysilicon modules with a cost of 0.7 Euro/Wp should be a realizable.

Basic category	Technology	Aspects	2007-2013	2014-2020	2020-2030 and beyond
Advanced inorganic thin-film technologies	Spheral CIS solar cells	Material	Deposition technology	Industrial implementation > 12 % on industrial level ≈ 0.5-0.8 €/Wp	Implementation of advanced concepts of solar spectrum tailoring in ultra-thin solar cells to reach < 0.5 €/Wp (see also 3.2.2)
		Device	Parallel interconnection		
		Performance	14%		
		Cost	N.A.		
	Thin-film polycrystalline Si solar cells	Material	Improving poly-Si electronic quality, deposition upscaling	Industrial implementation 12-14% on industrial level ≈ 0.5-0.8 €/Wp	
		Performance	14% / monolithic module process		
		Cost	N.A.		

Table 1: R&D issues for Emerging and Novel PV-Technologies (taken from page 44 of the 2009 version of the Strategic Research Agenda document as found on http://www.eupvplatform.org/)

The expected impact of the proposed project is to enhance the efficiency of large-area polysilicon modules, thereby increasing their cost-effectiveness. Since all the main European institutes working on thin-film polysilicon solar cells are joining forces within this project, a substantial acceleration in the improvement of the cost-effectiveness of polysilicon modules and therefore the market development of this type of thin-film solar cells is expected.

The combination of a real thin-film concept (using only a few micrometers of active material on glass), with its large potential for cost reduction, and of crystalline Si, is a highly innovative approach. The fact that crystalline Si is used for the active material in our module concept means that we can tap from the wealth of knowledge and expertise that is available from the bulk crystalline Si PV industry and from the microelectronics industry. This gives our approach an excellent starting point for a successful development.

In addition, the development of device parts such as heterojunctions (emitters/BSF), temperature stable passivation layers and texturization processes for the polysilicon material under investigation can also be of considerable interest for related technologies (such as thin Si ribbons or Si films made by a layer transfer process).

The targeted cost reduction to a value below 0.7 euro/Wp will also have a positive impact on the acceptance of photovoltaics by the public and by politics. Moreover, since “energy efficiency” is currently of great interest in public discussion, photovoltaics will be an example of one of the highest electricity production efficiencies that have been achieved of all power generators (with the additional advantage of using cost-free energy from the sun on the input side, of course).

At the start of the project, the partnership consisted of five research institutes (IMEC, Fraunhofer ISE, CNRS-InESS, Czech Academy of Science – FZU, and HZB) and one company (CSG Solar AG). The active participation of CSG within this project targeted the following benefits:

- It would allow the consortium to produce in-line module demonstrators (39 x 30 cm^2) by application of the developed process steps in the pilot line of CSG.

- It would allow the consortium to accurately determine the influence of the developed technologies on the cost-effectiveness of polysilicon modules.

- It would ensure that obtained results and technologies developed within the project could be transferred to production lines at the end of the project.

At M21, the industrial partner CSG Solar AG however became insolvent and had to stop all activities and hence leave the consortium. To be able to continue the project and achieve all technical and valorisation goals described above, two new industrial partners were included into the consortium from M27 onwards, namely Evonik Industries and Suntech R&D Australia (SRDA).

4.1.3 Description of the main S&T results/foregrounds

This part describes the main results achieved per work package.

Work package 1:

In WP1, the PolySiMode consortium has pursued four approaches to produce polysilicon layers for thin film solar cell devices: Solid phase crystallization (SPC) of a-Si, a seed layer approach based on aluminium-induced crystallization of a-Si and epitaxial thickening, direct growth, and electron-beam crystallization of a-Si. While SPC and directly grown layers yield rather small grains of maximum 3µm size, the seed layer approach and, in particular, the crystallization by an electron beam allow for much larger grains up to 30µm (seed layers) or even one millimeter (e-beam crystallization).

By the SPC approach no further improvement of the material quality in terms of open circuit voltage and of the efficiency could be achieved. However, electron-beam evaporation of silicon was established as new deposition method exceeding the rates achievable with conventional plasma-enhanced chemical vapor deposition (PECVD) techniques by more than a factor of 20, thus offering a further substantial cost reduction potential in industrial production. It has been shown that polysilicon deposited by electron-beam evaporation followed by SPC exhibits a slightly better solar cell performance compared to PECVD-grown devices if planar substrates were used. As a 'side' result coming along with the gained knowledge about growth and crystallization of electron-beam evaporated silicon on textured surfaces, a fabrication process for large-area periodic polysilicon nanostructures was developed with applications in the fields of photovoltaics and photonics.

A new efficiency record was achieved for the seed layers approach. By epitaxial thickening of seed layers prepared by aluminium-induced crystallization of a-Si a solar cell efficiency of 8.5% was achieved, coming along with an excellent material quality reflected in an open circuit voltage of 522mV.

Two high-rate silicon deposition methods have been identified to be able to deliver the up to 15µm thick polysilicon layers by direct crystalline growth within a few minutes: Atmospheric pressure chemical vapour deposition (APCVD) and the above mentioned electron-beam evaporation of silicon. Although the electrical material quality of such directly grown polysilicon layers is limited, they are a perfect precursor material for the electron-beam crystallization technique.

The most promising technique turned out to be the e-beam crystallization approach enabling the largest grain sizes, the best material quality in terms of open circuit voltage, and a significant increase of throughput by fast liquid phase fabrication processes. Efficiencies up to 5.9% and a reproducibly high polysilicon material quality reflected in open circuit voltages above 530mV could be achieved. A potential analysis of these solar cells based on available cell data, particularly the excellent open circuit voltages, predicts an achievable efficiency over 11% with improved device concept.

Work package 2:

The main goal of WP2 was to improve the electrical quality of the polysilicon thin films after deposition and/or crystallisation.

In the course of the project, two fast and effective methods to improve the electrical material quality of Si absorber materials with grain sizes in the range of tens to hundreds of micrometers have been established: a lamp-field and a laser based annealing technology. The two methods are advantageous over the standard Rapid Thermal annealing (RTA) as the heating energy is introduced by radiation alone. That enables us to heat up mainly the absorber material and keeping the thermal load of the substrates at a very low level. Several combinations of glasses and glass surfaces have been tested in the two new set ups. The processes were optimised so that we were able to apply the maximal temperature load to the absorber before corrupting the substrates. Thereby several processes have been established both with the lamp-field and the laser set up that have been found to be superior in terms of material quality to the standard RTA process.

The second part of this work package dealt with the improvement of the material quality by atomic hydrogenation defect passivation. Several set-ups for hydrogenation processing have been tested and compared in order to find an optimal process. Furthermore different types of material quality have been characterised and the main achievement was the fundamental understanding and the successful adaptation of the process sequence with annealing and hydrogen passivation processes. For each specific material another specialised sequence has been established. We therefore found that the best process parameters for thermal annealing and hydrogen passivation can be quite different depending on the crystallisation procedure although the materials look the same at first glance. Our understanding of defect development during the processes has hereby also been improved significantly.

An additional part of WP 2 was the introduction of amorphous Si layers as hetero BSF as well as emitter layers. This was done successfully for lab type processing. Unfortunately we were not successful in adapting a newly developed low-cost a-Si:H deposition process. Although first solar cells led to some success, technological difficulties which had to be met for very high V_{oc} values, could not be overcome due to a lack of time.

Work package 3:

WP3 focused on advanced light trapping. Since the Jsc of state-of-the-art polysilicon devices is pretty high (~ 30 mA cm^{-2} for a 2 micron thick absorber) due to the very effective light confinement developed by CSG Solar AG in the past, the PolySiMode project focused more on the improvement of the material quality of the absorbers (improvement in Voc) than on a further improvement of the already very effective light trapping scheme available. Nevertheless, the following achievements were accomplished:

- A new glass texturing process in which the glass is abraded with a bead blaster and glass damage is removed by an etching step has been successfully introduced into the CSG production process, leading to a substantial gain in absolute efficiency on 1.4 m2 panels.

- Plasma texturing of the rear Si surface has been developed to create a Lambertian reflection and oblique coupling of the light into the absorber. Moreover, a significant improvement in the fill factor of devices has been observed after plasma texturing. This type of texturing is especially suited for absorbers made by electron beam evaporation of a-Si and crystallization, since these absorbers need to be grown on flat or only slightly textured glass substrates to achieve a high material quality. Plasma texturing the rear silicon is then crucial to obtain a high current density.
- Optical simulations allowed identifying the optimal geometrical and optical parameters of the ARC coating layer between the glass and the poly-Si layer in our solar cell devices. An estimated gain of 10% in current density can be achieved by using this optimized ARC layer compared to the standard SiNx layer currently used in state-of-the-art devices.

Work package 4:

In WP4 the PolySiMode consortium has developed new approaches to microscopic characterization of electronic properties of microcrystalline and polycrystalline Si thin films, with resolution down to a few nanometres. The methods were mainly based on point contact represented by the tip of a conductive cantilever in an atomic force microscopy (C-AFM) or by multiple contacts navigated by scanning electron microscopy. The local conductivity maps were used to characterize polycrystalline Si layers prepared by different methods and their changes during the technological steps.

It was found that under certain conditions the tip modifies the sample surface by local anodic oxidation. The resulting oxide may even fundamentally change the character of the local conductivity map, leaving the grain boundaries more conductive than the oxidized grains. This research led to guidelines how to avoid oxidation and even how to remove oxide from aged and oxidized samples.

Another important advance was the clear distinction between the dark conductivity and photoconductivity maps. This progress allows for measurement of local photoresponse at different grains or at different positions on the sample.

We found that locating the grains, grain boundaries or defects in various microscopes (using electron or optical beams or scanning probe) requires a precision on the order of 100 nm or better after repeated mounting of the sample. This surpasses the current capabilities of microscopic tables. We have thus developed a localization procedure which uses a combination of scratches using a diamond stylus and indentation marks prepared by a microhardness tester. The procedure was tested for locating the same spot in Raman microspectroscopy (optical microscopy), EBSD (electron microscopy) and C-AFM. The technique allows for repeated sample mounting even after various technological steps and may find wider use in materials research.

Important advances were made in using the Raman microspectroscopy, a fast, non-destructive and contactless tool, which is widely used to assess the crystalline nature of the polycrystalline Si films and even its electronic properties. We have developed a novel use of Raman spectroscopy to evaluate the light trapping capabilities in Si thin films. Typical thickness of the silicon thin films used for solar cells is between 0.3 – 3 µm, which is not enough for complete absorption of near infrared light. In order to improve the light absorption, silicon films are deposited on rough substrates. We have found that the absolute intensities of the Raman spectra excited by a 785 nm laser are strongly affected by light scattering on a rough microcrystalline surface. This effect is due to the proportionality of the Raman intensity to the laser path length in the silicon film, which may be increased several times by light trapping. Correlation between the absolute Raman intensity and the final properties of the cell (IQE and JSC) was demonstrated and Raman spectroscopy thus became also a candidate for use as an inline characterization tool described in WP5.

Among the other characterization approaches we want to point out the use of microwave detected photoconductance decay method (MWPCD) which was adapted to the specific properties of polycrystalline Si layers and which is another candidate for inline characterization.

Work package 5: Demonstration and Cost calculation

The main objectives were to implement process steps developed within this project at module (30 x 39 cm^2) level, to develop a standard in-line characterisation procedure for polysilicon modules, and to determine the cost-effectiveness of new process steps when implemented in production.

Effect of new process steps on the efficiency at 30x39 cm^2 module level

Due to the limited resources after the exit of CSG from the consortium and the shift of the project focus to e-beam recrystallized samples, a further fabrication into larger modules has not been pursued. However, *Line Focus Rapid Thermal Annealing (LF-RTA)* was found to lead to an increase in quality of cells and minimodules, measured by V_{oc}. V_{oc} values after the hydrogenation ranged up to 400 mV. *Laser thermal annealing (LTA)* of CSG produced polycrystalline silicon (pc-Si) multilayer samples was done at InESS to reduce the defects and dopant activation. Before laser treatment, V_{oc} of the samples are around 185±5 mV. Maximum V_{oc} obtained is 288±5 mV, i.e. an improvement of 100 mV before plasma hydrogenation.

Direct comparison of LTA & conventional RTA on planar “SUNTECH samples” showed a relative improvement of 3.6% in V_{oc}, 1.4% in pseudo fill factor (pFF) and 4.3% in pseudo efficiency (pEff), when laser thermal annealing is used in place of rapid thermal annealing.

Laser Crystallization with a dual wave length laser was evaluated at InESS in collaboration with HZB. 2 µm thick a-Si films were crystallized with the help of 40 nm highly phosphorus doped poly-silicon (pc-Si) layer deposited on SiN coated borosilicate glass. Raman spectra proved successful crystallization, but with a grain size of less than 100 nm and no preferential orientation. A decrease of FWHM was observed with increase in laser power and increase of substrate temperature. The sample processing temperature was limited due to melting of the borosilicate glass.

Unfortunately, no working cells were obtained from these samples due to damage of the underlying n+ layer.

In order to further increase the short circuit current of CSG samples a *plasma texturing* process was introduced at ISE. Jsc of up to 19.3 mA/cm² and a V_{oc} of 486 mV were measured compared to 17,7 mA/cm² and 466 mV for unstructured samples.

Although these new processes could not be applied to the module line at CSG, the knowledge gained from these experiments has significantly enhanced the process know-how at the institutions involved. Pathways for new processing routes have been investigated and can be made available to the interested commercial customer.

Development of in-line characterization and monitoring

At the PV production lines each module is characterized upon completion by a flasher, which means the measurement takes place at the end of the production line. For improved process control and optimization and implementation of non-contact inline measurement tools is desirable.

Microwave-detected photoconductance decay (MWPCD) measurements on polycrystalline Si thin-film material on glass have been carried out by ISE. MWPCD is a well-established characterization technique in the semiconductor and photovoltaic fields. Excess charge carriers are generated in the sample by a short laser pulse and the decay of photoconductance is detected by following the microwave reflectance. The time constant of the decay is extracted and associated with the effective minority carrier lifetime. In the PolySiMode project, a commercially available MWPCD setup WT2000 (Semilab Co. Ltd.) was used and adapted for polycrystalline Si films. MWPCD was proven to be a likely online measurement tool for polycrystalline silicon.

The time-resolved *terahertz spectroscopy* is a contact-free method able to follow the local (~10 nm) in-plane motion of charges with a subpicosecond to nanosecond time resolution. Furthermore, different conductivity mechanisms may then appear simultaneously as unique fingerprints in the time resolved terahertz spectra (Drude-like conductivity, hopping, etc).

At FZU experiments were done to test the THz spectroscopy for polycrystalline Si films at a home-built system. A lot of further effort is required to adapt it for poly-Si measurements. However, due to rapid progress of the THz technology motivated by detection of explosives for security purposes, turn-key commercial systems are becoming available for use in industrial process control. To our knowledge, we obtained the first results in THz domain for polycrystalline Si thin films. It remains to be seen whether the technique would be sensitive to passivation or rapid-thermal annealing of the samples.

Raman micro-spectroscopy is contactless and non-destructive measurement method which does not require special sample preparation. At FZU a RenishawInVia with 365, 442 and 785 nm laser excitation wavelengths is used.

The Raman spectra may be used for several diagnostics purposes: crystallinity of the film, analyse light trapping, evaluate intrinsic stress and holes density (or doping efficiency – crucial for open circuit voltage V_{OC} values) and carrier lifetime at high injections levels. In order to increase sensitivity of the method to carrier's density, 785 nm laser should be used for excitation of the Raman spectra, which also allows to get as much information as possible. In order to provide information about the sample homogeneity, Raman systems needs to allows recording multiple spots, which is available on the market.

Te feasibility of integrating the mentioned techniques depends strongly on the compatibility with the conditions that govern typical production lines: number of necessary measurements per module, number of pulses per measurement and integration times, acceptable spot sizes, precision of position of substrate with respect to the measurement head (focal depth), resistance to vibrations etc.

In batch processing the total measurement time for a 1 x 1,4m² substrate should not exceed 1-2 minutes. This means only 1-2 measurements in the case of Terahertz spectroscopy, while Raman and microwave PCD could perform a larger number (> 25) of measurements per substrate. When equally distributed over 1 x 1,4 m², each of 25 measurements would represent an area of 24 x 24 cm².

Under these basic considerations, Terahertz Spectroscopy appears to comply easily with the restrictions on minimum focal depth and could deliver of the order 1-2 measurements per substrate in a batch processing scenario.

Raman and microwave photoconductive detection techniques, would be able to deliver a much more detailed map of the poly-Si properties of the module. Commercial systems allow reducing the measurement time to the sub-second regime and are able to perform mapping of areas. Also microwave based techniques for the detection of photoconductivity are commercially available for measuring the photoconductivity.

For some production lines it might be attractive to characterize the modules while they are moving on a conveyor belt. As times for laboratory measurements are not compatible with typical belt speeds an adaption is needed like moving the measurement heads at the same speed as the belt for the duration of the measurement, which leads to some inaccuracy. But the most promising path to reliable inline measurement on a moving substrate would be the simplification of the data collection.

Another objective of the project was to improve the calibration of module IV-measurement under illumination. The investigations of polycrystalline silicon on glass devices showed that there was an improvement in uncertainty of the mismatch correction thanks to the matched reference cell made during the project. The determination of the spectral response out of a module is challenging and specially prepared modules with single contacted cells are necessary. Also the resolution of the spectral response is critical due to interferences. The comparison between dc- and flash simulator measurements showed good congruence, so that the larger flash simulator could be used for module characterization.

Demonstration of a 30 x 39 cm2 module with an efficiency of at least 12%

A device stack built on borofloat glas using liquid phase crystallization by means of a line shaped electron beam was produced. The device evolves a modified version of the CSG contact system. The first attempt to transfer crystallized layers to SRDA was not successful in terms of device performance but showed the applicability of the SRDA contact scheme on liquid phase crystallized absorbers as a module cell voltage of 372 mV per cell was achieved.

Parallel to these experiments device processing was continued at HZB using a MESA etch based cell architecture relying on an a-Si:H hetero-junction. As the design suffers from a large metalized area - covering 16% of the cell's front side - the active area values j_{sc}=19.2 mA/cm², eta =5.9% provide a realistic view of the absorbers quality.

Besides this result using high rate electron beam evaporated silicon as precursor, a comparison was realized using ISE's high rate APCVD process for absorber deposition. The I(V) curves of the fabricated c-Si(p)/a-Si:H(n+) heterojunction cells show a high and homogenous V_{oc} up to 532 mV as well as an increased fill factor of 61% mostly caused by a reduced series resistance due to higher absorber dopant level. However, a low short circuit current density of 13,7 mA/cm³ remains due to various loss mechanisms.

While the deliverable of 12% module efficiency was not reached, progress has been made in terms of material quality as reflected in the reproducibly achieved open circuit voltages quite above 500 mV with a record of 532 mV. The applicability of the original CSG contact scheme was demonstrated.

An optimized cell contacting scheme as well as post crystallization treatments are expected to enhance the short circuit current density as a potential analysis of these cells performed based on available cell data predicts an achievable j_{sc} above 28,7 mA /cm², thus boosting the device performance to over 11%. These values don't account for any improvement related gain in V_{oc}.

Cost benefit analysis of new module process developed within the project

Within PolySiMode potential cost savings for alternative processes and parameters were estimated.

Substrate

So far, boro-silicate glass supplied by Schott (BOROFLOAT® 33) was used as the reference substrate material. The development of new processes for crystallization allows usage of other substrates that do not require high-temperature stability. In this case a price reduction for the substrate up to 80% is possible.

Silicon deposition

CSG used for production an Oerlikon KAI 1200 PECVD equipment. Today more efficient silicon deposition techniques are available on the market. Besides PECVD which is also offered by Leybold, APCVD, which is developed at Fraunhofer ISE and Ebeam deposition are the most promising future deposition techniques. Although Ebeam deposition is not commercially available at the moment, first cost estimations predict a cost saving potential of up to 80% compared to the CSG standard process.

Crystallization

CSG used a 24 hours oven process for solid phase crystallization of silicon, which is a cost driver due to its long processing time. Within this project the cost saving potential of Zone-Melt-Recrystallization (ZMR) and Electron-beam crystallization (EBC) were reviewed. Zone-Melt-Recrystallization is also a solid-phase crystallization process, but reduces the necessary crystallization time to minutes. First cost estimations predict a cost reduction about one order of magnitude.

EBC is a liquid phase crystallization process. HZB is leading the development of EBC for silicon photovoltaics. Unfortunately, this process is so far only available at a laboratory scale and reliable cost estimation for a pilot or production scale would require upscaling experiments and theoretical simulations. These were beyond the scope of this project. However, there is a strong interest in the scientific community and at commercial tool manufacturers to investigate this technology further.

Overall, a cumulated cost saving potential of about ≈1 €/Wp was identified for the “updated” CSG process, upon implementation of the three steps described above.

4.1.4 Potential impact and main dissemination activities and exploitation results

Potential impact

The European PV technology Platform has defined a strategic research agenda (SRA) with several research challenges that, if properly addressed, will provide significant advances to the European industry. Thin-film polysilicon devices were mentioned in this agenda in 2009 at the start of this project as among the most promising candidates for advanced inorganic thin film technologies. Therefore PolySiMode has contributed to the improvement of the European technological base by the development and demonstration of thin-film polysilicon cells and modules.

Since all the main European institutes working on thin-film polysilicon solar cells were joining forces within this project, a substantial acceleration in the improvement of the cost-effectiveness of polysilicon modules and therefore the market development of this type of thin-film solar cells has been achieved.

Moreover, the combination of a real thin-film concept (using only a few micrometers of active material on glass), with its large potential for cost reduction, and of crystalline Si, is a highly innovative approach, giving the European industry a clear advantage.

Communication and dissemination

A public website of the PolySiMode project is available at www.polysimode.eu. Its content includes a general presentation of the project. Updates concerning public dissemination and events were made on a regular basis.

The consortium has published 20 scientific papers in peer-reviewed journals with results obtained within PolySiMode. Moreover, the consortium has presented 54 contributions at international conferences and workshops in the form of invited presentations, regular oral presentations and posters. Conferences included top conferences in the field such as the European Photovoltaic Solar Energy conference, the IEEE Photovoltaic Specialists conference and the E-MRS spring meeting. The PolySiMode project also resulted in 10 PhD and master theses.
Work done within the frame of PolySiMode was also presented at the IUVSTA summer school on Physics at Nanoscale, which was organized with support of the PolySiMode project in June 2011 in Devet Skal, Czech Republic.

Exploitation

The PolySiMode project led to 3 patent applications. The main exploitable results generated by polySiMode include:

- Large-area silicon nano-architectures by combining nanoimprint-lithography and Si electron-beam evaporation
- Electron-beam evaporation as high-rate deposition technique for silicon thin films
- Electron-beam crystallization as high-throughput fabrication technique for high-quality polysilicon thin films
- Continuous wave laser processing for defect passivation and for crystallization
- Definition of a procedure on how to locate the same spot in various microscopic measurement techniques in order to characterize the same sample spot during different stages of the production process
- The use of Raman Spectroscopy for light-trapping characterization
- Halogen lamp induced rapid thermal annealing and rapid solid phase crystallisation
- Plasma texturisation of polysilicon for light trapping purposes
- a-Si/c-Si heterojunctions for emitter and back surface field
- Improved hydrogen plasma passivation

Within PolySiMode, several processes have been developed and optimized for an enhanced thin-film polysilicon module technology. It is now up to the European actors to capitalize on these results to contribute to the European leadership by providing innovative PV solutions to the market.

4.1.5 Website and relevant contact details

The PolySiMode public website is available at: www.polysimode.eu

The list of main project contacts is:

IMEC – coordinator: Dr Ivan Gordon, gordoni@imec.be, Tel: +32 (0)16 28 82 49

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4.2 Use and dissemination of foreground

4.2.1 Section A (public)

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication ?
1	Polycrystalline silicon thin-film solar cells: Status and perspectives	C. Becker, D. Amkreutz, J. Haschke, D. Lockau, V. Preidel, T. Sontheimer, S. Steffens, B. Rech	Solar Energy Materials & Solar Cells	Submitted (invited submission)			2013			no
2	Chemical speciation at buried interfaces in high-temperature processed polycrystalline silicon thin-film solar cells on ZnO:Al	C. Becker, M. Pagels, C. Zachäus, B. Pollakowski, B. Beckhoff, B. Kanngießer, B. Rech	Journal of Applied Physics	Accepted			2013		DOI: 10.1063/1.4789599	no
3	Defect annealing processes for polycrystalline silicon thin-film solar cells.	S. Steffens, C. Becker, J.-H. Zollondz, A. Chowdhury, A. Slaoui, S. Lindekugel, U.	Material Science and Engineering B	accepted			2012		Doi: 10.1016/j.mseb.2012.11.002	no

		Schubert, R. Evans, B. Rech								
4	Direct growth of periodic silicon nanostructures on imprinted glass for photovoltaic and photonic applications	C. Becker, V. Preidel, T. Sontheimer, C. Klimm, E. Rudigier-Voigt, M. Bockmeyer, B. Rech	Phys. Status Solidi C	9			2012	2079–2082		no
5	Directional growth and crystallization of silicon thin films prepared by electron-beam evaporation on oblique and textured surfaces	J.J. Merkel, T. Sontheimer, B. Rech, C. Becker	Journal of Crystal Growth	Accepted			2013		Doi: 10.1016/j.jcrysgro.2012.12.037	no
6	Characterization and control of crystal nucleation in amorphous electron beam evaporated silicon for thin film solar cells	T. Sontheimer, S. Scherf, C. Klimm, C. Becker, B. Rech	Journal of Applied Physics	110			2011	063530		no
7	Polycrystalline silicon thin films by high-rate electron-beam evaporation for photovoltaic applications – Influence of substrate texture and temperature	C. Becker, T. Sontheimer, S. Steffens, S. Scherf, B. Rech	Energy Procedia	10			2011	61-65		no
8	Large-area 2D periodic crystalline silicon nanodome arrays on nanoimprinted glass exhibiting photonic band structure effects.	C. Becker, D. Lockau, T. Sontheimer, P. Schubert-Bischoff, E. Rudigier-Voigt, M. Bockmeyer, F. Schmidt,	Nanotechnology	23			2012	135302		no

		B. Rech								
9	High-temperature laser annealing for thin film polycrystalline silicon solar cell on glass substrate	A. Chowdhury	Applied Physics A: Materials Science & Processing	107 (3)	Springer-Verlag	Heidelberg	2012	653-657		yes
10	Comment on "Current routes in hydrogenated microcrystalline silicon"	A. Vetushka, A. Fejfar, M. Ledinský, B. Rezek, J. Stuchlík, J. Kočka	Physical Review B	81			2010	237301(1)-237301(4)	10.1103/PhysRevB.81.237301	no
11	*Raman mapping of microcrystalline silicon thin films with high spatial resolution*	M. Ledinský, A. Vetushka, J. Stuchlík, A. Fejfar, and J. Kočka	Phys. Status Solidi (c)	7			2010	704-707	10.1002/pssc.200982832	no
12	*Role of the tip induced local anodic oxidation in the conductive atomic force microscopy of mixed phase silicon thin films*	A. Vetushka, A. Fejfar, M. Ledinský, B. Rezek, J. Stuchlík, and J. Kočka	Phys. Status Solidi (c)	7			2010	728-731	10.1002/pssc.200982777	no
13	The structure and growth mechanism of Si nanoneedles prepared by plasma-enhanced chemical vapor deposition	J. Červenka, M. Ledinský, J. Stuchlík, H. Stuchlíková, S. Bakardjieva, K. Hruška, A. Fejfar and J. Kočka	Nanotechnology	21 (41)			2010	415604(1)-415604(7).	10.1088/0957-4484/21/41/415604	no
14	Local photoconductivity of microcrystalline silicon thin films	M. Ledinský, A.	Phys. Status Solidi-Rapid	5 (10-11)			2011	373 - 375	10.1002/pssr.201105413	no

	measured by conductive atomic force microscopy	Fejfar, A. Vetushka, J. Stuchlík, B. Rezek, J. Kočka	Res. Lett.							
15	Local photoconductivity of microcrystalline silicon thin films excited by 442 nm HeCd laser measured by conductive atomic force microscopy	Ledinský, Martin, Antonín Fejfar, Aliaksei Vetushka, Jiří Stuchlík, a Jan Kočka	Journal of Non-Crystalline Solids	358 (17)			2012	2082-2085	10.1016/j.jnoncrysol.2012.01.015	no
16	Electrical properties of carbon nanowall films	Itoh, T., Y. Nakanishi, T. Ito, A. Vetushka, M. Ledinsky, A. Fejfar, J. Kocka, a S. Nonomura	Journal of Non-Crystalline Solids	358 (17)			2012	2548-2551	10.1016/j.jnoncrysol.2012.01.062	no
17	Conductive atomic force microscopy on carbon nanowalls	A. Vetushka, T. Itoh, Y. Nakanishi, A. Fejfar, S. Nonomura, M. Ledinský, J. Kočka	Journal of Non-Crystalline Solids	358 (17)			2012	2545–2547	10.1016/j.jnoncrysol.2011.12.094	no
18	Three novel ways of making thin-lm crystalline-silicon layers on glass for solar cell applications	I. Gordon, F. Dross, V. Depauw, A. Masolin, Y. Qiu, J. Vaes, D. Van Gestel, J. Poortmans	Solar Energy Materials & Solar Cells	95			2011	S2-S7	DOI: 10.1016/j.solmat.2010.11.031	no
19	Metal-induced crystallization for	D. Van	Solar Energy	Submitted (invited			2013			no

	thin-film polycrystalline silicon solar cells: achievements and perspective.	Gestel, I. Gordon, J. Poortmans	Materials & Solar Cells	submission)						
20	Crystalline thin-film silicon solar cells: where crystalline quality meets thin-film processing	F. Dross et al	Progress in Photovoltaics: Research and Applications	20			2012	770-784	DOI: 10.1002/pip.1238	no

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
1	Presentation	HZB	(Re)crystallized silicon: Status, perspective and innovative structures (invited)	19.-23.3.2012	Fourth International Workshop on Thin-Film Silicon Solar Cells (IWTFSSC-4) Neuchatel, Switzerland	Scientific Community (higher education, Research) - Industry	*200*	worldwide
2	Presentation	HZB	Large-area silicon nanostructures on imprinted glass for photovoltaic and photonic applications	14.-18.5.2012	E-MRS spring meeting 2012, Strasbourg, France	Scientific Community (higher education, Research) - Industry	*200*	worldwide
3	Presentation	HZB	Defect annealing processes for polycrystalline silicon thin-film solar cells. E-MRS spring meeting	14.-18.5.2012	E-MRS spring meeting 2012, Strasbourg, France	Scientific Community (higher education, Research) - Industry	*200*	worldwide
4	Presentation	HZB	Crystallization of electron beam evaporated amorphous silicon films on oblique-angled substrates.	14.-18.5.2012	E-MRS spring meeting 2012, Strasbourg, France	Scientific Community (higher education, Research) - Industry	*200*	worldwide
5	Presentation	HZB	3D periodic polysilicon nanostructures on nanoimprinted glass for advanced solar	24.-28.9.2012	27th European Photovoltaic Solar Energy Conference (EUPVSEC27), Frankfurt, Germany	Scientific Community (higher education, Research)	*200*	worldwide

			cell architectures			- Industry		
6	Presentation	HZB	Polycrystalline silicon thin film solar cells by high-rate electron-beam evaporation	9.-13.5.2011	E-MRS spring meeting 2011, Nice, France	Scientific Community (higher education, Research) - Industry	*200*	worldwide
7	Presentation	HZB	Polycrystalline silicon thin film solar cells by high-rate electron-beam evaporation	05.-09.09.2011	26th European Photovoltaic Solar Energy Conference (EUPVSEC26), Hamburg, Germany	Scientific Community (higher education, Research) - Industry	200	worldwide
8	Presentation	HZB	Neue Produktionsprozesse für polykristalline Silizium-Dünnschichtsolarzellen (invited)	17.-20.10.2011	Industrieausstellung und Workshopwoche Vakuumbeschichtung und Plasmaoberflächentechnik (V2011), Dresden, Germany	Scientific Community (higher education, Research) - Industry	60	Germany
9	Presentation	HZB	Challenges and opportunities of electron beam evaporation in the preparation of poly-Si thin film solar cells	20-25.06.2010	35th IEEE Photovoltaic Specialists Conference, Hawaii, USA	Scientific Community (higher education, Research) - Industry	2010	worldwide
10	Presentation	InESS	Laser processing for thin film crystalline silicon solar cells	11-16.08.2012	SPIE, San Diego, USA	Scientific Community (higher education, Research) - Industry	>100	worldwide
11	Presentation	InESS	Laser annealing of thin film polycrystalline silicon solar cel	6-8.06.2012	Photovoltaic technical conference, Aix en Provence, France	Scientific Community (higher education, Research) - Industry	>100	worldwide
12	Presentation	InESS	Defect annealing in polysilicon films by CW laser treatments	14-18.05.2012	European Material Research Society Spring Meeting, Strasbourg, France	Scientific Community (higher education,	>250	worldwide

						Research) - Industry		
13	Presentation	InESS	CW LASER THERMAL ANNEALING OF POLYSILICON THIN FILMS	8-13.08.2011	International Union Materials Research conference, Cancun, Mexico	Scientific Community (higher education, Research) - Industry	>200	worldwide
14	Presentation	ISE	Electrical Characterisation of Poly-Crystalline Silicon Thin-Film Material	25/052011	Photovoltaic technical conference, Aix-en-Provence	Scientific Community (higher education, Research) - Industry	200	worldwide
15	Poster	ISE	Direct Deposition of µc-Si Films with APCVD on Borosilicate Glass	04/09/2011	26th European Photovoltaic Solar Energy Conference (EUPVSEC26), Hamburg, Germany	Scientific Community (higher education, Research) - Industry	4500	worldwide
16	Poster	ISE	Solid phase crystallisation and rapid thermal annealing processes for crystalline silicon on glass in a movable two sided halogen lamp oven	04/09/2011	26th European Photovoltaic Solar Energy Conference (EUPVSEC26), Hamburg, Germany	Scientific Community (higher education, Research) - Industry	4500	worldwide
17	Poster	ISE	µc-Si Solar Cells by Direct Deposition with APCVD	28/09/2012	27th European Photovoltaic Solar Energy Conference (EUPVSEC27), Frankfurt, Germany	Scientific Community (higher education, Research) - Industry	4000	worldwide
18	Thesis	ISE	Lebensdauermessungen an kristallinen Silicium-dünnschicht-solarzellen (Bachelor)	30/09/2012	Freiburg university	Scientific Community (higher education, Research) - Industry	-	-

19	Thesis	ISE	Mitteltemperatur-CVD von Siliciumschichten für die Photovoltaik (PhD)	ongoing	Konstanz university	Scientific Community (higher education, Research) - Industry	-	-
20	Thesis	FZU	Mechanical and Electrical Properties of Microcrystalline Silicon Thin Films Studied by Raman microspectroscopy and combined atomic force microscopy (PhD)	March 2011	Charles University in Prague	Scientific Community (higher education, Research) - Industry	-	-
21	Thesis	FZU	Modeling of internal fields in nanostructural silicon films by finite-elements method (BSc)	June 2011	University of West Bohemia, Pilsen	Scientific Community (higher education, Research) - Industry	-	-
22	Thesis	FZU	Study of properties of heterostructured thin silicon films in nanometer resolution (BSc)	March 2012	Czech Technical University in Prague	Scientific Community (higher education, Research) - Industry	-	-
23	Thesis	FZU	Microscopic measurements of the properties of nanostructured silicon thin films (BSc)	September 2012	Czech Technical University in Prague	Scientific Community (higher education, Research) - Industry	-	-
24	Thesis	FZU	Study of Polycrystalline Silicon Thin Films at Various Temperatures by Raman Microspectroscopy (BSc)	September 2012	Czech Technical University in Prague	Scientific Community (higher education, Research) - Industry	-	-

25	Thesis	FZU	Annealing of Polycrystalline Silicon Thin Film Solar Cells in Water Vapour (PhD)	ongoing	Czech Technical University in Prague	Scientific Community (higher education, Research) - Industry	-	-
26	Thesis	FZU	Thin films of polycrystalline silicon for solar cells (PhD)	ongoing	Czech Technical University in Prague	Scientific Community (higher education, Research) - Industry	-	-
27	Thesis	FZU	Raman spectroscopy for light trapping measurement (MSc)	ongoing	Technical University Liberec	Scientific Community (higher education, Research) - Industry	-	-
28	Presentation	FZU	Microscopic Characterizations of Nanostructured Silicon Thin Films for Solar Cells (invited)	April 25 - 29, 2011	Symposium A: Amorphous and Polycrystalline Thin-Film Silicon Science and Technology 2011 MRS Spring Meeting April 25 - 29, 2011	Scientific Community (higher education, Research) - Industry	4000	worldwide
29	Presentation	FZU	Internal Fields in Nanostructured Silicon Thin Films for Photovoltaics (invited)	October 7-8th, 2010,	3rd International Symposium on Innovative Solar Cells, October 7-8th, 2010, Tokyo Tech Front, Tokyo, Japan, organized by Tokyo Institute of Technology, The University of Tokyo, AIST and NEDO	Scientific Community (higher education, Research) - Industry	200	worldwide
30	Presentation	FZU	Microscopic Study of Silicon Thin Films (invited)	21.-23.9.2011	Nanocon 2011, 3rd International Conference 21.-23.9.2011, Brno, Czech Republic	Scientific Community (higher education, Research) - Industry	150	worldwide
31	Presentation	FZU	Microscopic Raman and photo-	September 19 - 23, 2011	E-MRS 2011 FALL MEETING, Warsaw University of Technology,	Scientific Community	>100	worldwide

			conductive characteristics of amorphous and microcrystalline silicon films (invited)		Poland	(higher education, Research) - Industry		
32	Presentation	FZU	Determination of Single Microcrystalline Silicon Grains Preferential Crystallographic Orientation by Polarized Raman spectroscopy	August 8 - 13, 2010	XXII Int. Conf. On Raman Spectroscopy, AIP Conference Proceedings Volume 1267 (AIP, Boston, Massachusetts, 2010), pp. 1109-1110. Editor(s): P. M. Champion, Northeastern University, L. D. Ziegler, BU, ISBN: 978-0-7354-0818-0	Scientific Community (higher education, Research) - Industry	1000	worldwide
33	Poster	FZU	Microscopic Measurements of Polycrystalline Silicon Thin Films on Glass	5-9, September 2011	26th European Photovoltaic Solar Energy Conversion, Hamburg, Germany 5-9, September 2011. EU PVSEC Proceedings, 2788–2790. Hamburg, 2011.	Scientific Community (higher education, Research) - Industry	4000	worldwide
34	Presentation	FZU	Annealing of Thin Film Polycrystalline Silicon Solar Cells in Water Vapour	3-4 May 2012	7th Czech Photovoltaic Conference, Eds. , 3-4 May 2012, Brno, Technological Park of VUT Brno, Czech Republic	Scientific Community (higher education, Research) - Industry	40	national
35	Poster	FZU	Light trapping measurement in silicon thin film by Raman spectroscopy	3-4 May 2012	7th Czech Photovoltaic Conference, Eds. , 3-4 May 2012, Brno, Technological Park of VUT Brno, Czech Republic	Scientific Community (higher education, Research) - Industry	40	national
36	Poster	FZU	Charge transport through grain	6-10 September 2010	25th European Photovoltaic Solar Energy Conference and Exhibition,	Scientific Community	4000	worldwide

			boundaries in mixed phase silicon thin films studied by conductive atomic force microscopy		5th World Conference on Photovoltaic Energy Conversion, 2011 Valencia	(higher education, Research) - Industry		
37	Poster	FZU	Relative Measurement of Light Trapping in Silicon Thin Films by Raman Spectroscopy	6-10 September 2010	25th European Photovoltaic Solar Energy Conference and Exhibition, 5th World Conference on Photovoltaic Energy Conversion, 2011 Valencia	Scientific Community (higher education, Research) - Industry	4000	worldwide
38	Poster	FZU	Internal fields in nanostructured silicon thin films for photovoltaics	6-10 September 2010	25th European Photovoltaic Solar Energy Conference and Exhibition, 5th World Conference on Photovoltaic Energy Conversion, 2011 Valencia	Scientific Community (higher education, Research) - Industry	4000	worldwide
39	Poster	FZU	Conductive atomic force microscopy of delicate nanostructures in torsional resonance mode	June 8-10, 2011	International Workshop on Scanning Probe Microscopy for Energy Applications, June 8-10, 2011, Mainz, Germany	Scientific Community (higher education, Research) - Industry	100	worldwide
40	Presentation	FZU	Nanoscale Conductance Study of Delicate Nanostructures by	August 21-26, 2011	24th International Conference on Amorphous and Nanocrystalline Semiconductors-ICANS 2011,	Scientific Community (higher education,	>300	worldwide

			Torsional Resonance Tunneling Atomic Force Microscopy		August 21-26, 2011, Nara, Japan	Research) - Industry		
41	Poster	FZU	Microscopic Study of Electronic Properties of Individual Components of Nanostructured Solar Cells	24th - 28th September 2012	27th European Photovoltaic Solar Energy Conference and Exhibition, 24th - 28th September 2012, in Frankfurt, Germany	Scientific Community (higher education, Research) - Industry	4000	worldwide
42	Poster	FZU	Influence of gold catalytic layer on Growth of Silicon Nanowires	24th - 28th September 2012	27th European Photovoltaic Solar Energy Conference and Exhibition, 24th - 28th September 2012, in Frankfurt, Germany	Scientific Community (higher education, Research) - Industry	4000	worldwide
43	Poster	FZU	Water vapour passivation of poly-Si thin film solar cells	24th - 28th September 2012	27th European Photovoltaic Solar Energy Conference and Exhibition, 24th - 28th September 2012, in Frankfurt, Germany	Scientific Community (higher education, Research) - Industry	4000	worldwide
44	Presentation	FZU	Conductive Atomic Force Microscopy on Hydrogenated Microcrystalline Silicon and Polycrystalline Silicon Thin Films for Solar Cells	9 - 14.12.2010	The Third International Forum on Multidisciplinary Education and Research for Energy Science, 9 - 14.12.2010, Ishigaki, Okinawa, Japan	Scientific Community (higher education, Research) - Industry	200	worldwide

45	Presentation	FZU	Microcrystalline Silicon Preferential Crystallographic Orientation by Polarized Raman Micro-Spectroscopy	9 - 14.12.2010	The Third International Forum on Multidisciplinary Education and Research for Energy Science, 9 - 14.12.2010, Ishigaki, Okinawa, Japan	Scientific Community (higher education, Research) - Industry	200	worldwide
46	Presentation	FZU	In Situ Measuring System Designed for Improvement of Poly-Si Thin Film Solar Cells	Dec.17-21, 2011	The Fourth International Forum on Multidisciplinary Education and Research for Energy Science, Hawaii, USA	Scientific Community (higher education, Research) - Industry	200	worldwide
47	Presentation	FZU	Influence of Gold Catalytic Layer on Growth of Silicon Nanowires	Dec.17-21, 2011	The Fourth International Forum on Multidisciplinary Education and Research for Energy Science, Hawaii, USA	Scientific Community (higher education, Research) - Industry	200	worldwide
48	Presentation	FZU	Influence of Gold Catalytic Layer on Growth of Silicon Nanowires	10 - 12 November 2011	The 3rd International Workshop on Nanotechnology and Application IWNA, Vietnam 2011	Scientific Community (higher education, Research) - Industry	100	worldwide
49	Poster	FZU	Conductive atomic force microscopy of delicate nanostructures	July 23 - 27, 2012	International Conference on Nanoscience + Technology, July 23 - 27, 2012 Paris	Scientific Community (higher education, Research)	2000	worldwide

						- Industry		
50	Presentation	FZU	Microscopic study of Silicon Thin Films (Invited)	22.-23.3.2011	SPM workshop 22.-23.3.2011, Valtice, organized by Czech Metrology Institute, http://gwyddion.net/workshop_cz.php	Scientific Community (higher education, Research) - Industry	50	national
51	Presentation	FZU	Internal fields in nanostructured Silicon Thin Films for Photovoltaics	11th November 2010	5th Czech Photovoltaic Conference, Brno	Scientific Community (higher education, Research) - Industry	50	national
52	Presentation	FZU	Internal Fields in Nanostructured Silicon Thin Films	June 28 — July 2, 2010	2nd European Seminar on Coupled Problems (ESCO) June 28 — July 2, 2010 Pilsen, Czech Republic	Scientific Community (higher education, Research) - Industry	100	worldwide
53	Presentation	FZU	Perspectives of Thin Film PV	October, 1 – 5, 2012	lecture at 3rd Summer School organized by EC MARIE CURIE INITIAL TRAINING NETWORK, Institute of Physics AS CR, Vila Lanna, Prague, Czech Republic. vila Lanna, Praha	Scientific Community (higher education, Research) - Industry	20	European
54	Presentation	IMEC	Metal induced crystallization of amorphous silicon for photovoltaic solar cells (Invited)	24-26.07.2010	Asia-Pacific Conference on Semiconducting Silicides and Related Materials Science and Technology Towards Sustainable optoelectronics	Scientific Community (higher education, Research) - Industry	100	worldwide
55	Presentation	IMEC	Thin-film polycrystalline silicon	20-25.06.2010	35th IEEE Photovoltaic Specialists Conference, Hawaii, USA	Scientific Community	1000	worldwide

			solar cells with low intragrain defect density made via laser crystallization and epitaxial growth (Plenary)			(higher education, Research) - Industry		
56	Presentation	IMEC	Thin-film crystalline silicon solar cells at imec (Invited)	27-28.05.2010	Photovoltaic technical conference, Aix-en-Provence, France	Scientific Community (higher education, Research) - Industry	150	worldwide
57	Poster	IMEC	Aluminum-Induced Epitaxy and Crystallization of a-Si: a comparative study of structural and electrical quality for thin-film Si solar cells application	7-11.06.2010	E-MRS spring meeting 2010, Strasbourg, France	Scientific Community (higher education, Research) - Industry	200	worldwide
58	Poster	IMEC	8.5% eciency for thin-lm polycrystaline silicon solar cells: a study of hydrogen plasma passivation,	6-10.09.2010	25th European photovoltaic solar energy conference and exhibition	Scientific Community (higher education, Research) - Industry	4000	worldwide
59	Poster	IMEC	Thin-lm polycrystalline-silicon mini-modules on non-silicon substrate	6-10.09.2010	25th European photovoltaic solar energy conference and exhibition	Scientific Community (higher education, Research) - Industry	4000	worldwide
60	Presentation	IMEC	A way to >14% pc-Si solar cells?! (Invited)	25-29.04.2011	MRS spring meeting 2011, San Francisco, USA	Scientific Community (higher education, Research) - Industry	200	worldwide
61	Presentation	IMEC	Thin-film crystalline silicon solar cells at	9.-13.5.2011	E-MRS spring meeting 2011, Nice, France	Scientific Community	200	Worldwide

			imec (Invited)			(higher education, Research) - Industry		
62	Presentation	IMEC	Microscopy study of thin-film polycrystalline silicon solar cells: where optical, electrical and structural material characterization meet each other (Invited)	14.-18.5.2012	E-MRS spring meeting 2012, Strasbourg, France	Scientific Community (higher education, Research) - Industry	200	worldwide
63	Presentation	IMEC	Thin film solar cells research: where nanotechnology meets photovoltaics	30.05-04.06.2011	International Summer School on Physics at Nanoscale	Scientific Community (higher education, Research)	200	Europe
64	Presentation	CSG	Crystalline Silicon on Glass - a unique challenge for thin film PV	30.05-04.06.2011	International Summer School on Physics at Nanoscale	Scientific Community (higher education, Research)	200	Europe

4.2.2 Section B (Confidential or public: confidential information to be marked clearly)

Part B1

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[3]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
Patent	NO	Filed 25.8.2011	German Patent 10 2011 111 629.3	Verfahren zur Herstellung periodischer kristalliner Silizium-Nanostrukturen	C. Becker, T. Sontheimer, E. Rudigier-Voigt, M. Bockmeyer, B. Rech
Patent	No	Published	WO 2011/026915 A1	Process for manufacturing a crystalline silicon layer	D. Van Gestel
Patent	No	Published	US 2012/0248455	Process for manufacturing a crystalline silicon layer	D. Van Gestel

Part B2

Type of Exploitable Foreground[4]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
General advancement of knowledge	Large-area silicon nanoarchitectures by combining nanoimprint-lithography and Si electron-beam evaporation	no		Solar cells, optical devices (optical filters, photonic crystals)	1. Energy (solar cells) 2. Communication (photonic crystals)	Open for licensing	A materials patent has been filed in 2011	HZB, SCHOTT AG (owners)
General advancement of knowledge	Electron-beam evaporation as high-rate deposition technique for silicon thin films	no		Solar cells, thin-film transistors, CMOS	1. Energy (solar cells)	Open for licensing	Internal know-how	HZB
General advancement of knowledge	Electron-beam crystallization as high-throughput	no		Solar cells, thin-film transistors, CMOS	1. Energy (solar cells)	Open for licensing	A materials patent has been filed in 2010	HZB

Type of Exploitable Foreground[4]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	fabrication technique for high-quality polysilicon thin films							
General advancement of knowledge	Continuous wave laser processing	no		Solar cells, TFTs, CMOS	D35.1.1 - Production of electricity M72.1 - Research and experimental development on natural sciences and engineering	Open for licensing	Internal know-how	CNRS
General advancement of knowledge	Annealing of polycrystalline Si films in oxyhydrogen flame	YES		Solar cells, TFTs, CMOS	1. Energy (solar cells) M72.1 - Research and experimental development on natural sciences and engineering	Open for licensing	Patent is under preparation	FZU
General advancement of knowledge	Definition of a procedure how to locate the same spot in various microscopic measurement techniques	no	31/12/2013		M72.1 - Research and experimental development on natural sciences and engineering	Open for licensing	Internal know-how	FZU
General advancement of knowledge	Raman Spectroscopy for light-trapping detection	no		solar cells, detectors	1. Energy (solar cells) M72.1 - Research and experimental development on natural sciences and engineering	Open for licensing	Internal know-how	FZU
General advancement of	Direct deposition of	no		Solar cells, TFTs, CMOS	1. Energy (solar cells)	Open for licensing	Internal know-how	ISE

Type of Exploitable Foreground[4]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
knowledge	poly Si on glass substrates							
General advancement of knowledge	Halogen lamp induced rapid thermal annealing	no		Solar cells, TFTs, CMOS	1. Energy (solar cells)	Open for licensing	Internal know-how	ISE
General advancement of knowledge	Halogen lamp induced rapid solid phase crystallisation	no		Solar cells, TFTs, CMOS	1. Energy (solar cells)	Open for licensing	Internal know-how	ISE
General advancement of knowledge	Hydrogen plasma passivation of polycrystalline silicon	no		Solar cells, detectors	1. Energy (solar cells) M72.1 - Research and experimental development on natural sciences and engineering	Open for licensing	Internal know-how	IMEC
General advancement of knowledge	Monolithic process flow and interdigitated contact design for substrate mode (illumination from the contact side) solar cells	no		Solar cells	1. Energy (solar cells) M72.1 - Research and experimental development on natural sciences and engineering	Open for licensing	Internal know-how	IMEC
General advancement of knowledge	Plasma texturisation of Silicon surfaces	no		Solar cells, detectors	1. Energy (solar cells) M72.1 - Research and experimental	Open for licensing	Internal know-how	IMEC

Type of Exploitable Foreground[4]	**Description of exploitable foreground**	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	**Exploitable product(s) or measure(s)**	**Sector(s) of application**	**Timetable, commercial or any other use**	**Patents or other IPR exploitation (licences)**	**Owner & Other Beneficiary(s) involved**
					development on natural sciences and engineering			
General advancement of knowledge	a-Si hetero-junctions as BSF or emitter	no		Solar cells, detectors	1. Energy (solar cells) M72.1 - Research and experimental development on natural sciences and engineering	Open for licensing	Internal know-how	IMEC

Additional information:

Description of exploitable foreground	**Additional information**
Large-area silicon nanoarchitectures by combining nanoimprint-lithography and Si electron-beam evaporation	The combination of nanoimprint-lithography, a method for high-throughput nanopatterning of large-area devices, with silicon thin-film technologies, large-are silicon nanostructures can be fabricated. The nanostructures can have applications in the field of photovoltaics as advanced light trapping systems but also in the field of photonics as photonic crystals. The exclusive use of upscalable fabrication processes allows for a high throughput and low costs. Further research is necessary to develop an appropriate concept implementing these silicon nanoarchitectures into an solar cell device, and to optimize the geometry for photonic applications.
Electron-beam evaporation as high-rate deposition technique for silicon thin films	Electron-beam evaporation (EBE) techniques allow for the deposition silicon with about 30-fold higher rates than conventional PECVD. These high rates enable a significant reduction of production costs with equivalent electrical material quality if planar substrates are used. Therefore, EBE might be of interest for any industry relying on crystalline silicon thin-films with high electrical material quality such as photovoltaics, but also TFT or CMOS technologies. Further research is necessary when textured substrates are required, e.g. for light trapping in solar cells.
Electron-beam crystallization as high-throughput fabrication technique for high-quality polysilicon thin films	Electron-beam crystallization (EBC) is a very promising solar cell technology in two regards: At first, poly-Si thin-films with the highest electrical material quality and the largest crystal grains can be prepared by EBC compared to other silicon thin-film crystallization techniques. Second, the crystallization process just lasts only a few seconds enabling a high-throughput and low fabrication costs. Therefore, EBC might be of interest for any industry relying on crystalline silicon thin-films with high electrical material quality such as photovoltaics, but also TFT or CMOS technologies. Further research is necessary to implement these poly-Si layers into an appropriate device. The impact is high because a very high material quality meets a fast and low-cost fabrication process.
Continuous wave laser processing	Rapid thermal processing (RTP) using many halogen lamps is widely used as a heating source for different purposes during the fabrication of electronic devices. It can be used for dopants diffusion and activation, crystallisation of an amorphous layer, epitaxy from a seed layer, annealing of defects…The main features of an RTP process are a high heating ramp (~200°C/sec), a plateau at a given temperature for 10 to 100 sec and then a rapid cooling down (~80°C/sec), all the steps are carried out under an appropriate gas ambient. The main drawback of effective implementation of the RTP process in electronics is heating of the whole structure which might be not desirable for different reasons (diffusion of impurities towards the active layer, a low temperature substrate…). For this purpose the use of ***laser beam as a thermal heating source*** can be an appropriate alternative to RTP. Two options were proposed in the project and worked efficiently: • For thin silicon film in particular laser beam was used to produce polycrystalline silicon by crystallization (LIC) of an amorphous silicon layer deposited on glass or metal foil.

Description of exploitable foreground	Additional information
	• we also showed that it possible to apply CW laser processing for laser induced epitaxy (LIE) from a polycrystalline silicon seed layer coated with a thick a- Si , • we also demonstrated laser induced annealing (LIA) of defects in thick polycrystalline silicon. These processes are of very great interest towards the formation of high efficient polycrystalline thin film silicon solar cells, but also beyond this specific application. * LIC process: The CW laser induced crystallisation of amorphous silicon allows the formation of large grained polycrystalline silicon, with grains up to 100μm in size. Such process can be employed to other semiconductor materials such as Germanium, Silicon-Germanium alloys, silicon-carbide alloys and others. Such foreground ca be exploited by companies interested in photovoltaic application to form a seed polycrystalline layer to be thickened, but it is also of interest for the thin-film transistors (TFTs) applications as well as to form the poly-Si gate for microelectronics without affecting the rest of the structures. Further research concerns the formation of a <u>quasi-monocrystalline layer</u> by this process which needs a better control of the laser beam shape and the laser processing conditions (power, scan speed, pre- heating). * LIE process: In the project, the CW laser induced epitaxy was made possible by irradiating a thick (1-2μm) amorphous silicon lying on a polysilicon layer used as a seed for silicon epitaxy. We have found that despite that the epitaxial layer is not completely conformal to the seed film, the grain size distribution is more favourable and larger grains are produced. Such foreground can be exploited by the photovoltaic companies who wish to produce thin film crystalline silicon on low cost substrates (soda lime or metal sheets) but also by microelectronics manufacturers as it is for instance possible to form a poly-Si gate at low temperature without affecting the rest of the structures. Further investigations concerns the epitaxy of a much thicker (>3μm) amorphous silicon layer on textured substrates. * LIA process: In the project, CW laser irradiation was successfully applied to anneal defects present in polysilicon multilayer structure without interdiffusion of impurities between the layers. We have strongly improved the open circuit voltage of related solar cells structure by more than 100mV after CW laser irradiation at the sub-melt point as compared to the nontreated polysilicon structure. Temperatures as high as 1300 °C for short time (<1sec) were reached during the laser irradiation. Possible next action could be to fabricate a complete "laser" polysilicon solar cell structure by preparing the seed Si layer by laser induced crystallisation (LIC) of a highly doped amorphous silicon, forming the absorbing film by laser induced epitaxy of lightly doped a-Si deposited on the LIC seed layer, and finally annealing the whole structure by CW laser to reduce the defects density and activate dopants if needed. Such "foreground" can be exploited for all applications which need a short time, local heating below the melting point of the materials to anneal, activate or diffuse impurities. The process can be used for all semiconductor technologies (III-V devices, TCOs…).
Annealing of polycrystalline Si films in	There are different approaches to prepare a thin film crystalline silicon layer with a small amount of defects, which is one of the basic requirements for effective solar cells. Some of the common crystallization processes are for instance Rapid Thermal Annealing (RTA) or Aluminium-Induced Crystallization and Layer Exchange (ALILE). Other alternatives are electron or laser beam crystallization which became focus of much research effort in the later stage of the PolySiMode project.

Description of exploitable foreground	**Additional information**
oxyhydrogen flame (Confidential)	Finally, at the last part of the PolySiMode research a new alternative appeared, namely the crystallization and possibly also passivation in hydrogen-oxygen flame, both in one step. Crystallization in the hydrogen-oxygen flame is a solid phase crystallization process. Mixture of hydrogen and oxygen is burned and ignited flame is moved above a sample in appropriate distance to make optimum temperature gradient in the crystallized silicon layer. Ratio of hydrogen and oxygen in burned gaseous mixture can be changed and reducing character can be smoothly changed to oxidizing. A similar crystallization approaches have been already tested previously, but then the burned gaseous mixture was hydrogen with lower hydrocarbon gases. The novelty of the use of oxyhydrogen flame for this purpose is based on a pure hydrogen-oxygen gaseous mixture in which the passivation of the prepared layer is probable due to the water vapour which is the only product of the reaction and one part of the PolySiMode research was oriented towards this approach. Passivation by heated water vapour was considered as an alternative to common passivation by plasma hydrogenation. The hydrogen-oxygen flame contains always some amount of non-burned hydrogen and oxygen molecules that are decomposed (temperature of the flame is up to 3,000 °C) and its passivation effect to crystallized thin film silicon layer is very probable. The process may be activated by the heat delivered by the flame. The parameter space of this approach is now being explored, with particular attention to the very important parameter of the temperature gradient in a thin film layer, which is closely connected with speed of movement of the flame, angle of the flame to the sample, distance between the sample and the flame, etc.
Definition of a procedure how to locate the same spot in various microscopic measurement techniques	Locating the grains, grain boundaries or defects in various microscopes (electron, optical or scanning probe) requires a precision on the order of 100 nm or better after repeated mounting of the sample. This surpasses the capabilities of the microscopic tables. The only possibility is to make markers. We have developed a procedure which uses a combination of scratches using a diamond stylus and indentation marks prepared by a microhardness tester. The indenter marks already require a specialized equipment (we used *FISHERSCOPE* PicoDentor HM500 with Vickers tip). Their largest advantage is the possibility to prepare a line of indenter marks in a line with defined spacing which can be used to precisely orient the substrate after repeated mounting in the microscopes. The centre of the marks can be used to identify the position on the surface with precision down to 100 nm or even better. Most importantly, the centres seem to be well defined for all microscopies which we have used. The diamond stylus scratches are readily made by hand with virtually no costs, and they serve as quick orientation on the samples to locate the line of indenter marks. The marks can then be used as a coordination system to locate the same spot with < 100 nm, even though there are no distinguishable features in the sample morphology at the particular microscopy technique used. The procedure was tested for locating the same spot in both Raman microspectroscopy (optical microscopy), EBSD (electron microscopy) and atomic force microscopy. The technique allows for repeated sample mounting even after various technological steps and may find wider use in materials research.
Raman Spectroscopy for light-trapping detection	Raman spectroscopy is a fast, non-destructive and contactless tool suitable for characterization of silicon in all known forms. In case of polycrystalline silicon films, Raman spectra are used to assess the crystalline nature of the films: crystalline disorder and stress may be deduced from the width and shift of the LO-TO phonon band centred at 520 cm^{-1}. Moreover, if the crystalline silicon layers are p (/p+) doped, high concentration of free holes affects the silicon phonon spectra by Fano effect and the Raman spectra are therefore significantly changed. By analysing the Fano type asymmetry and the spectral position of the first order Raman peak crucial properties such as Shockley-Read-Hall recombination lifetime, doping density and stress can be extracted simultaneously. Typical thickness of the silicon thin films used for solar cells is between 0.3 – 3 µm, which is not enough for complete absorption of near infrared light. In order to improve the light absorption, silicon films are deposited on rough substrates optimized for light trapping. We have found that the absolute intensities of the Raman spectra excited by 785 nm laser are strongly affected by light scattering on rough microcrystalline surface. This effect is due to the proportionality of the Raman

Description of exploitable foreground	Additional information
	intensity to the laser path length in the silicon film, which may be increased several times by light trapping. Therefore series of Raman spectra were measured on complete polycrystalline solar cells deposited on three types of glass-substrates with different light scattering characteristics. Weakly absorbed 785 nm laser diode (with absorption depth around 10 µm) was used for Raman spectra excitation. Strong correlation between the absolute Raman intensity and the final properties of the cell (IQE and J_{SC}) was demonstrated. Study of the phenomenon continues.
Direct deposition of poly Si on glass substrates with decent quality for Si thin film solar cells, also applicable in a high rate, high throughput tool	Direct deposition of poly Si on glass combines very high deposition rates with high crystalline quality. The crystalline quality is very well comparable with the standard SPC material and therefore already interesting especially for the PV sector. Grain sizes as well as lifetimes have so far even shown higher values as comparable material. This process due to the fast and cost effective deposition also allows for significantly thicker absorber layers which in turn can increase the device performance. With the drastically reduced cost structure of this process in comparison to PECVD/SPC material the process is highly competitive. However, the implementation into a device still needs some R&D work.
Halogen lamp induced rapid thermal annealing increases crystalline quality for low quality material drastically. High throughput machine available.	Halogen lamp induced rapid thermal annealing drastically increases crystalline quality for low quality material. It has been shown that this process can be superior to the standard RTA process. For an implementation on an already available high throughput machine no major problems are foreseen. However additional research is still needed, especially with respect to the use of more cost effective glass substrates which normally show decreased temperature stability.
Halogen lamp induced rapid solid phase crystallisation reduces time and cost for SPC processing. Also high throughput machine available.	Halogen lamp induced rapid solid phase crystallisation bares the potential to reduce processing time and cost for SPC processing. Good results have been shown with this compared to the standard SPC process. The setup also allows the implementation of an already available high throughput machine which can be operated in an in-line mode. Still a lot of work has to be done, also in regard to low T melting substrates.

Description of exploitable foreground	**Additional information**
Hydrogen plasma passivation of polycrystalline silicon	Two types of hydrogen plasma, direct plasma and remote plasma, were used to passivate defects in thin film polysilicon layers and were compared at solar cell level. The remote plasma results in higher hydrogen concentration in the Si layers and higher short circuit currents compared to the direct plasma hydrogenation. In addition, solar cell results suggest that the hydrogen plasma introduces damages to the surface layer of the polysilicon and lead to the deterioration of Voc. Additional research is still needed to fully understand how hydrogen plasma passivation needs to be adapted to different polysilicon layers made by various techniques (e.g. there is a big difference in plasma hydrogenation parameters leading to optimal passivation between polysilicon layers made by SPC and those made by the seed layer + thermal CVD approach.
Monolithic process flow and interdigitated contact design for substrate mode (illumination from the contact side) solar cells	Multiple module fabrication methods for thin-film silicon solar cells on a supporting substrate are reported in literature. However, most of the methods proposed in literature use glass as substrate and are applicable in superstrate-mode only, i.e. with light incident through the supporting glass substrate. In our approach, either glass or alumina ceramics are used as substrate and light is incident from the contact-side of the device. In order to reduce light losses due to a dense contacting scheme, the area covered by contacts is kept as small as possible by the use of an interdigitated contact scheme which is designed in a way to reduce resistivity losses. The module design is based on an interdigitated cell design and is monolithic; using the same contacts both for cell contacting and cell-to-cell contacting, which results in lower process complexity and throughput time. The proposed monolithic process flow, in which emitter and cell-to-cell contacting are combined into a single step, is capable to produce modules without decrease in shunt resistance. Isc values are comparable to cell Isc values and Voc values are the sum of the Voc values of individual cells. More development is needed to come to an industrially viable fabrication process since currently we still use photolithography to make these interdigitated monolithic mini-modules.
Plasma texturisation of Silicon surfaces	We developed a plasma texturing process to enhance the short-circuit current of our polysilicon solar cells by lowering the front surface reflection and ensuring an oblique coupling of incident light into the cells. Chemical methods to texture the front surface like anisotropic etching in NaOH or KOH solutions and acidic isotropic etching are not applicable to our thin polysilicon layers since these methods rely on the removal of a large amount of silicon. We developed a plasma texturing process for polysilicon that removes around 1 µm of silicon. The as-grown surface of our layers is quite rough and has a reflectance without ARC of around 35% in the visible light spectrum. After plasma texturing, the surface of the pc-Si layers shows much smaller features and has a reflectance without ARC of only 15%. Furthermore, the reflectance is nearly completely diffuse after plasma texturing while there is a large specular component in the reflectance of as-grown layers. The Jsc of resulting cells is typically enhanced by 20-30% after plasma texturing while Voc and fill factor are both also slightly improved. Plasma texturing is therefore a very promising method to enhance light confinement in thin-film polysilicon solar cells. More development is needed to come to an industrially viable plasma texturing process.
a-Si heterojunctions as BSF or emitter	We compared heterojunctions to homojunctions on identical polysilicon layers. Heterojunctions were formed by deposition of thin double layers of undoped and doped (P or B doping) a-Si using PECVD at 180 C. Polysilicon cells with a heterojunction BSF or emitter show larger Voc values than cells with a homojunction. Depending on the polysilicon material used, the difference can be between 10 to 100 mV. The higher Voc values obtained with heterojunctions compared to homojunctions are most likely the result of a better surface and/or bulk passivation. Additional research is still needed to fully understand why the heterojunctions lead to higher Voc values.

4.3 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	240826
Title of Project:	Improved Polycrystalline-Silicon Modules on Glass Substrates
Name and Title of Coordinator:	Dr. Ivan Gordon

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***NO***
2. Please indicate whether your project involved any of the following issues (tick box) :	
RESEARCH ON HUMANS	
• Did the project involve children?	No
• Did the project involve patients?	No
• Did the project involve persons not able to give consent?	No
• Did the project involve adult healthy volunteers?	No
• Did the project involve Human genetic material?	No
• Did the project involve Human biological samples?	No
• Did the project involve Human data collection?	No
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	No
• Did the project involve Human Foetal Tissue / Cells?	No
• Did the project involve Human Embryonic Stem Cells (hESCs)?	No
• Did the project on human Embryonic Stem Cells involve cells in culture?	No
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	No
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	No
• Did the project involve tracking the location or observation of people?	No
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	No
• Were those animals transgenic small laboratory animals?	No
• Were those animals transgenic farm animals?	No

• Were those animals cloned farm animals?	No
• Were those animals non-human primates?	No
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	No
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	No
DUAL USE	
• Research having direct military use	No
• Research having the potential for terrorist abuse	No

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	0	1
Work package leaders	1	5
Experienced researchers (i.e. PhD holders)	4	21
PhD Students	3	13
Other	15	25

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**10**
Of which, indicate the number of men:	6

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project? ○ ~~Yes~~ X **No**

6. Which of the following actions did you carry out and how effective were they?

	Not at all effective				Very effective
❑ Design and implement an equal opportunity policy	○	○	○	○	○
❑ Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑ Organise conferences and workshops on gender	○	○	○	○	○
❑ Actions to improve work-life balance	○	○	○	○	○

○ Other:

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

X **No**

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

X **Yes-** please specify

Master and PhD students

○ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

○ Yes- please specify

X **No**

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

X Main discipline[5]: 2.2

X Associated discipline[5]: 2.3

X Associated discipline[5]: 1.2

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)* ○ Yes X **No**

11b **If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?** ○ No ○ Yes- in determining what research should be performed ○ Yes - in implementing the research ○ Yes, in communicating /disseminating / using the results of the project		
11c **In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?**	○ ○	Yes No
12. **Did you engage with government / public bodies or policy makers (including international organisations)**		
○ No ○ Yes- in framing the research agenda ○ Yes - in implementing the research agenda ○ Yes, in communicating /disseminating / using the results of the project		
13a **Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?** ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible) ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible) ○ No		

13b **If Yes, in which fields?**

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level? ○ Local / regional levels ○ National level ○ European level ○ International level	

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?		**20**
To how many of these is open access[6] provided?		**1**
How many of these are published in open access journals?		**0**
How many of these are published in open repositories?		**0**
To how many of these is open access not provided?		**19**
Please check all applicable reasons for not providing open access:		
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[7]: ……………		**Lack of information on open access**
15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**2**
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**
17. How many spin-off companies were created / are planned as a direct result of the project?		**0**
Indicate the approximate number of additional jobs in these companies:		

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:	
❑ Increase in employment, or	❑ In small & medium-sized enterprises
❑ Safeguard employment, or	❑ In large companies
❑ Decrease in employment,	❑ None of the above / not relevant to the project
X Difficult to estimate / not possible to quantify	

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*
Difficult to estimate / not possible to quantify	X

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes X **No**

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes X **No**

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

X Press Release	❑ Coverage in specialist press
❑ Media briefing	❑ Coverage in general (non-specialist) press
❑ TV coverage / report	❑ Coverage in national press
❑ Radio coverage / report	❑ Coverage in international press
X Brochures /posters / flyers	X Website for the general public / internet
❑ DVD /Film /Multimedia	X Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑ Language of the coordinator	X English
❑ Other language(s)	

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES
1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]